# 22 | Participatory water monitoring (PaWaMo)

**Subekti Rahayu, Rudy H. Widodo, Meine van Noordwijk and Bruno Verbist**

Participatory Water Monitoring (PaWaMo) involves local community members in measuring and monitoring water flow using several simple quantitative indicators. These indicators can be used as an index for assessing and comparing the patterns of relationship between river flow and rain as a basis for monitoring changes of hydrological functions at sub-watershed level.

## Introduction

Well-maintained watershed functions are caused by well-managed river flows, especially when supported by social institutions that maintain a balance between individual and public interests. Today, people increasingly realize that by planting trees with economic value in their agricultural system they are also maintaining watershed functions at the same time because trees help stabilise hill slopes as well as prevent soil loss through erosion and water flow. However, issues related to watershed management are not only a matter of planting an amount of critical land with trees. Watershed management has different dimensions and each problem requires a different approach.

Overcoming problems of landscape management requires open communication between everyone involved (researchers, community members and government policy-makers) leading to negotiation and agreement in joint rehabilitation actions. Integrated understanding about a watershed and its characteristics is required to inform these processes, including 1) the interaction between landscape and rainfall; and 2) the landscape as water organisms' habitat functioning as an indicator of water quality and pollution levels.

## Objectives

PaWaMo is a way of answering 1) how local communities and scientists together can assess the 'weak points' of a landscape that greatly affect the circumstances of downstream areas; 2) how to monitor sediment in river water; 3) what are the physical and chemical characteristics of a river's water; and 3) how to use water organisms to assess the quality of a river?

## Steps

Watershed functions can be looked at in two ways: 1) supply aspects, which consist of river-water quantity (discharge), time, river-flow quality; and 2) demand aspects, which consist of availability of clean water and prevention of floods, landslides and mud puddles (Figure 22.1). Limited access to clean water is a main determinant in poverty and poor health. The problem of insufficient and untimely water supply for downstream communities can be dealt with using two approaches.

1. Technical approach, usually applied in the river body in the middle of a watershed through, among other means, increasing water flow to prevent flooding in critical areas, building dams or reservoirs as temporary water holders and/or building pipelines or water catchments (ponds, water towers) to distribute drinking water from upstream to downstream consumers.
2. Land-use approach in upstream areas, that is, by designating forests as protected and/or managing land in view of buffered water delivery.

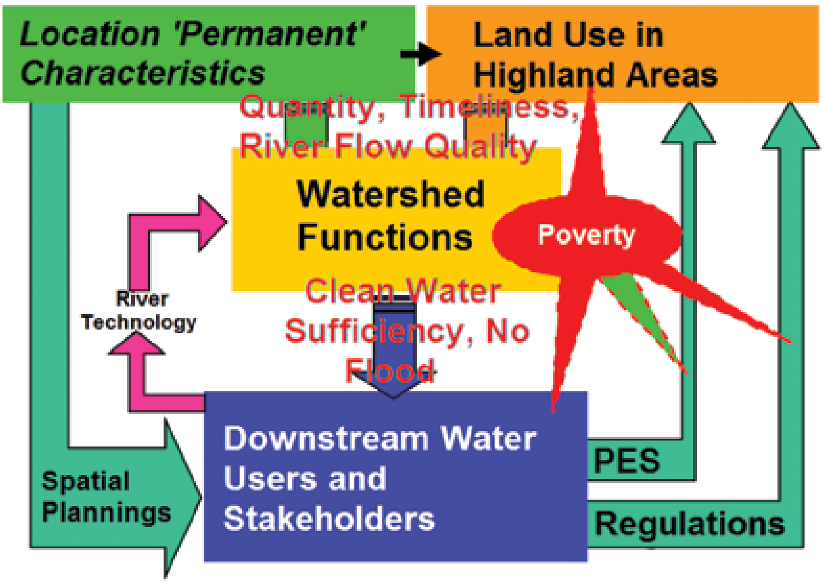



**Figure 22.1.** Reciprocal relations in a watershed

**Note:** Between 1) upstream areas that provide watershed functions in terms of quantity, time and quality of river water; and 2) area characteristics, both permanent (such as geology and topography) and non-permanent (such as land-use types and their impacts on downstream areas). PES = Payments for Environmental Services

## Case study: water quality biomonitoring in Way Petai, Sumberjaya, Lampung province, Indonesia

Conversion of forests to shrubland, coffee gardens and rice fields in the Way Besai watershed, Sumberjaya, Lampung province, Indonesia, has reduced water quality. Biomonitoring activities using macroinvertebrates were performed in the upstream part of the Way Petai River—one of the Way Besai tributaries—to assess the impact of land-use conversion on water quality.

Six sample plots in forests, shrubland, coffee gardens and rice fields were established along the Way Petai River during the wet and dry seasons in 2005. The result of data observation and analysis based on the Family Biotic Index is shown in Figure 22.2.

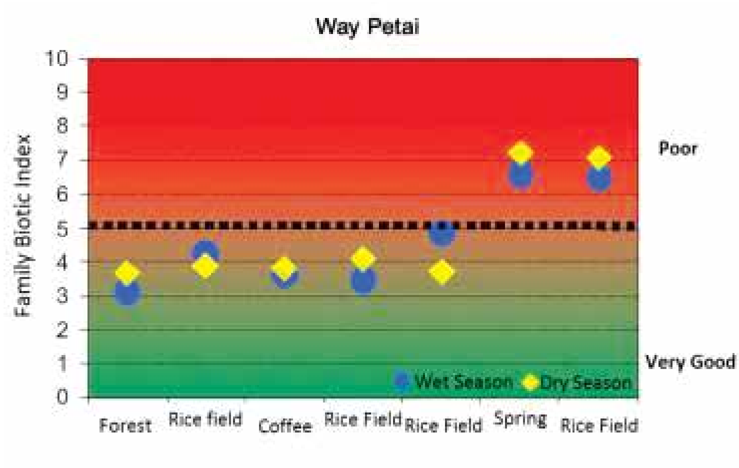



**Figure 22.2.** Water quality in upstream part of Way Besai River based on Family Biotic Index
**Source:** Andy Dedecker and Ans Mouton (dry season 2005 data); Indra Suryadi (wet season 2005 data)

Figure 22.2 shows that the quality of river water flowing through the forest is better than that in rice fields and coffee gardens. As for the spring, the water quality was classified as poor because of human use of the water for washing and bathing. In addition, the spring was located near a traditional market and rice fields, so that market garbage and pesticide residues from the fields contaminated the river near the spring. The bad water quality around the spring affected the water quality in the rice fields that were located downstream from the spring. Water quality during wet seasons was nearly equal to dry seasons.

## ■ Key reference


Rahayu S, Widodo RH, van Noordwijk M, Suryadi I, Verbist B. 2013. *Water monitoring in watersheds*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

# 23 | Rapid agro-biodiversity appraisal (RABA)

**Laxman Joshi, Endri Martini and Hesti Lestari Tata**

The Rapid Agro-Biodiversity Appraisal (RABA) is a diagnostic tool designed to measure the perceptions of different stakeholders about biodiversity conservation and to assess the feasibility of establishing a 'rewards for environmental services' mechanism in a target area.

## Introduction

With rapid deforestation taking place across the tropics, the associated biodiversity loss has become a global concern. Until recently, most of the approaches to biodiversity conservation were based on a spatial segregation of functions focused on protected areas and on intensive agriculture (to reduce pressure on natural forests). The results of such endeavours, however, have been less than satisfactory. A second approach maintains biodiversity within productive landscapes.

A combination of the two approaches is most likely to retain biodiversity and agricultural production but there is always the threat of competition between conservation and economic development. Specific incentives might be needed to ensure that the conservation aspect of these systems is not lost in the process.

RABA is a tool for appraising the perspectives of stakeholders regarding biodiversity conservation and the feasibility of providing rewards for environmental services (RES) in biodiversity-rich areas. RABA uses techniques and tools based on rapid rural appraisal, stakeholder analysis and local ecological knowledge. It captures the perspectives of sellers, buyers and intermediaries and generates initial data necessary for these groups to develop a rewards system (Figure 23.1).

RABA is not a stand-alone tool for assessment of detailed biodiversity richness. Selecting an area for establishing a RES mechanism is normally based on credible information about the richness or uniqueness of existing biodiversity that may be verified through local consultations. For areas where reliable biodiversity data are unavailable, the Quick Biodiversity Survey (QBSur) of indicator flora and fauna can be used as a complementary tool.

## Objectives

1. Assist potential investors to explore the benefits of agrobiodiversity conservation.
2. Assist the managers of richly agrobiodiverse landscapes to understand their key selling points for investment in conservation.
3. Provide cost-effective approaches to intermediaries (brokers).

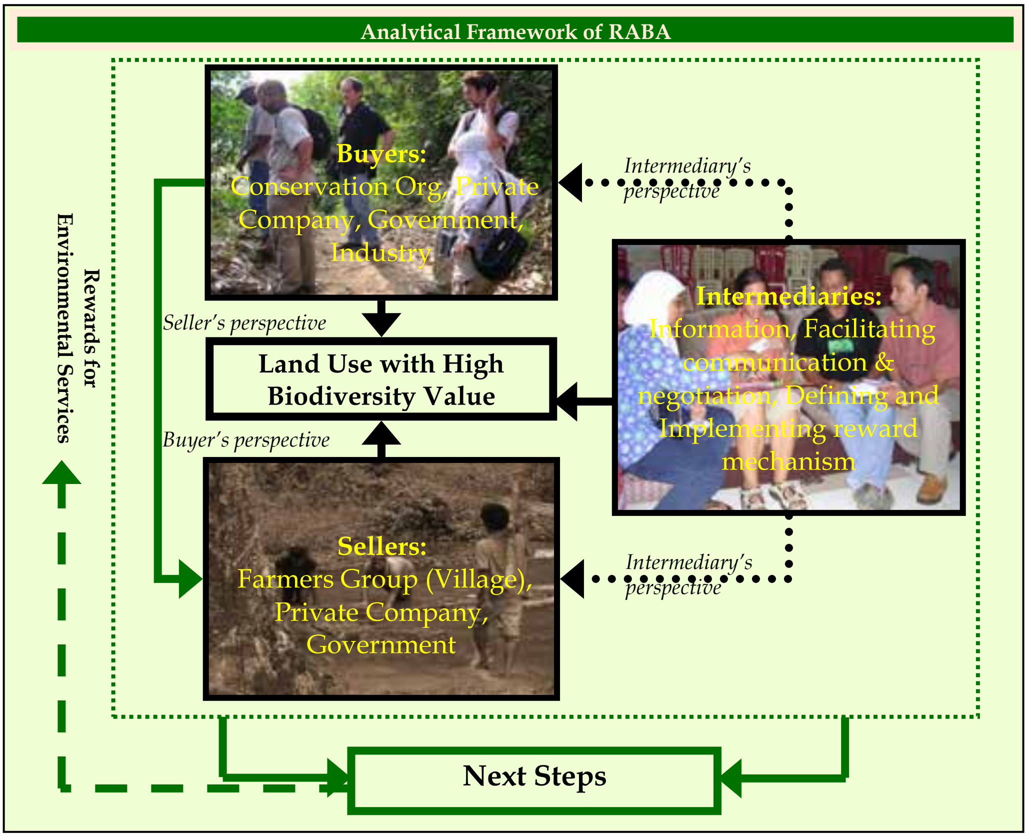



**Figure 23.1.** RABA analytical framework

## Steps

RABA involves four steps: 1) scoping; 2) identifying potential partners; 3) negotiating agreements; and 4) monitoring and evaluating compliance and outcomes (Table 23.1). Each step requires addressing a number of questions, which are detailed in the table below. As an analytical framework, RABA offers insights into, and guidance on, the important elements that should be considered in developing a RES mechanism.

**Table 23.1.** Steps in a RABA appraisal

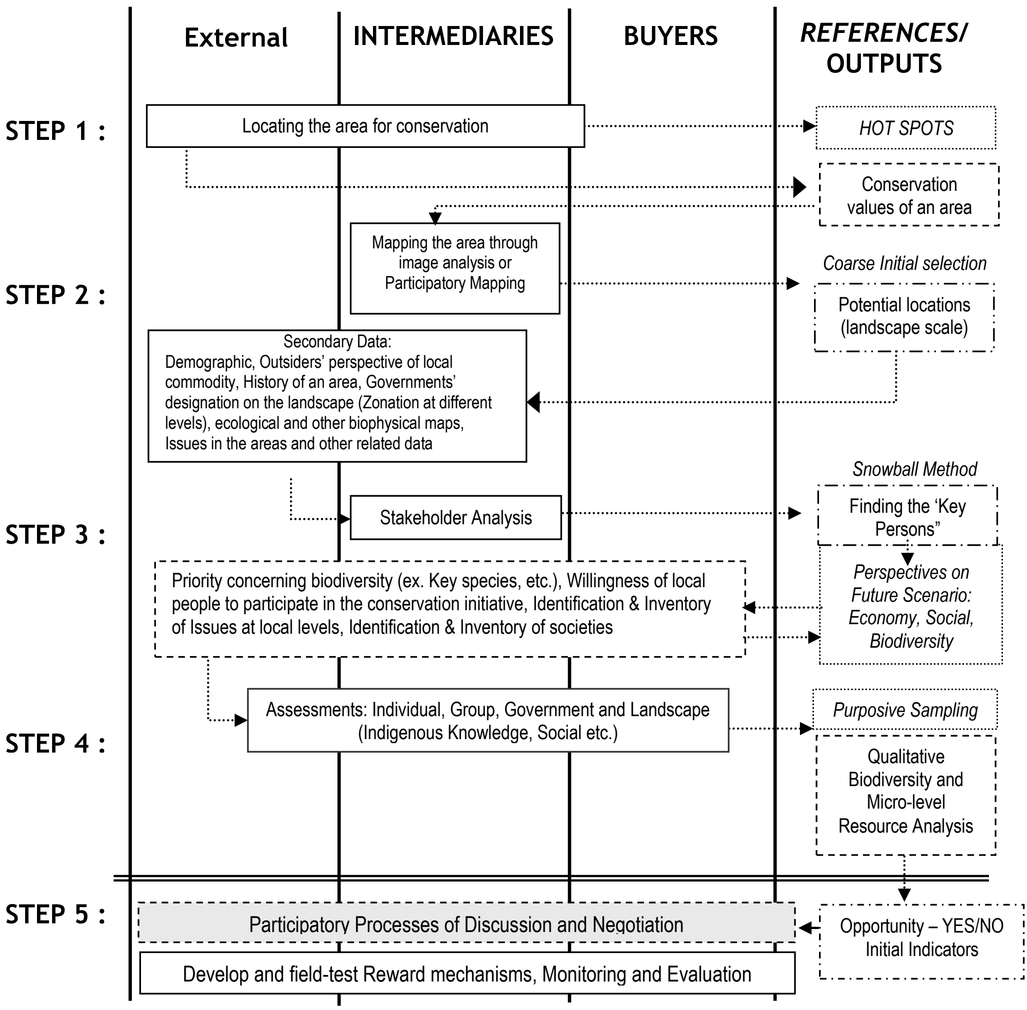
| Steps | *Rapid Agrobiodiversity Appraisal* | Sellers' perspective | Buyers' perspective |
|---|---|---|---|
| | | Communities that manage or control biodiversity-rich agroecosystems | Institutions interested in conserving agrobiodiversity |
| Scoping | | • What do we have that is of interest to outside stakeholders?<br>• What is the downside of conservation?<br>• How can we benefit from maintaining biodiversity?<br>• What 'willingness to pay' can we expect? | • Where are the areas under threat? Where are conservation activities most needed? What species and ecosystems are under threat?<br>• Who can effectively influence conservation uses in these areas?<br>• What 'willingness to sell' can we expect? |
| Identifying potential partners | | • Whom should we talk to?<br>• What documentation do we need? | • Who can effectively and equitably represent all local actors?<br>• Does local government represent local interests? |
| Negotiating agreements | | • How do we balance the restrictions that may be imposed on us with any rewards? | • How do we know we can trust the sellers? What are the guarantees? |
| Monitoring and evaluating compliance and outcomes | | • How can we deal with defectors and free riders in the community?<br>• How will we know the buyer is satisfied? | • How will compliance (at output level) be monitored?<br>• How will outcomes be monitored? |

## RABA process

The initial stages of RABA consist of acquiring, collating and analysing data. The selection of a location for establishing RES can be based on available data and secondary information. Identifying land uses and assessing potential threats to biodiversity in the location are also important. Spatial analysis can provide baseline data to be used in pinpointing areas with potential for conservation. Participatory mapping can be a useful tool but spatial analysis using satellite imagery and aerial photographs is more objective and can help in planning and future monitoring. The next step is to identify threats to biodiversity in the area of interest and opportunities to counter these threats. Areas that are either severely or minimally threatened may not be of interest to potential buyers of environmental services. The optimal threat level is difficult to measure and depends on the context. Secondary data (biophysical, ecological, socioeconomic and policy) enriches the understanding of past, current and possible future situations.

Stakeholder analysis can help to identify people and institutions that have vested interests in resource management in the area. Stakeholder analysis is a four-step process: 1) identifying key stakeholders; 2) assessing their interest and potential impact; 3) assessing their influence and importance; and 4) outlining a strategy for their involvement in conservation. Understanding power relations between and within stakeholder groups and conflicts, current and future, is necessary for developing appropriate strategies for conservation and RES. Awareness of stakeholders' expectations is also essential.

Assessing local perceptions of agrobiodiversity indicates the relative importance that local people assign it and hence the potential for conservation. Various aspects—such as tenure and rights to land, social strata, economy and livelihoods, local knowledge about the environment and agrobiodiversity, institutions, threats and opportunities—can be explored using various tools and methods.



## Case study: Rubber agroforests in Bungo district, Jambi province, Indonesia

Bungo district in Jambi province is located between three national parks—Bukit 12, Bukit 30 and Kerinci Seblat)—on the island of Sumatra, Indonesia. The area harbours many endemic species and, at the same time, has been significantly altered by human activities. Like many other districts in the area, Bungo is rapidly losing its forests. Previously dominant lowland tropical forests with rich biodiversity have been replaced by monoculture cultivation. Habitat for most flora and fauna is disappearing very fast and now exists only in small 'island' national parks and reserves. Fortunately, 'jungle rubber' (old, complex rubber agroforestry) systems are still commonly practised in Bungo. Previous research in Bungo indicates that these agroforests are becoming increasingly important as a reservoir of forest diversity and now provide some of the services valued in natural forests. As the financial gains from monoculture plantations are much higher than from jungle rubber, conversion to monocultures is taking place rapidly. Providing rewards for the environmental service of agrobiodiversity conservation in rubber agroforestry systems was proposed as a way to offset the opportunity costs from alternative land uses. Hence, RABA was developed and tested in the area. A graphical depication of the summary of the findings can be found below.

**Value**

- Sumatra is one of the hotspots in terms of biodiversity and little of its lowland forest are protected
- Jungle rubber is similar to secondary forest in structure and richness
- Jungle rubber gives good income to farmers
- Buffer zone for the nearby forest and protected areas

**Opportunity**

- People perceive that the most tangible environmental service of jungle rubber is watershed functions and not agrobiodiversity conservation.
- Increasing productivity of jungle rubber through improvement but not losing the environmental-service benefit from it
- Participatory land use planning

**Trust**

- Lack of trust between local people and government
- Local people are willing to negotiate with outsiders if there is a benefit for them

**Threat**

- Conversion to monoculture crops (rubber or oil palm)
- Top-down attitude in respect to land use change
- Increasing price of rubber

**Figure 23.2.** Graphical depiction of the summary findings of a rapid agrobiodiversity assessment in Bungo district, Jambi

The results of the RABA application in Bungo provided sufficient evidence and confidence to proceed with developing a RES mechanism. The understanding and recognition of environmental services provided by jungle rubber have increased, both among local villagers and external stakeholders. Efforts to develop long-term benefits through ecocertification of jungle rubber are underway.

## Key reference

Kuncoro SA, van Noordwijk M, Martini E, Saipothong P, Areskoug V, Eka Dinata A, O'Connor T. 2006. *Rapid Agrobiodiversity Appraisal (RABA) in the context of environmental service rewards.* Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia RegionalProgram. http://www.worldagroforestrycentre.org/sea/Publications/searchpub.asp? published=1496

# 24 | Quick biodiversity survey (QBSur)

**Hesti Lestari Tata, Nurhariyanto, Pandam N. Prasetyo, Jihad, Laxman Joshi and Endri Martini**

The Quick Biodiversity Survey (QBSur) diagnoses the 'biodiversity health' of a landscape, including its agricultural components that are usually not considered as niches providing ecosystem services. QBSur provides information on the diversity of plants, birds and bats; the biodiversity gradient of areas with high and low biodiversity levels; and perceptions of local stakeholders on (agro-) biodiversity and their interests in conservation.

## Introduction

Biological diversity (biodiversity) is the number, variety and variability of living organisms, which can be described in term of genes, species and ecosystems. Biodiversity plays an important role in sustaining the world's ecosystems. The conversion of forests to intensive agriculture and monoculture plantations leads to a loss of biodiversity in any landscape. Generally, the rich biodiversity in natural or managed systems does not provide tangible benefits: a reason why local people may not be interested in conservation initiatives.

Payment for agrobiodiversity conservation involves extensive consultations with both beneficiaries and providers of conservation services. These environmental services' providers usually live in agricultural landscapes with high local and global biodiversity values or which harbour species of special interest, such as tigers, orangutans, rhinos or endangered birds. Data on such high-value species and biodiversity richness are usually available. Occasionally, however, where detailed and current biodiversity data are unavailable or need to be validated, a rapid survey may provide sufficient information necessary for instigating a full RABA. The QBSur was developed for this purpose. Besides information on vegetative species, QBSur also studies animal diversity, such as birds and bats, which play important roles in the ecosystem as pollinators, seed dispersal agents and biological controllers. Furthermore, humans as an integral component in an ecosystem play the most important role, exercising direct influence over land-cover changes. Thus, local people's understanding of local activities and their effects on biodiversity are also captured in the QBSur.

## Objectives

A QBSur assesses the biodiversity of plants, birds and bats within a landscape, identifying areas of higher and lower biodiversity and the links between them, as well as providing a detailed picture of the health of the biodiversity. Perceptions of the local people with regard to local practices and the use of resources as well as perceptions of biodiversity are analyzed.

## Steps

QBSur uses indicator plant and animal groups. The animal groups, which include dung beetles, bats, small mammals, primates and birds, can be modified depending on their importance in the locality but the survey technique should be maintained for consistency and data comparison.

The QBSur can be conducted in two weeks in consultation with experts. A local guide who is knowledgeable about local plants and animals is necessary for the field work.

Indicator animals and plants are surveyed along kilometre-long transects; the layout and frequency of sample points are determined by the animal groups being surveyed (Figure 24.1). Time and other resources permitting, the number of transects can be increased to improve the accuracy of survey data.

In general, the survey, identification, data analysis and reporting can be completed in about six weeks.

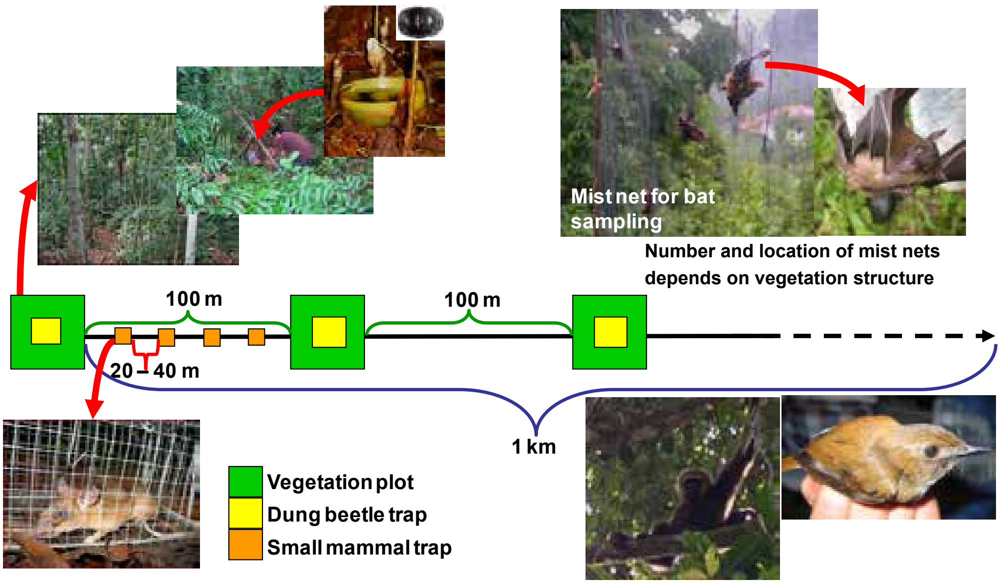



**Figure 24.1.** Sampling locations of vegetation plots and dung beetle and small mammal traps along a transect

## Case study: QBSur of a rubber estate

Rubber plantations in Dolok Merangir, Indonesia, have a long history. The first was established in 1916 for the Goodyear tyre company. In 2005, the Dolok Merangir and neighbouring Aek Tarum plantations were sold to Bridgestone, a tyre company based in Japan. We conducted a QBSur focussing on the diversity and species' composition of vegetation in the plantations compared with the surrounding smallholdings and forests. The QBSur resulted in recommendations on how to improve biodiversity on the Bridgestone estate.

### Summary of findings

- All farmers perceived that rubber agroforests were the most important land use as they could provide sources of income, food and environmental services. The second-most important land use was smallholding oil palm, followed by smallholding rubber monoculture. These provided the main cash income for households.

- People's understanding of biodiversity was closely associated with livelihoods' patterns and social practices, as biodiversity contributed to their daily needs and was related to specific knowledge. However, the boom in palm-oil production and its high prices had influenced farmers' decisions in conserving high-biodiversity ecosystems.
- Forest loss was followed by an increase in tree-based systems, such as rubber monoculture and oil palm. Smallholding rubber areas decreased while oil-palm plantations rose dramatically during the period 1970 to 2010. Early conversion of the forest at Dolok Merangir implied relatively stable, non-forest, land-use systems for a longer period of time and, by the time of the QBSur, the rubber plantations had developed into a mature system. The old rubber systems provided a more stable habitat for the different biodiversity components in the plantation area and this might benefit biodiversity conservation.
- Vegetation analysis was conducted in the three habitats of rubber plantation, rubber smallholding and forest. Rubber plantations had the lowest vegetation diversity owing to the intensive management practices to increase latex productivity. On the other hand, farmers traditionally grew various useful species in their agroforests through protecting seedlings, maintaining plant diversity at all stages. The species' composition of the tree stage was completely different. The sapling and pole stages on the plantations and rubber smallholdings were dominated by rubber trees as this was the productive stage for latex and hence the farmers maintained the rubber and minimized competition from other trees.
- Carbon and nitrogen are two important elements in soil organic matter. Soil analysis at the rubber plantations and smallholding rubber sites indicated that the carbon–nitrogen ratio was relatively constant across all soil depths but was slightly lower than in forest soil. This implied that the nitrogen content on the rubber plantations and smallholding sites was higher than in the forest soil. Fertilizer application may have affected the nitrogen content at these sites. In addition, soil fertility on the smallholding and rubber plantation sites was lower compared to forest soil.
- Bird diversity was analyzed in four habitats (forest, rubber smallholding, rubber plantation and emplacement) and 728 individual birds were recorded, consisting of 142 species from 42 families. The types of bird, categorized by feeding habit (guild type), decreased with vegetation type. Forests were the most diverse for bird species, with 17 guilds. This implied that the rubber plantations did not provide a suitable environment for some birds with specific roles. The differences in the tree composition of the three habitats of the plantations and their surroundings influenced bird species' richness, diversity and composition.
- Additionally, a large number of raptor bird species were found in the rubber plantations, such as the Brahminy Kite *(Haliastur indus)*, the White-bellied Sea Eagle *(Haliaeetus leucogaster)*, the Black Eagle *(Ictinaetus malayensis),* the Crested Hawk-eagle *(Spizaetus cirrhatus),* Blyth's Hawk-eagle *(Spizaetus alboniger)* and the Crested Serpent Eagle *(Spilornis cheela)*. All these raptors are protected under Indonesian laws and regulations. Moreover, the high number of raptors implied that this area was important as part of their home range. The availability of food in the rubber plantations and their surroundings was important in supporting the population.
- Based on the bird protection status published by the International Union for Conservation of Nature and Natural Resources, within the four habitats we recorded 12 species that were categorized as 'near threatened' and two species categorized as 'vulnerable'. In addition, one bird species listed in CITES Appendix I—*Rhinoplax vigil* (Helmeted Hornbill)—was encountered in the forest habitat.

- Bat diversity in the three habitats was studied to identify the level of species' richness and their roles and functions in the habitat. We live-trapped 234 individual bats from three families, consisting of 11 species, with eight of the species in the suborder Megachiroptera (fruit eaters) while the rest were Microchiroptera (insect eaters). Insect-eating bats play an important role as predators of mosquitoes and other plant pests, while the Megachiroptera are pollinators and seed dispersal agents. According to the IUCN status lists, all the bat species encountered in the study area were categorized as 'least concern'. The low value of bat diversity along each transect illustrated that the rubber plantations were in an alarming condition owing to the imbalance in the number of individuals of each species within the community.

### Recommendations from the QBSur

Buffer zones, such as rubber agroforestry smallholdings, play a role as corridors for animals to reach forests. Vegetation in rubber agroforests supports bird and bat diversity. To improve biodiversity in the area, we recommended preserving the intermediary vegetation, such as in riparian areas, along the main roads, sealed roads in the plantation and on steep slopes.

As an intermediary region could be a corridor between one region and another on the border of a plantation, we recommended to not only plant rubber trees but also a mix of other trees to provide food and places for nesting and resting for birds and bats (subject to the fruit not being preferred by humans, so it is left for the animals).

Trees with a narrow canopy would minimize light competition with the rubber trees that make up the main commercial crop in the plantations. Several suitable species for planting are *Ficus* species, *Canarium indicum* (canarium nut) and *Syzigium polyanthum* ('salam'). Bamboo could be planted along the river banks to support birds and bats by providing places for nesting. In addition, other tree species, such as *Inga (Euphorbiaceae), Sonneratia (Lythraceae)* and *Palmae* can also support bats.

## ■ Key references

Kuncoro SA, van Noordwijk M, Martini E, Saipothong P, Areskoug V, Eka Dinata A, O'Connor T. 2006. *Rapid Agrobiodiversity Appraisal (RABA) in the context of environmental service rewards*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia RegionalProgram. http://www.worldagroforestrycentre.org/sea/Publications/searchpub.asp? published=1496

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# 25 | Rapid carbon stock appraisal (RaCSA)

**Meine van Noordwijk and Kurniatun Hairiah**

The Rapid Carbon Stock Appraisal (RaCSA) assesses the status of carbon stocks in a given geographical area and develops scenarios of carbon sequestration or restoration resulting from potential land-use and management changes. RaCSA integrates procedures for developing land-use scenarios that can enhance carbon sequestration, prevent land degradation, promote sustainable land productivity and increase people's livelihoods.

## Introduction

At the time of writing, about 10% of the emissions of carbon dioxide ($CO_2$) that cause global climate change are due to land-use changes in the tropics (Le Quéré et al 2013). The contribution of agriculture to other greenhouse gasses is up to 30%. While most policies have so far focused, rightly so, on the fossil fuels that cause the bulk of the $CO_2$ emissions, the land-use change can no longer be ignored.This land-based emission is the major part of emissions for many developing countries. Global mechanisms for providing economic incentives for maintaining and restoring carbon stocks are taking shape. The United Nations Framework Convention on Climate Change (UNFCCC) regulates the Clean Development Mechanism (CDM) that includes afforestation and reforestation activities. Under discussion is an approach to reducing emissions from deforestation and degradation in developing countries (REDD). Voluntary market mechanisms, which are not included in country commitments to reduce emissions, target various combinations of landscape restoration and protection of tree cover and carbon stocks.

## Objectives

RaCSA is designed to provide a basic level of locally relevant knowledge to inform discussions on emissions reductions. It introduces a scientifically sound methodological framework of accounting for carbon sinks, while focusing on activities that can improve local livelihoods and alleviate rural poverty.

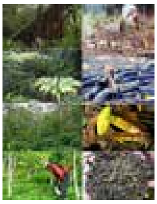
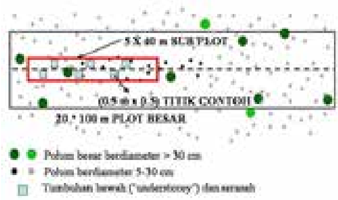
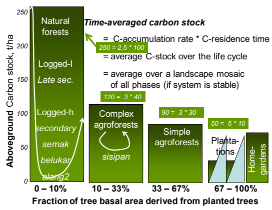
The purpose of RaCSA is to provide a cost-effective and time-bound (within 6 months) appraisal that:

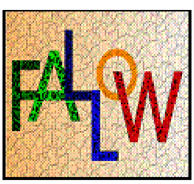
- provides reliable data on carbon stocks in a defined landscape, historical changes and the impact of continuing land-use changes on projected emissions, with or without specific interventions to increase or retain carbon stocks;
- identifies the primary issues in the local trade-off between carbon stocks and livelihoods and the opportunities to achieve more sustainable development pathways; and
- enhances shared understanding between stakeholders as a step towards free, prior and informed consent in contracts to increase or retain carbon stocks.

## Steps

**Table 25.1.** RaCSA activities and outputs

<table>
<tr><th>Activities</th><th>Objectives</th></tr>
<tr><td>1. 

Initial appraisal of the landscape, focused on the dynamics of tree cover</td><td>To define the unit of assessment (integrated livelihoods/ landscape unit), its gradients in tree and forest cover, mineral and peat soils, land-use and land-cover types, major issues in the current debate</td></tr>
<tr><td>2. 
Explore local ecological knowledge and the economics of local tree and forest management combined with a rapid household socio-economic survey</td><td>
To document livelihoods' strategies of the farmers pertaining to land-use practices and key drivers of change in the landscape</td></tr>
<tr><td>3. 

Plot-level carbon data in representative land-cover units and; integrating from plot to time-averaged carbon stock of land-use types; an updated version of the ASB carbon stock protocol provides the tree and soil-level data</td><td>To assess the performance of existing land-use systems as carbon sinks and/or in preserving carbon stocks.</td></tr>
<tr><td>4. Combine remote-sensing imagery and ground-truthing data within a sufficiently sensitive 'legend' to provide spatial analysis of land-cover changes</td><td>To estimate carbon stocks of the main land-use practices at plot level as well as their integration at landscape level</td></tr>
<tr><td>5. Explore policy-makers' ecological knowledge of tree and forest management and spatial planning rules</td><td>To explore the opportunities to use or adjust existing policy frameworks to enhance carbon storage in the landscape</td></tr>
<tr><td>6. 
Scenario studies of changes in carbon stocks and welfare through modelling land-use and carbon-stock dynamics in the landscape</td><td>To appraise landscape carbon-stock dynamics in relation to drivers of change as a basis for selecting interventions that enhance people's welfare and maintain or increase carbon stocks</td></tr>
</table>

The results need to be communicated in a simple format that focuses on the main trade-offs and decisions that can be made within a landscape. The primary data on carbon stocks can contribute to national databases and subsequently be used for national reporting. The ground-truthing and spatial analysis can similarly contribute to future analysis of the dynamics in larger areas, while the trade-off data and scenario models can be used for direct comparisons with other landscapes.

## Case study of RaCSA application

RaCSA was applied in Nunukan district, East Kalimantan province, Indonesia, to monitor carbon stocks in an area where forest conversion, illegal logging and fire were causing substantial carbon emissions. Community-based forest management, such as agroforestry and low external input sustainable agriculture, were seen as options that could provide sustainable livelihoods for local farmers while increasing or maintaining carbon sequestration. Agriculture competed with logging as the most profitable activity.

According to a household survey, there were three main tree-based systems in the area: 1) smallholding plantations of oil palm and pepper; 2) 'jakaw' (an upland rice fallow rotation system); and 3) a fruit-based system where farmers planted fruit trees in logged-over forest between remnant trees of low-commercial value. These systems were estimated to store carbon as shown in Table 25.2.

**Table 25.2.** Mean aboveground carbon stocks of land-use systems sampled in Nunukan

| Land-use systems | Carbon stock (Mg ha$^{-1}$) |
|---|---|
| Primary forest | 230 |
| Logged-over forest aged 0–10 years | 207 |
| Logged-over forest aged 11–30 years | 213 |
| Logged-over forest aged 31–50 years | 184 |
| Jakaw aged 0–10 years | 19 |
| Jakaw aged more than 10 years | 58 |
| Agroforestry aged 0–10 years | 38 |
| Agroforestry aged 11–30 years | 73 |
| Imperata grass | 4 |
| Upland rice | 5 |

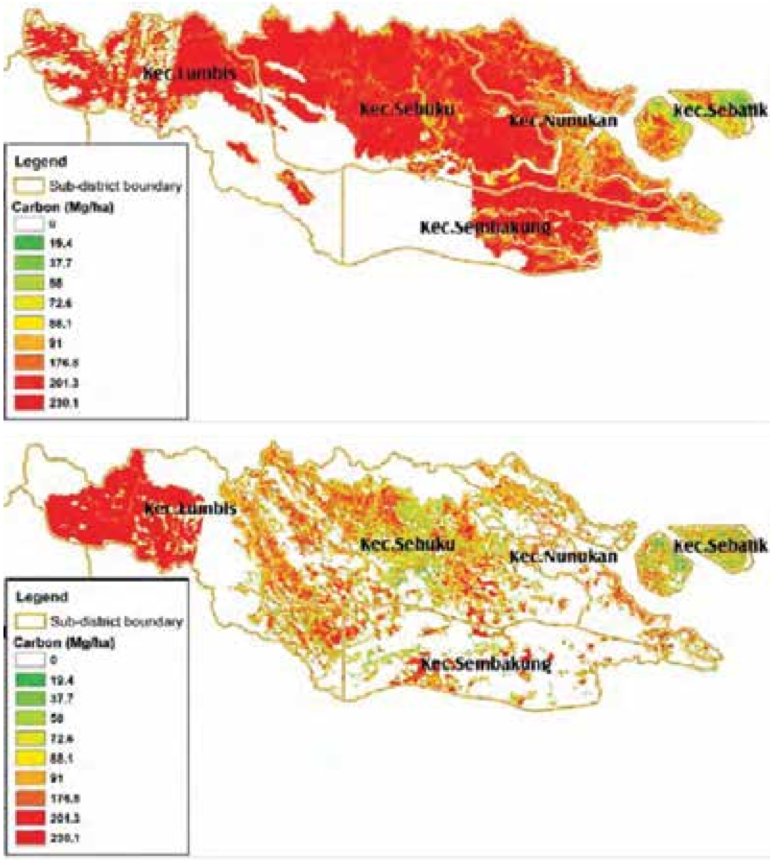



**Figure 25.1.** Distribution of land cover, Nunukan, 1996 (top) and 2003 (bottom)

An assessment of carbon stocks in the area estimated that carbon density in 1996 was 210 Mg ha$^{-1}$, while in 2003 it was 166 Mg ha$^{-1}$. During that period, primary forest was converted to other land uses at the rate of 3.9% year$^{-1}$. The estimated rate of carbon sequestration for the jakaw systems was 3.7 Mg ha$^{-1}$ year$^{-1}$ and for agroforestry systems it was 2 Mg ha$^{-1}$ year$^{-1}$.

Modelling exercises suggested that both income and landscape-level carbon stocks in Nunukan were decreasing, as non-sustainable logging remained the most profitable land-use option (Figure 25.1). Efforts to improve the profitability of agroforestry through better market development did not result in a greater adoption of the practice, since logging activities continued to provide better income (Figure 25.2). Thus, both per capita income and carbon stocks remained similar to the current trend. Reducing the timber market price by 25–50% reduced income without changing existing carbon stocks. If the market price was decreased 75–100%, people adopted agriculture and agroforestry to compensate for the income lost from logging.

The recommendation for policy in Nunukan was for promoters of agroforestry and community-based natural resource management to work together to achieve global and local benefits. A substantial increase in the profitability of agroforestry was needed before this practice could be considered an attractive alternative to illegal logging.

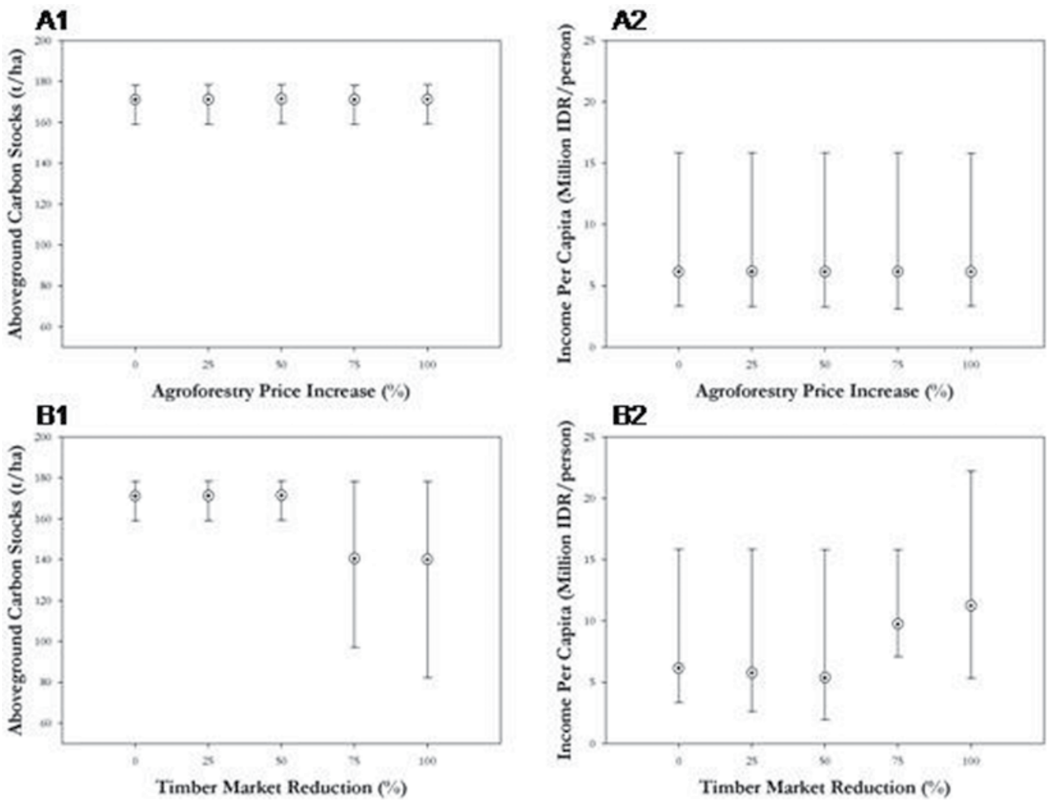



**Figure 25.2 .** Simulation results

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# 26 | Reducing emissions from peatlands (REPEAT)

**Maswar, Meine van Noordwijk and Fahmuddin Agus**

Reducing Emissions from Peatlands (REPEAT) is a methodological tool designed to fill the gaps in our knowledge about peatlands. REPEAT simplifies collecting data and the subsequent consideration of land-use options.

## Introduction

Peatlands accumulate plant matter over hundreds of years because decomposition is slower than organic inputs owing to lack of oxygen, low nutrient content and types of organic matter that are biochemically resistant to decomposition. These lands can store greater amounts of carbon than the best-stocked rainforest.

Most agriculture on peatland requires drainage of the land and use of fertilizers, both of which increase microbial breakdown of the peat, resulting in large carbon dioxide ($CO_2$) emissions. When fire is used to clear peatland, emission of $CO_2$ can be greater than from old, dense rainforest and conversion to monoculture tree crops, such as oil palm, also creates large amounts of emissions. However, some modification of peat swamp-forests—to increase the numbers of trees that are valuable to humans—produces little, if any, emissions but data on such types of agroforestry are scarce. REPEAT is designed to make it easier to collect these data.

## Objectives

Practical ways to sample an undisturbed peat profile, and assess its carbon stock and emissions owing to changing the land use of the natural peatland ecosystem to a mostly agricultural one.

## Steps

### 1. Assess the carbon stock in peatland soils based on depth, density and carbon content

The most popular and simplest way to sample undisturbed peat profiles is to use a peat auger, that is, a plate fin and a rotating half-circular sampler with a cutting edge along one side. Having reached the desired sample depth, the user turns the entire sampler 180° clockwise. During turning, the fin remains in position as the sampler completes the circle thereby forming an enclosed core sample. Figure 26.1 shows the full procedure for collecting peat soil samples to determine bulk density calculated by dividing the mass of the oven-dried sample by the volume of the core sample, ash and carbon content measured by 1) loss-on-ignition (LOI method); and 2) hydrogen peroxide digestion (Walkley and Black method).


**Figure 26.1.** Soil-sampling procedure and analysis for both bulk density and ash content

**Note:** a, b and c = peat-soil sampling procedure; d and e = bulk density determination; f, g and h = ash content determined by LOI method

## 2. Quantify the annual rate of $CO_2$ loss by measuring subsidence and compaction

Land subsidence is a symptom of the collapse of peat layers above the water table, owing to oxidation. Usually, subsidence is associated with an increase in the bulk density of the remaining peat and a correction factor is needed before subsidence data can be used for $CO_2$ emission estimates. Peat subsidence can be measured with a metal rod or other marker inserted into the underlying mineral soil (Figure 26.2). The distance between the soil surface and measuring point is recorded at three-monthly or yearly intervals. Adjacent to the stick, samples for bulk density need to be made at the start and end of the measurement period.

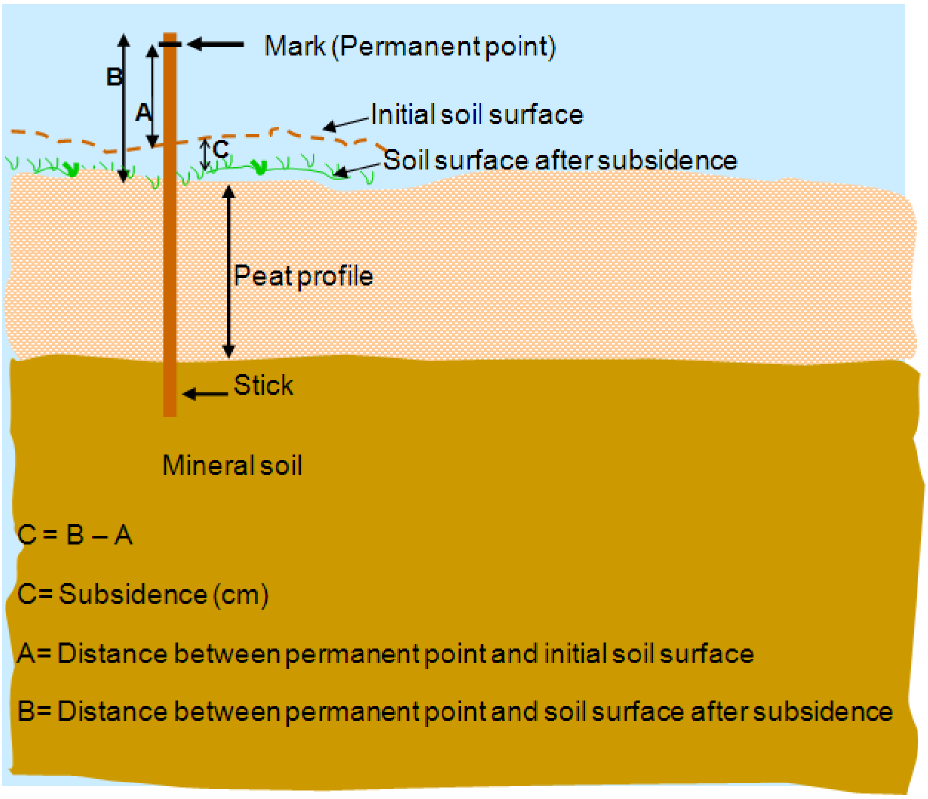


**Figure 26.2.** Conventional (field) method for measurement of peatland subsidence

## 3. Extrapolate to a broader spatial context through the use of ash content as internal tracer

In theory, carbon loss from peatland can be estimated from the progressive increase in mineral (ash) content after drainage, burning and/or a combination of both. This type of loss of the organic matter in the peat material sees the mineral fraction become more concentrated on the surface of peatland (Grønlund et al 2008, Turetsky and Wieder 2001, Maswar 2010). Carbon loss from the surface of peatland can be estimated based on the increase in ash concentration on the oxidation profile of peat soils.

## 4. Relate $CO_2$ loss to drainage, fertilisation and other aspects of agriculture or agroforestry

Carbon loss from the surface of peatland owing to fertiliser application can be quantified from the increase in ash concentration. By measuring subsidence and compaction in transects perpendicular to the drains and monitoring the groundwater table at measurement locations, emissions can be related to the deepest groundwater depth in a season or year. Carbon loss from peatland burning can be quantified based on the difference in ash concentration in the surface layers of burned and unburned peatland.

## 5.Identify 'best practice' and options for further improvement of low-emission peatland use

Maintaining peatland implies maintaining the conditions for low peat oxidation: wet and nutrient poor.

### Example of application

Studies show that sites with a maximum depth of groundwater table of 20–40 cm have the lowest overall greenhouse gas emission rates, as shallower groundwater leads to methane emissions (Handayani 2009). In practice, the horizontal distance between drains is closely related to the depth of water table in the drain required to achieve sufficient drainage for all trees. A finely distributed network of shallow drains can allow good tree growth at low net emission rates.

Rubber trees on peatland can be grown without high fertiliser application rates, as the latex removed from the field has low nitrogen content, in contrast to oil palm, which has high fertiliser requirements. Rubber agroforests on peat in Aceh Barat were found to have low $CO_2$ emission rates. Other agroforestry systems, such as those with *Dyera* species ('jelutung'), have properties similar to *Hevea brasiliensis* (rubber) and returned similar results. Native fruit trees on peatland tend to be restricted to nutrient-enriched zones close to rivers.

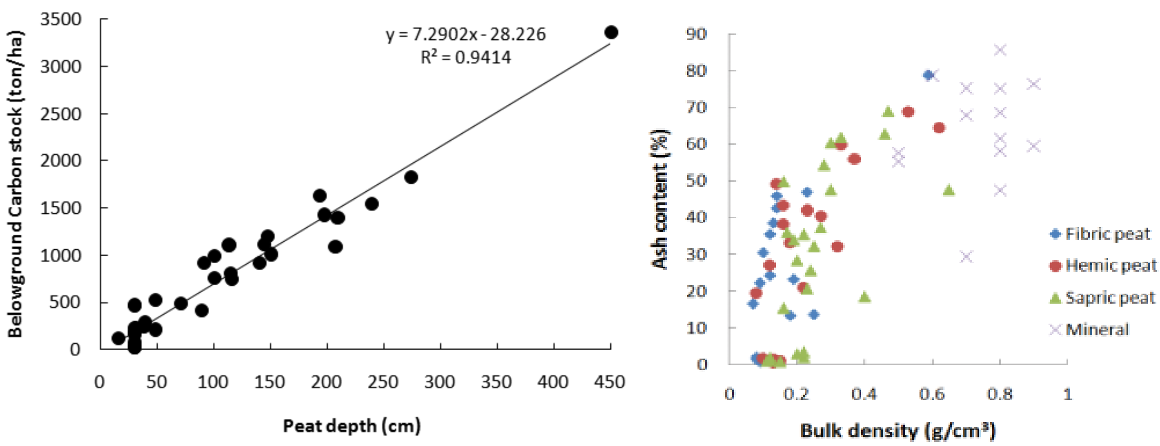


**Figure 26.3.** Example of the relationship between peat depth and total belowground carbon stock and the relationship between bulk density and ash content in samples from Lamandau, Central Kalimantan, Indonesia

**Data source:** Joshi et al 2010

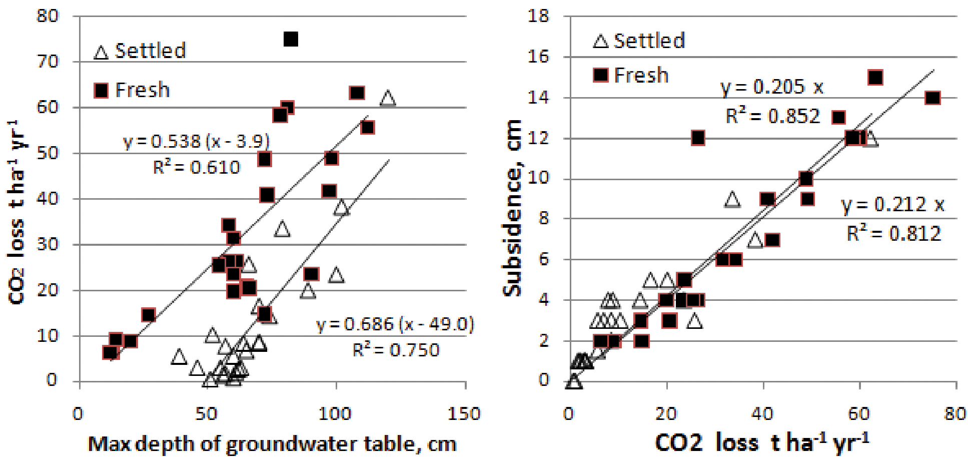


**Figure 26.4.** Example of the relationships between maximum depth of groundwater table and the calculated annual rate of CO2 loss owing to peatland decomposition

**Note:** For 'fresh' sites with recent (last two years) change in their drainage condition and 'settled' sites where drain depth was increased further in the past

**Data source**: Maswar 2010

## Open questions

Because of the importance of reliable $CO_2$ emission estimates and the uncertainties in each of the methods, a triangulation approach that uses multiple methods is advisable. There are several important questions to consider.

- How variable are estimates of carbon loss or $CO_2$ emission when different tools and methods are used?
- How can point data be extrapolated to field and landscape scales by understanding the drainage and fertilisation patterns on top of the inherent variability of peat domes?
- What low-emission agroforestry practices can be further developed for supporting low-carbon-emission livelihoods options in peatlands?

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# 27 | Re-assessing oxygen supply and air quality (ROSAQ)

**Meine van Noordwijk and Betha Lusiana**

A storyline that remains popular in public discourse and policy making is that trees provide oxygen. While scientists may argue that there is an excess rather than shortage of oxygen in the atmosphere, there are important issues of air quality that trees and forests interact with. The Re-assessing Oxygen Supply and Air Quality (ROSAQ) tool provides some pointers to how these can be tackled as part of a landscape approach.

## Introduction

Tropical forests are often portrayed as the lungs of the world. Lungs of humans (common with all animals) interface with the atmosphere by reducing its oxygen and increasing its carbon-dioxide content (so forests might be the 'anti-lungs' rather than the lungs of the world). Among the positive roles of trees (and other vegetation) we often see 'provisioning of oxygen'. While technically correct (at least during the daytime in the growing season), this provisioning does not qualify as an 'ecosystem service' because these are based on 'benefits people derive from'. With over 20% of the global atmosphere consisting of oxygen—which plays a major role in fire events—there is no shortage of the gas. Even within closed buildings the purported 'lack of oxygen' is rather an excess of other gasses that have accumulated. Opening windows is the easiest way to solve that issue and provide the desired environmental service.

Yet, trees that are strategically placed do play important functions with respect to air quality. The ROSAQ tool was designed to shift the frequently asked questions about air quality into an exploration of the three interacting knowledge domains: local, policy-makers' and modellers' ecological knowledge, as used in other tools.

## Objectives

Contribute to the identification of realistic roles of strategically placed trees and forests in improving air quality, while responding to commonly repeated concerns about oxygen supply.

**Table 27.1.** Air pollutants can affect air quality in many ways

<table>
<tr><th>Pollutant (http://en.wikipedia.org/wiki/Air_pollution)</th><th>Mechanism by which trees and forests may interact with the pollutant</th></tr>
<tr><td>Particulates, alternatively referred to as particulate matter, atmospheric particulate matter or fine particles, are tiny particles of solids or liquid suspended in a gas. In contrast, 'aerosol' refers to particles and the gas together. Sources of particulates can be human-made or natural. Some particulates occur naturally, originating from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray. Human activities, such as the burning of fossil fuels in vehicles, power plants and various industrial processes also generate significant amounts of aerosols. Averaged over the globe, anthropogenic aerosols—those made by human activities—currently account for about 10% of the total amount of aerosols in our atmosphere.</td><td>Deposition depends on wind speed, so effects of trees and tree rows on turbulence can influence local deposition.</td></tr>
<tr><td>Sulfur oxides (SOx), especially sulfur dioxide, a chemical compound with the formula $SO_2$. $SO_2$ is produced by volcanoes and in various industrial processes. Since coal and petroleum often contain sulfur compounds, their combustion generates sulfur dioxide. Further oxidation of $SO_2$, usually in the presence of a catalyst such as $NO_2$, forms $H_2SO_4$, and thus acid rain. This is one of the causes for concern over the environmental impact of the use of these fuels as power sources.</td><td rowspan="2">Wet leaf surfaces, for example, of trees, can lead to enhanced deposition of ammonium sulfate. Although trees thus clean the air, they may suffer from the 'acid rain' effect of this deposition.</td></tr>
<tr><td>Ammonia ($NH_3$) is emitted from agricultural processes. Ammonia is a compound with the formula $NH_3$. It is normally encountered as a gas with a characteristic pungent odour. Ammonia contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to foodstuffs and fertilisers. Ammonia, either directly or indirectly, is also a building block for the synthesis of many pharmaceuticals. Although in wide use, ammonia is both caustic and hazardous.</td></tr>
<tr><td>Nitrogen oxides (NOx), especially nitrogen dioxide, are expelled from high temperature combustion and are also produced naturally during thunderstorms by electrical discharge. Can be seen as the brown haze dome above or plume downwind of cities. Nitrogen dioxide is a chemical compound with the formula $NO_2$. It is one of the several nitrogen oxides. This reddish-brown toxic gas has a characteristic sharp, biting odour. $NO_2$ is one of the most prominent air pollutants.</td><td>Leaves with wet surfaces and open stomata can absorb some nitrogen oxides on their way to the atmosphere.</td></tr>
<tr><td>Carbon monoxide (CO) is a colourless, odourless, non-irritating but very poisonous gas. It is a product of incomplete combustion of fuel, such as natural gas, coal or wood. Vehicular exhaust is a major source of carbon monoxide.</td><td></td></tr>
<tr><td>Volatile organic compounds (VOCs) are an important outdoor air pollutant. In this field they are often divided into the separate categories of methane ($CH_4$) and non-methane (NMVOCs). Methane is an extremely efficient greenhouse gas which contributes to enhanced global warming.</td><td>Some tree-produced VOCs are implied in rainfall triggering as they form condensation nuclei for raindrops, potentially enhancing the air-clearing effect of rainfall.</td></tr>
<tr><td>Odors, such as from garbage, sewage and industrial processes</td><td></td></tr>
</table>

## Steps

### 1. Exploration of local ecological knowledge (LEK)

The LEK component is straightforward as there is likely some recognition of what constitutes 'fresh' air but no specific knowledge of individual gasses, such as oxygen. Components that may be explored deeper are 'dust', 'smoke', 'haze', 'bad smell'.

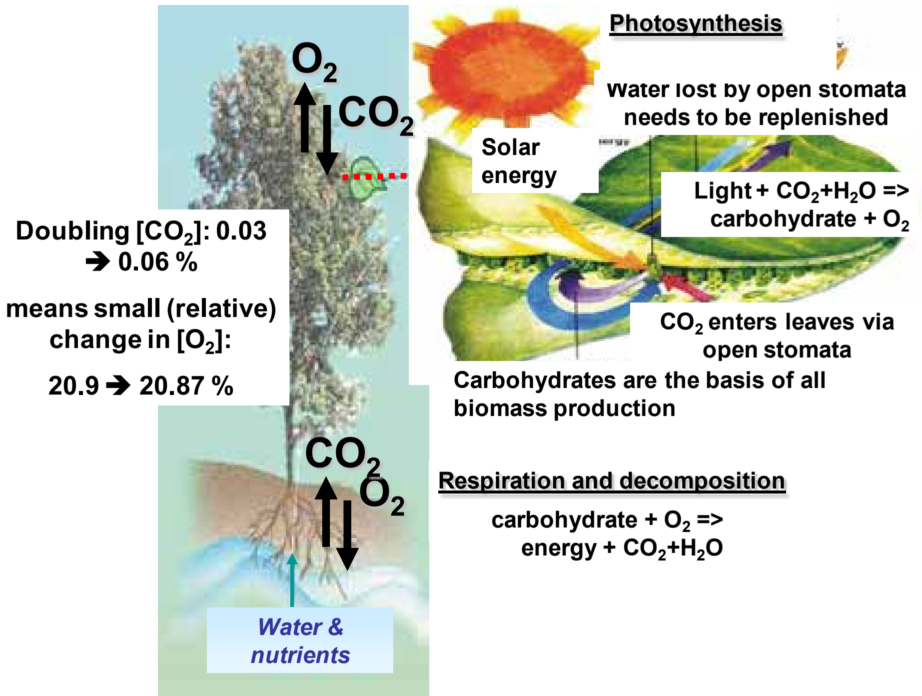



**Figure 27.1.** Leaf-level relationship between oxygen and carbon dioxide, with the consequences for both if the atmosheric $CO_2$ concentration doubles

### 2. Exploration of modellers' ecological knowledge (MEK)

Table 27.1 indicates possible mechanisms by which trees and forests can filter or increase deposition of air pollutants. Such effects have been documented for trees in urban environments but often require specialized equipment.

For oxygen, the MEK component is also straightforward. For example, the carbon dioxide ($CO_2$) emission estimates for Indonesia can be mole-per-mole converted to oxygen ($O_2$) consumption estimates (applying a factor or 32/44 for conversion), at least if we ignore the temporary storage in flows of organic products, which causes a time-lag between production and consumption of oxygen. The basic equation for photosynthesis (=>) and respiration/decomposition/fire (<=) is:

$$6CO_2 + 6H_2O + energy <=> C_6H_{12}O_6 + 6O_2$$

Because Indonesia is a net emitter of $CO_2$, its consumption of $O_2$ is greater than the $O_2$ that it produces. Spatial analysis can readily convert land-cover-change maps to $O_2$ consumption maps.

### 3. Exploration of policy-makers' ecological knowledge (PEK)

The PEK component is the most intriguing, as concerns over oxygen persist in the absence of evidence, or while the concepts are clearly challenged by science.

Air pollutant control, focused on point sources of industrial pollution, the domestic burning of organic fuel sources as well as biomass burning in relation to land use (and land-use change), has become a specialized part of environmental management. There is little explicit attention to filtering effects of trees and forests in most cases.

## Case study: Forestry Ministry asks Japan to check air quality

In 2008, Indonesia challenged Japanese scientists to check the balance between the amount of fresh oxygen produced by its protected forests and amounts of forest fire haze affecting neighbouring countries. This information could be an important way to counter repeated international protests over Indonesia's haze problems.

Indonesia has the largest forested area in the region, with some 120 million hectares of tropical forests. Annual forest fires causing massive amounts of air pollution prompted protests from the Singaporean and Malaysian governments. The president of Indonesia formally apologized to the country's neighbours for haze incidents in 2006, the second most severe after the 1997 haze disaster that blanketed Singapore and Malaysia.

Responding to the Ministry's request, a Japanese researcher said that it was difficult but technologically possible to calculate the amounts of smoke emanating from Indonesian forest fires. Rather than requiring new measurement techniques, the totals can be estimated from the reported carbon balance:

$$\text{Net effect on atmospheric oxygen supply} = -32/44 \text{ X Net emissions of } CO_2 \text{ to the atmosphere}$$

Unfortunately for the Ministry, the researcher concluded that Indonesia is, and will be, a net consumer (not producer) of oxygen until it becomes 'carbon neutral'.

# 28 Biofuel emission reduction estimator scheme (BERES): land-use history, production systems and technical emission factors

**Meine van Noordwijk, Ni'matul Khasanah and Sonya Dewi**

The Biofuel Emission Reduction Estimator Scheme (BERES) is an integrated assessment method for estimating carbon dioxide and other greenhouse gas emissions related to biofuel production. It includes three different phases of crop production processes within lifecycle analysis and is in line with EU-mandated calculations. The phases are 1) land conversion; 2) crop production; and 3) post-harvest commodity transport and processing.

## Introduction

Biofuels appeared to be such a nice way of facing the climate change challenge: they reduced political dependence on fossil fuel supply, could be used with minimal changes to engines and modes of transport, and provided new sources of income for rural economies. However, calculations of the area needed to make a dent in fossil-fuel use quickly showed that biofuels could not make a substantial contribution to 'clean' energy without using large areas of land and interfering with markets for food crops. If biofuel production extends beyond agricultural areas it will often increase emissions of carbon dioxide. The net effect will be a lower estimate of emission reduction than expected but if high carbon stock land is cleared then biofuel use can also increase net emissions. The debate on such emission enhancement has focussed on oil palm in the humid tropics of Southeast Asia, where forest and peatland conversion lead to large emissions, with or without a specific role for oil-palm expansion.

The public debate, however, has linked the two issues. The European Union provided guidance to countries on minimum standards that should be used when biofuels are included in national renewable energy plans. Until 2017, a minimum emission reduction of 35% has to be achieved for any fuel included in the scheme, shifting to 50% by 2017 and 60% beyond. Default estimates are given for major current or potential sources of biofuels. A procedure was established to calculate emission reduction factors, using a lifecycle approach for the supposedly typical production situation. Specific market flows of biofuels can apply for exception from this 'default' for the commodity but the procedures for that are not yet clear. These procedures, and their likely further development, create the need for exporting countries and entities to understand the steps in calculation and to do the research needed to get reliable data. Figure 28.1 shows examples of trees as biofuel sources in the tropics

**Figure 28.1.** Oil palm, coconut, jatropha and sugarcane: examples of biofuel feedstock sources

## Objective

BERES was designed to provide a transparent approach to lifecycle analysis of the emissions associated with production of biofuel feedstocks, as a basis for calculating carbon footprints.

## Steps

### 1. Identify and analyse time-series spatial data of land-cover changes combined with interviews with local witnesses

This includes negotiating the 'attribution' of the changes to various people (for example, legal, government-sanctioned and illegal logging; natural and human-induced fire). See ALUCT for details on the methods for reconstructing land-cover change.

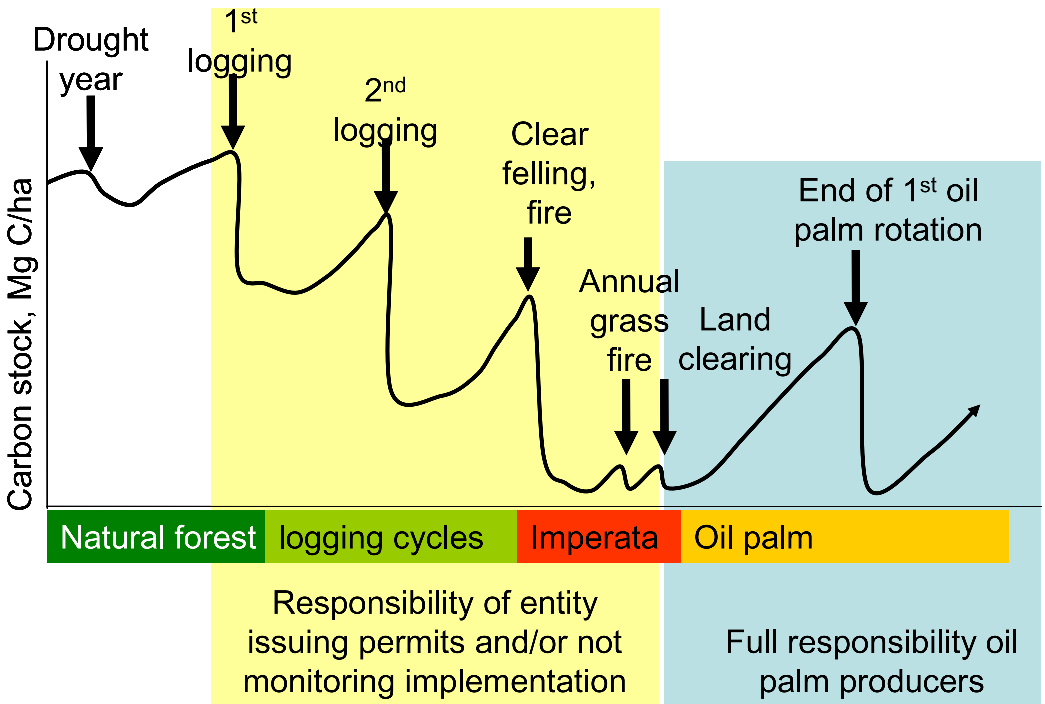



**Figure 28.2.** Trajectories of land uses and the dynamics of carbon stock

**Note:** Attribution is often contested more than what actually happened to aboveground vegetation

## 2. Estimate emissions due to crop production

*a. Estimate time-averaged carbon (C) stock of existing land cover, including plantations and surroundings in different production environments (for example, peat and mineral soil types) and management regimes (for example, nucleus/company, plasma and independent).*

The 'time-averaged C stock' is the sum of the average of five carbon pools (aboveground biomass, understorey vegetation, surface necromass, soil organic matter and roots) over a production cycle. When the preceding vegetation has a higher time-averaged C stock, the plantation starts with a 'carbon debt' with a 'payment time' or annualized draw on the biofuel carbon accounting. If it is lower, the calculation can reflect a net emission saving for the first production cycle. Methods for measurement of the pools are described in the RaCSA methodology and technical manuals.

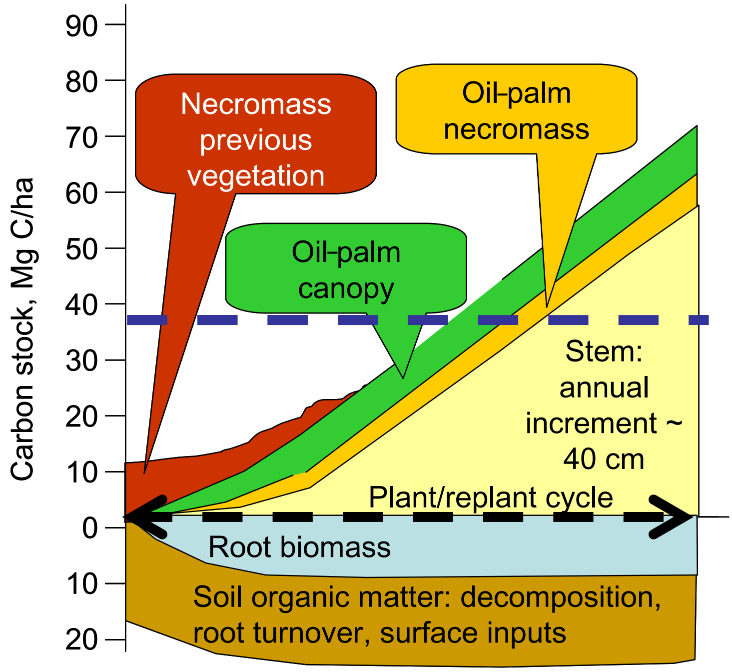



**Figure 28.3.** Components of C stock in oil-palm plantations, time-averaged over a planting cycle (schematic)

*b. Estimate emissions due to use of fertilisers*

This includes calculation of greenhouse gas emissions linked to fertiliser use. The Intergovernmental Panel on Climate Change's National Greenhouse Gas Inventory Guidelines suggest that 1% of N fertilizer is lost as $N_2O$ from agricultural systems. Other literature suggests this can be 4%. In the absence of site-specific measurements, both assumptions can be compared for impact on the end result.

## 3. Estimate emissions due to post-harvest commodity transport and processing

Emission factors for transport and milling are based on fossil-fuel use and technical design of the mill and processing steps before the product reaches the end-user.

## 4. Conduct sensitivity analysis

The net result is very sensitive to the preceding vegetation. For the oil-palm example, a minimum emission reduction efficiency of 35% can only be reached in a second production cycle or when oil palm replaced vegetation of less than 40 t C/ha. Investment in $CH_4$ capture at the mill can improve the situation. Where peat soils are used, the effects of drainage on emissions usually means the target efficiency cannot be met. A third factor with considerable influence is the use of N fertiliser in relation to yield. Increase in N use efficiency can lower costs as well as help reach the fossil-fuel substitution efficiency.

## Example of application

We applied BERES to 23 plantations in Indonesia that abided by what was considered 'good practice' and estimated whether the net emissions reduction of this 'good practice' was able to meet minimum European Union standards. The estimation of the net emissions included oil-palm lifecycle assessment (Figure 28.4).

Ten of the 23 plantations converted more than 60% of their area from forests to oil palm. In 91% of the plantations assessed, oil palm had replaced vegetation of more than 40 t C/ha thus incurring a carbon debt. The average net emissions rate of all sampled plantations owing to land-use conversion ranged 0–36 tonne of carbon dioxide equivalent per hectare per year ($CO_2eq$/ ha/yr).

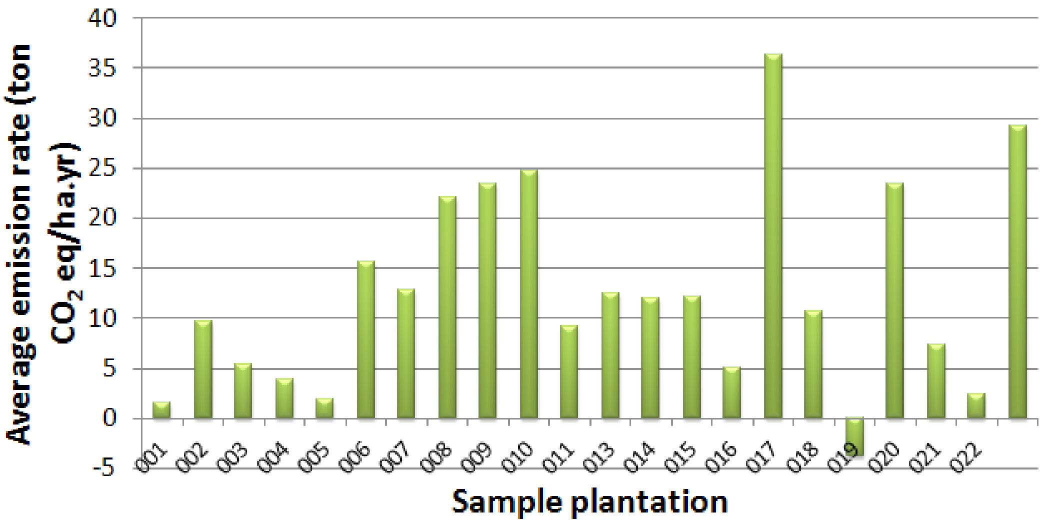



**Figure 28.4.** Average carbon dioxide emissions caused by land-use conversion

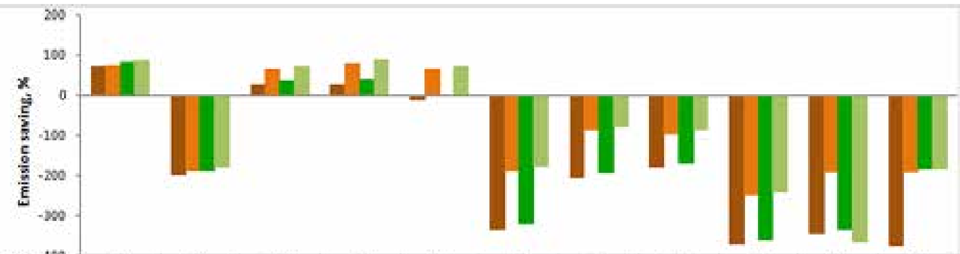
The average fresh fruit bunch production in Indonesia is approximately 18.8 t/ha/yr, which translates into an application rate for nitrogen fertiliser of 141 kg N/ha/yr (Figure 28.5 and Figure 28.6). The higher the yield, the more rapidly carbon debt can be neutralized and net emissions savings earned. However, higher yields depend on more than proportionally higher nitrogen fertiliser use. The additional nitrous oxide ($N_2O$) emissions need to be accounted for. Net effects depend on the assumed fraction of nitrogen fertilisers lost as $N_2O$.

A substantial part of the current production of palm oil can meet the directive for minimum emissions savings. In 39% (first-cycle assessment) and 78% (second-cycle or subsequent assessment) of the plantations, palm oil used for biodiesel can lead to emissions savings (calculated per standard European Union procedure) of at least 35%. Intensification and good management practices will increase emissions savings and decrease the product's carbon footprint.


| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N fertilizer, Kg N/ha | 110 | 77 | 110 | 137 | 152 | 77 | 127 | 110 | 154 | 114 | 128 | 114 | 199 | 257 | 140 | 252 | 164 | 164 | 136 | 67 | 104 | 178 | 178 |
| Initial C-stock, ton C/ha | 10 | 16 | 17 | 21 | 27 | 27 | 50 | 53 | 59 | 62 | 71 | 71 | 77 | 94 | 96 | 132 | 155 | 167 | 196 | 216 | 229 | 274 | 276 |
| Plantation ID | 019b | 022b | 019a | 021b | 011b | 022a | 021a | 005 | 011a | 016b | 015b | 016a | 004 | 018 | 014 | 007 | 020a | 020b | 009 | 010 | 017 | 023b | 023a |
| 1st cycle - w/o CH4 trap | 111.9 | 110.0 | 109.8 | 101.4 | 91.27 | 102.4 | 72.09 | 72.52 | 65.23 | 53.02 | 52.91 | 50.16 | 47.71 | 42.33 | 32.24 | 6.61 | -12.8 | -27.5 | -76.7 | -95.7 | -145. | -149. | -211. |
| 2nd cycle - w/o CH4 trap | 81.80 | 82.47 | 81.80 | 80.24 | 80.77 | 82.47 | 80.41 | 82.14 | 80.84 | 80.46 | 81.25 | 81.65 | 81.25 | 79.56 | 81.43 | 79.03 | 81.19 | 81.19 | 81.11 | 82.38 | 80.06 | 80.06 | 81.94 |
| 1st cycle - w/ CH4 trap | 121.5 | 119.6 | 119.5 | 111.1 | 100.9 | 112.0 | 81.73 | 82.15 | 74.87 | 62.65 | 62.55 | 59.79 | 57.34 | 51.96 | 41.87 | 16.25 | -3.19 | -17.9 | -67.1 | -86.1 | -136. | -139. | -202 |
| 2nd cycle - w/ CH4 trap | 91.43 | 92.11 | 91.43 | 89.88 | 90.40 | 92.11 | 90.05 | 91.78 | 90.48 | 90.10 | 90.89 | 91.29 | 90.89 | 89.19 | 91.07 | 88.66 | 90.82 | 90.82 | 90.74 | 92.02 | 89.70 | 89.70 | 91.58 |

**Figure 28.5.** Attributable emissions savings in relation to former carbon stock and nitrogen fertiliser application

**Note:** For plantations established on mineral soil and nitrogen loss as $N_2O$ is 1%. (Plantation ID with a = large company as a 'nucleus'; b = 'plasma' (satellite smallholding plantations))




| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N fertilizer, Kg N/ha | 145 | 136 | 128 | 128 | 128 | 91 | 91 | 122 | 124 | 136 | 136 |
| Initial C-stock, ton C/ha | 46 | 49 | 67 | 95 | 101 | 119 | 123 | 123 | 137 | 164 | 195 |
| Area of peat | 0.02 | 0.78 | 0.01 | 0.01 | 0.04 | 0.66 | 0.38 | 0.58 | 0.99 | 0.79 | 0.73 |
| Plantation ID | 001 | 003 | 013b | 015a | 013a | 006b | 006a | 002 | 008 | 012a | 012b |
| 1st cycle - w/o CH4 trap | 71.96 | -199.18 | 26.27 | 28.77 | -10.98 | -332.83 | -204.42 | -178.47 | -369.79 | -343.07 | -375.16 |
| 2nd cycle - w/o CH4 trap | 74.57 | -188.05 | 63.60 | 79.26 | 63.60 | -187.97 | -86.73 | -95.79 | -250.24 | -191.50 | -191.50 |
| 1st cycle - w/ CH4 trap | 81.60 | -189.54 | 35.91 | 38.51 | -1.35 | -320.49 | -194.78 | -168.83 | -360.16 | -333.43 | -181.87 |
| 2nd cycle - w/ CH4 trap | 84.20 | -178.42 | 73.23 | 89.00 | 73.23 | -175.64 | -77.10 | -86.15 | -240.60 | -365.52 | -181.87 |

**Figure 28.6.** Attributable emissions savings in relation to former carbon stock and nitrogen fertilser application

**Note:** For plantations established on mixed peat and mineral soils and nitrogen loss as $N_2O$ is 1%. (Plantation ID with a = large company as a 'nucleus'; b = 'plasma' (satellite smallholding plantations))

## ■ Key reference

Khasanah N, van Noordwijk M, Ekadinata A, Dewi S, Rahayu S, Ningsih H, Setiawan A, Dwiyanti E, Octaviani R. 2012. *The carbon footprint of Indonesian palm oil production*. Technical Brief 25: palm oil series. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. http://worldagroforestry.org/regions/southeast_asia/publications?do=view_pub_detail&pub_no=PB0047-12

# 29 | Generic river flow (GenRiver) at landscape level

Ni'matul Khasanah, Lisa Tanika, Betha Lusiana and Meine van Noordwijk

Generic River Flow (GenRiver) is a semi-distributed, process-based model that extends a plot-level water balance to sub-catchment level. It was developed for data-scarce situations and is based on empirical equations. The model can be used to explore the basic changes of river flow characteristics across spatial scales: from patch, sub -catchment to catchment. GenRiver is a simple river flow model that can be used to explore our understanding of historical changes in river flow owing to land-use changes.

## Introduction: why model river flow?

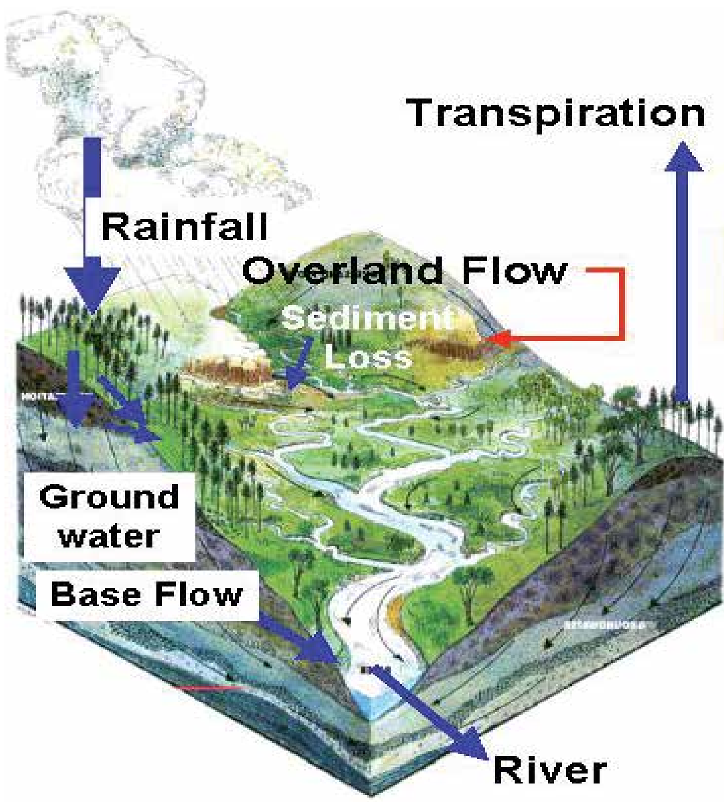



Figure 29.1. Schematic diagram of water flow in a catchment

Changes in land cover can significantly affect watershed functions. For example, they can change the amount of rainfall that reaches the ground and, consequently, the pathways of water flow over and through the soil, as well as affecting the rate of water use by plants. Most of the impacts on river flow can be explained by characteristics of the vegetation and soil. Empirical assessments of the dynamics of water flow as a function of changes to land-cover and soil properties require time and resources and need to take the temporal and spatial variation of rainfall into account. A model based on 'first principles', which integrates changes of land-cover and soil properties as driving factors of changes in river flow, can be used to explore scenarios of land-use change, provided it passes a 'validation' test against observed data.

## GenRiver

GenRiver is a generic model for analysing river flow. As is common in hydrology, it starts with the accounting of rainfall or precipitation (P) and traces the subsequent flows and storage in the landscape that can lead to either evapotranspiration (E), river flow (Q) or change in storage (ΔS):

$$P = Q + E + \Delta S \quad \text{.......................................(1)}$$

Hydrological models differ in the relations between the different terms of the balance equation and in the way they account for the 'slow flows'. Slow flows derive from water that infiltrates the soil but that takes a range of pathways (with various residence times) to reach the streams and rivers, depending on landform, geology, and extractions along the way.

The core of the GenRiver model consists of a 'patch'-level representation of daily water balance driven by local rainfall and modified by the land cover, land-cover changes, and soil properties of the patch. The patch can contribute to three types of stream flow: 1) surface quick flow on the day of the rainfall event; 2) soil quick flow on the next day; and 3) base flow via the gradual release of groundwater.

A river is treated as a summation of streams, each originating in a sub-catchment with its own daily rainfall, yearly land-cover fractions, and constant total area and distance to the river outflow (or measurement) point. Interactions between streams as they contribute to the river are considered to be negligible (that is, there is no 'backflow' problem). Spatial patterns in daily rainfall events are translated into average daily rainfall in each sub-catchment. The sub-catchment model represents interception, infiltration into the soil and rapid percolation into the subsoil as well as surface water flow and rapid lateral subsurface flow into streams, with parameters that can vary between classes of land cover.

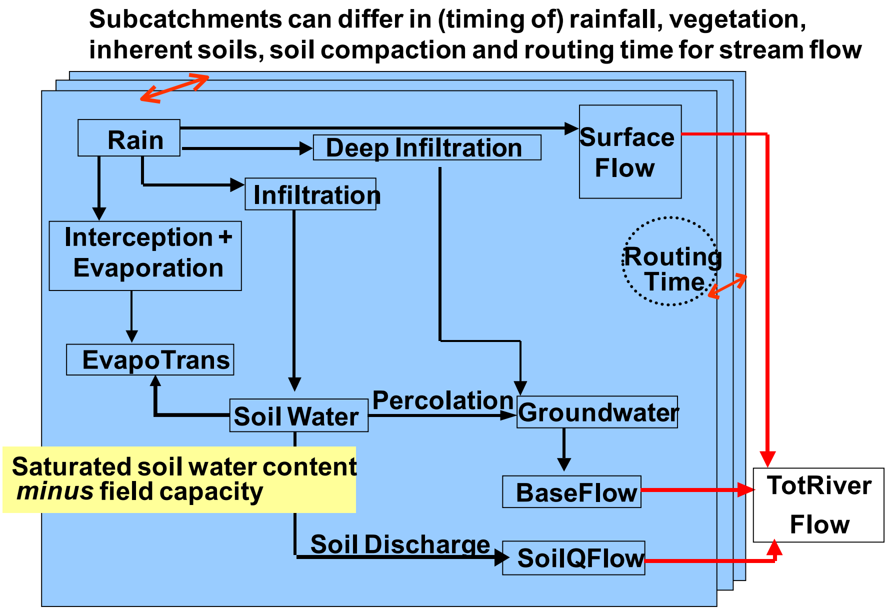



**Figure 29.2.** Schematic of the model aligned with the basisc plot-level water balance equation

The model has been built on the STELLA platform, with an accompanying Excel file to store input parameters; a NetLogo version of GenRiver is also available.

## Objectives

To help to simulate the effects of land-cover and climate changes on the hydrological functions of a watershed.

## Steps

Modeling is carried out using the following steps.

1. Data preparation and model parameterization.
2. Model calibration including evaluation on model performance.
3. Assessment of hydrological situation of the watershed.
4. Scenario development.
5. Model simulation based on scenarios developed in Step 4 to understand the impact of land-use changes on water balance and river flow.

## Example of application

GenRiver was used to analyze the response of Bialo watershed (11 417 km$^2$) to land-cover changes. The watershed is situated in Bantaeng and Bulukumba districts, South Sulawesi, Indonesia. Model simulations used rainfall data from 1989 to 2009. Annual rainfall ranged 1142–2668 mm per year.

In general, more than 58% of Bialo watershed area was dominated by agroforests (such as mixed-tree, clove, cocoa and coffee systems). Forests (primary and secondary) and rice covered 22.5% and 11% of the area, respectively. The remaining cover was shrub, grass, cleared land and settlements. The percentage area of each land-cover type in Bialo in 1989, 1999, 2005 and 2009 are presented in Figure 29.3.

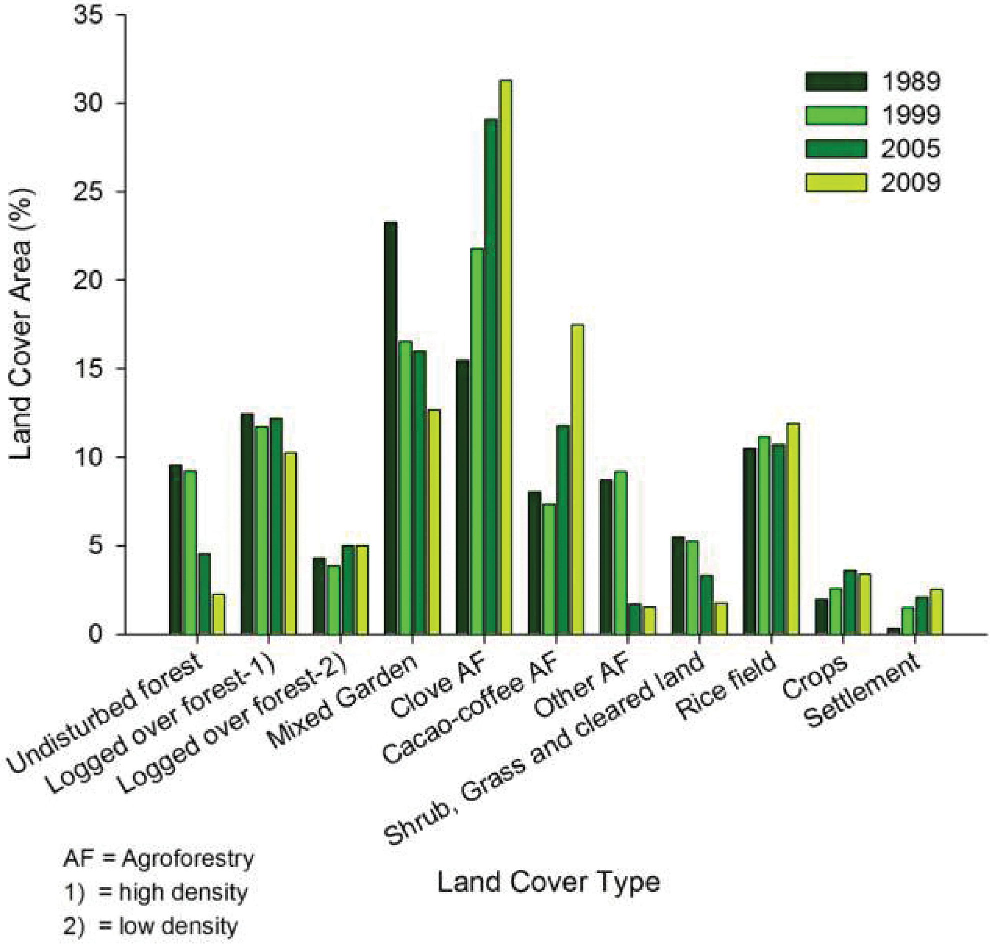



**Figure 29.2.** Land-cover percentages in Bialo watershed

Calibration and validation was carried out using river flow data from 1994–1995 and 1998–1999. The results showed that the hydrograph from GenRiver captured the patterns of observation data in the Bialo watershed with NSE values 0.55 and 0.63. According to Moriasi (2007), these NSE values are satisfactory criteria and can be used to simulate river flow of the watershed.

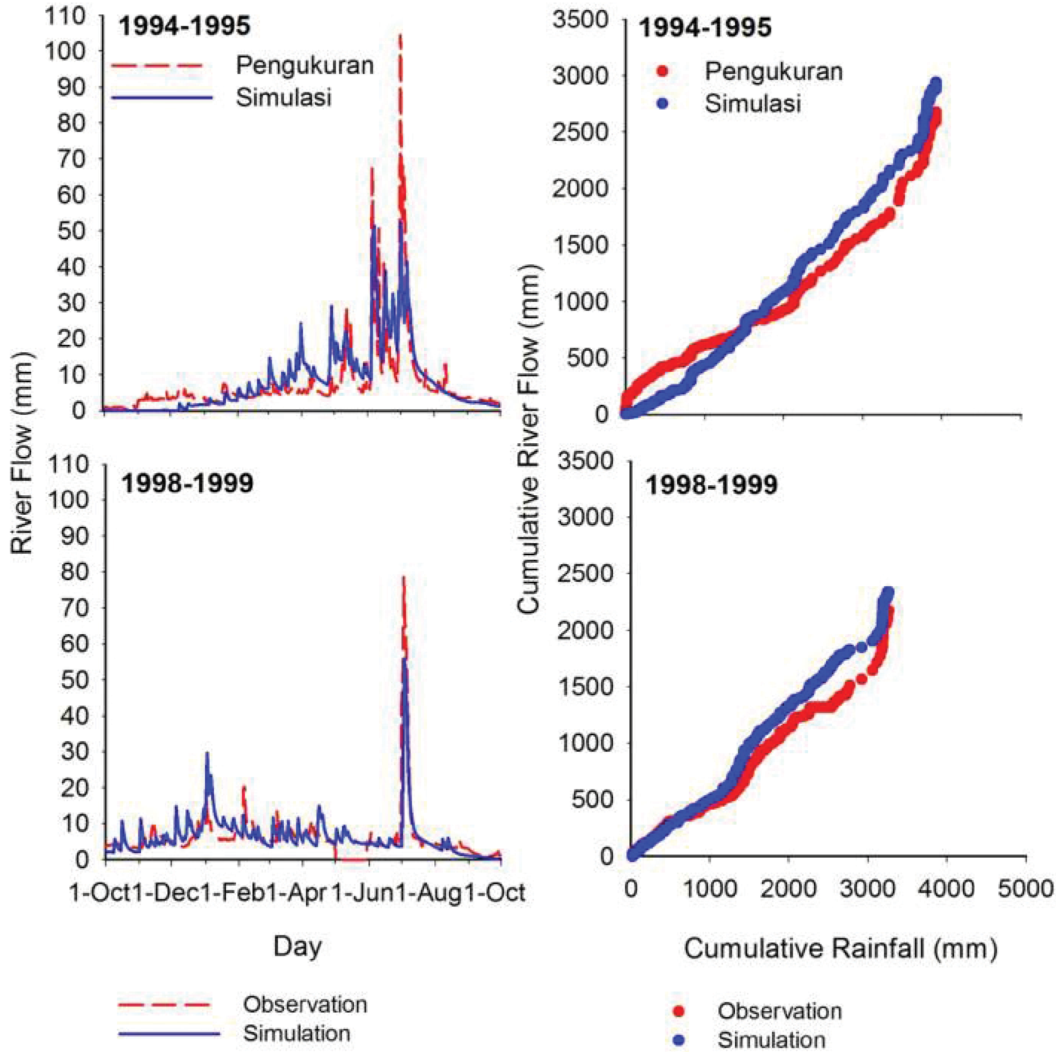



**Figure 29.3.** River flow simulations by GenRiver with actual observation

The results of the simulation of the impacts of land-cover changes on the water balance in Bialo watershed, using GenRiver, can be divided into three transition periods: 1) 1989–1999; 2) 2000–2005; 3) 2006–2009.

The first period (1989–1999) enjoyed annual rainfall ranging 1142–2668 mm and land-cover changes, such as the deforestation of 39 hectares, a decrease in mixed-tree gardens from 23.3% to 16.5%, a decrease in coffee and cocoa agroforestry from 8% to 7.3% and an increase of 6.3% and 0.5% of clove and other agroforestry, respectively. This led to an increase in evapotranspiration of 12.16% per year and a decrease in river discharge of 12.13% annually. The decrease was caused by the decline in surface flow (12.14% per year) and base flow (0.1% per year).

The second (2000–2005) and third (2006–2009) periods had annual rainfall ranging 1392–2194 mm and 1184–2365 mm, respectively. The main land-cover transition that occurred in these periods was in forests and clove agroforests. Forests decreased from 9.25 to 4.5% and then from 4.5% to 2.3%. Clove agroforests increased from 21.8 to 29.1% and then from 21.9 to 31.3%. This led to increased evapotranspiration of 0.53% per year and a decrease in river discharge of 0.43% annually. This change of river discharge featured increasing baseflow and decreasing surface flow.

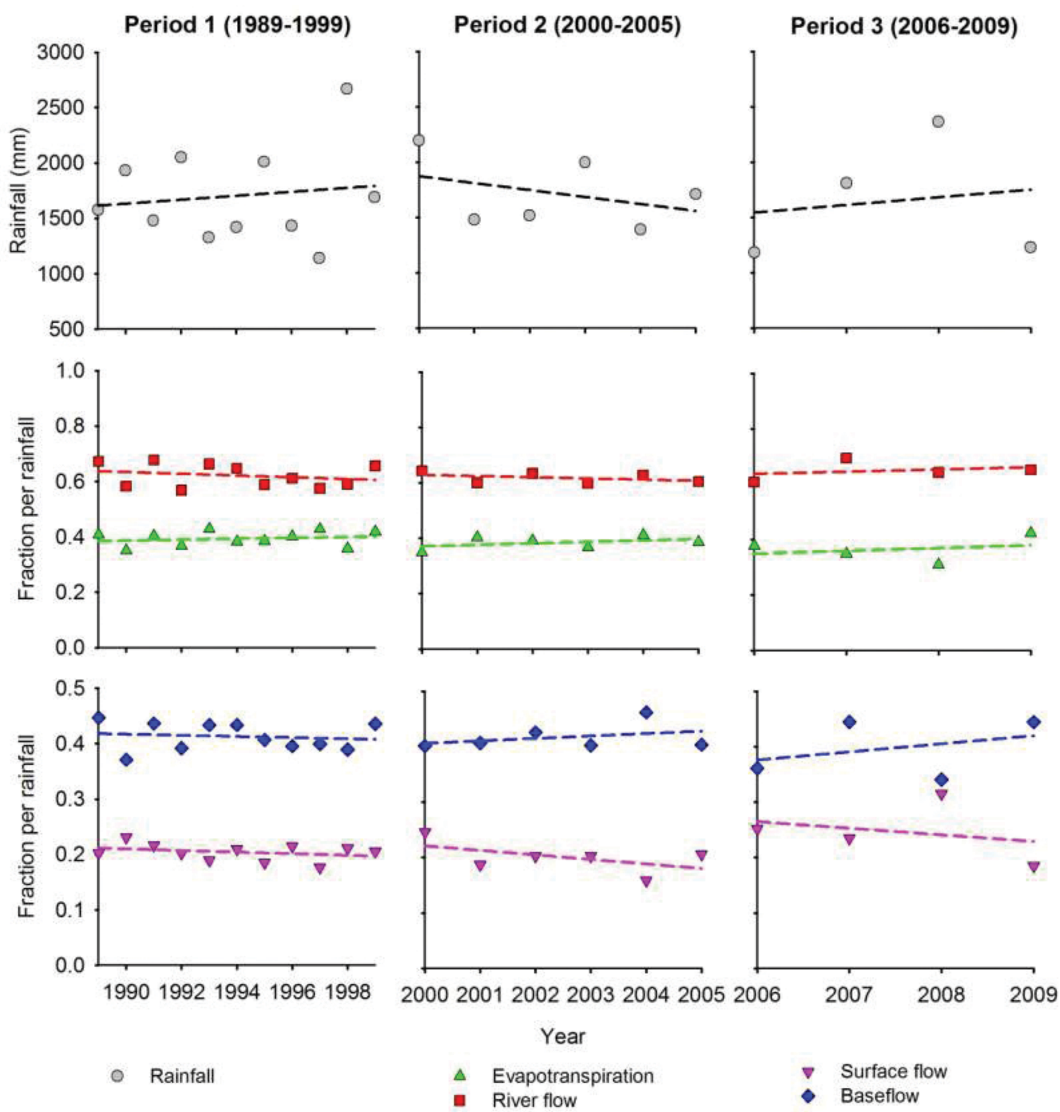



**Figure 29.4.** Simulation result of water balance in Bialo watershed using GenRiver model for each transition period

The assessment of the hydrological situation of a watershed is determined by the criteria and indicators of water transmission (total water yield per unit rainfall), buffering capacity (relationship of peak river flow and peak rainfall, linked to flooding risk) and gradual release of groundwater in the dry season, based on recharge in the rainy season (Table 29.1). These indicators all relate the flows of water to preceding rainfall and by doing so allow the analysis of relatively small land-use effects, superimposed on substantial year-to-year variation in rainfall.

To capture the impact of land-use changes, the indicators were scattered over the 21-year simulation period (Figure 29.1). The main effect of the changes seems to have been an increase in evapotranspiration and a decrease in total water yield as a fraction of total rainfall. The buffering capacity (buffering indicator, buffering relative, and buffering peak events) tended to be stable until 2009. The buffering indicator and relative buffering indicator had a negative correlation to the discharge fraction (fraction of river flow per rainfall) over the year (Figure 29.1).

**Table 29.1.** Average of indicators of watershed function

| | Observed | | | Simulated | | |
|---|---|---|---|---|---|---|
| | Min. | Average | Max. | Min. | Average | Max. |
| Total discharge fraction | 0.32 | 0.57 | 0.77 | 0.57 | 0.63 | 0.69 |
| Buffering indicator | 0.58 | 0.74 | 0.90 | 0.58 | 0.68 | 0.76 |
| Relative buffering indicator | 0.17 | 0.54 | 0.75 | 0.35 | 0.50 | 0.61 |
| Buffering peak event | -0.68 | 0.51 | 0.91 | 0.72 | 0.84 | 0.91 |
| Highest monthly discharge relative to mean rainfall | 1.36 | 2.30 | 3.61 | 1.62 | 2.38 | 3.18 |
| Overland flow fraction | | | | 0.16 | 0.21 | 0.32 |
| Soil quick flow fraction | | | | 0.00 | 0.00 | 0.00 |
| Slow flow fraction | | | | 0.33 | 0.41 | 0.47 |
| Lowest month fraction | | | | 0.01 | 0.18 | 0.44 |

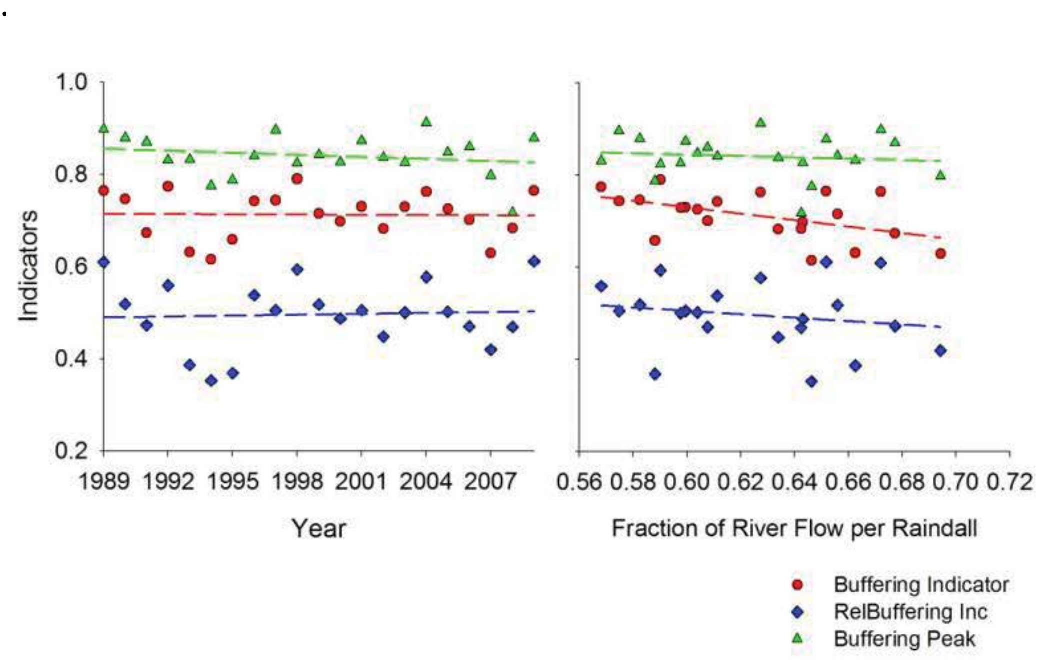



**Figure 29.5.** Trend of buffering capacity indicator over 21 years (1989–2009) and to discharge fraction

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Van Noordwijk M, Widodo RH, Farida A, Suyamto DA, Lusiana B, Tanika L, Khasanah N. 2011. G*eneric River and Flow Persistence models. User Manual Version 2.0*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. http://www.worldagroforestry.org/sea/publication?do=view_pub_detail&pub_no=MN0048-11.

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL. 2001. *Model evaluation guidelines for systematic quantification of accuracy in watershed simulations*. American Society of Agricultural and Biological Engineers 20(3):885–900.

# 30 | Flow persistence (FlowPer)

**Lisa Tanika and Meine van Noordwijk**

The Flow Persistence (FlowPer) model produces an indicator that summarizes the relationship between rainfall and river flow and current (today) with previous (yesterday) river flow. The flow persistence value can indicate how well the watershed is buffering rainfall and thus avoiding flash floods. Flow persistence values of above 0.8 may reflect good watershed conditions, while values below 0.4 indicate a poorly buffered watershed. The values can be used as a basis for conditional environmental services' rewards.

## Introduction

Analysis of watershed functions deals with complex factors that influence processes and patterns in the landscape that ultimately translate a temporal pattern of rainfall into a temporal pattern of stream flow, which aggregates to become a river. The Flow Persistence (FlowPer) model uses information from a time series of river-flow data to deduce what may happen upstream in the absence of knowledge on 'anthropogenic' intervention that could have occurred as well as the geological and climatic background.

The FlowPer model provides a parsimonious null-model that is based on temporal autocorrelation or an empirical 'flow persistence' in the river-flow data. The basic form is a recursive relationship between river flow (Q) on subsequent days:

$$Q_{t+1} = f_p Q_t + Q_{add}$$

where $Q_t$ and $Q_{t+1}$ represent the river flow on subsequent days, $f_p$ is the flow persistence value ($[0< f_p <1]$) and $Q_{add}$ is a random variate that reflects inputs from recent rainfall.

$Q_{add}$ and $f_p$ are related, as $\Sigma Q_{add\ i} = (1 - f_p) \Sigma Q$. Thus, if $f_p = 1$, $Q_{add} = 0$ and river flow is constant, regardless of rainfall (the ideally buffered system. If $f_p = 0$ there is no relation between river flow on subsequent days and the river is extremely 'flashy', alternating between high and low flows without temporal predictability within the frequency distribution of $Q_{add}$.

The term $Q_{add,i}$ can be described as a statistical distribution with a probability of a non-zero value, a mean and a measure of variance, plus two parameters that describe a seasonal pattern (peak and shape of the distribution, for example, Weibull[1]).

If we partition the total flow $Q_{tot}$ into water flow by three pathways (surface runoff, interflow and groundwater flow), we can obtain $Q_{tot} = Q_{runoff} + Q_{interflow} + Q_{gwflow}$. Each type of flow pathway will typically have a different flow persistence, $f_{p,runoff}$, $f_{p,interflow}$ and $f_{p,gwflow}$, respectively.

[1] Weibull distribution is a continuous probability distribution (in probability theory and statistics)

$$Q_{tot,t+1} = (f_{p',runoff}(Q_{runoff,t}/Q_{tot,t}) + f_{p',interflow}(Q_{interflow,t}/Q_{tot,t}) + f_{p',gwflow}(Q_{gwflow,t}/Q_{tot,t}))Q_{tot,t} + Q_{add,t}$$

As we can expect values for $f_{p'runoff}$, $f_{p'interflow}$ and $f_{p'gwflow}$ of about 0, 0.5 and close to 1, respectively, we can interpret the relative contributions of the three flow pathways from the overall $f_p$ value.

## Objectives

1. FlowPer provides indicators of how well a watershed is provisioning the stability of river flow.
2. FlowPer serves as a parsimonious (parameter-sparse) null model that allows quantification of the increments in model prediction that is achieved with spatially explicit models.

## Steps

1. Gather daily river-flow data and rainfall data in addition to calculating flow persistence value ($f_p$).
2. Calculate $f_p$ and $Q_{Add}$ value using 'Preparation Input FlowPer.xls'.
3. Assess the hydrological function based on $f_p$ and rainfall data.
4. Run FlowPer to predict other daily river discharges based on $f_p$ value.

## Case study: Bialo watershed

Bialo Bayang-Bayang discharge station is located in upper Bialo watershed, South Sulawesi, Indonesia. This station covers 5020 hectares, 44.9% of Bialo watershed, which is mainly dominated by forest. However, from during 1989 to 2009, the forest area (both primary and secondary) in Bialo watershed decreased from 49 to 36%. The area was largely converted to clove agroforestry.

We analyzed the buffering capacity of the Upper Bialo watershed using FlowPer. The purpose was to make a quick assessment of the watershed condition based on river discharge behaviour. The result showed that the flow persistence values tended to increase with an average value of 0.8, reflecting good watershed conditions (Figure 30.1).

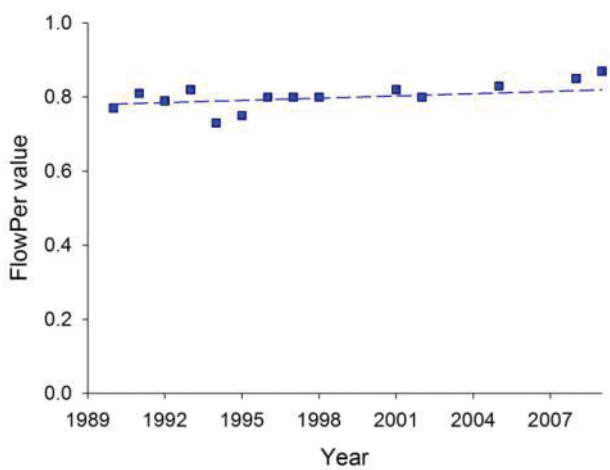


**Figure 30.1.** FlowPer value in Bialo Bayang-Bayang station over a 21-year simulation

The example of river discharge prediction using FlowPer is shown in Figure 30.2. The generation of this river discharge is based on $f_p$ value 0.75 and $Q_{Add}$ 0.4. The model evaluation between observed and simulated shows that both river discharges has a daily correlation 0.49 and 0.86 for monthly correlation. It means that the FlowPer can predict river discharge using a simple parameterization.

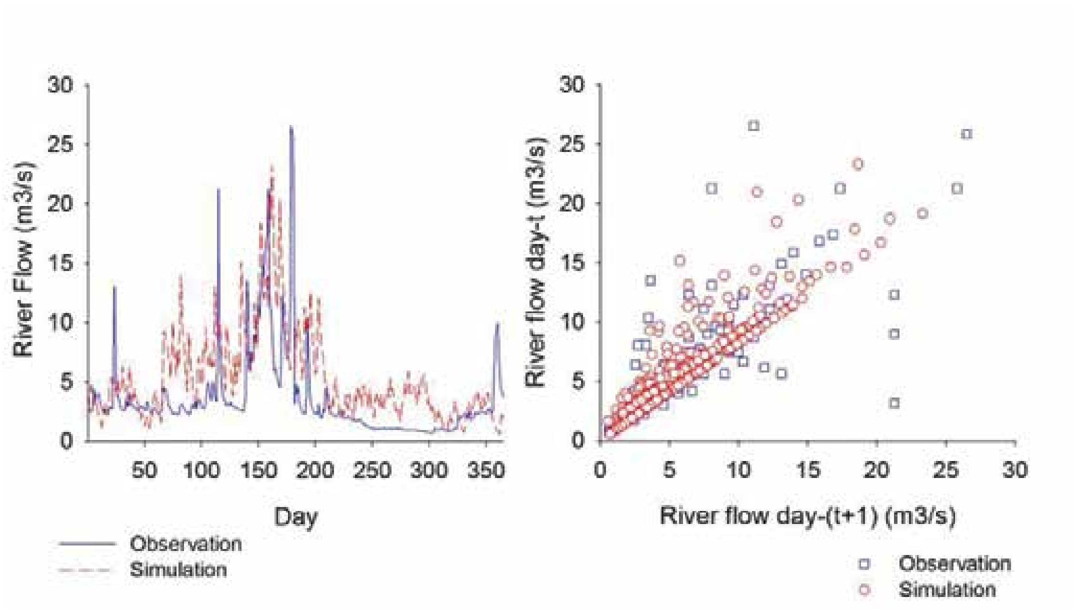


**Figure 30.2.** Example of the type of 'fit' that can be achieved for the six parameter null-model. This simulation used Upper Bialo watershed data for 1993

## ■ Key reference


Van Noordwijk M, Widodo RH, Farida A, Suyamto D, Lusiana B, Tanika L, Khasanah N. 2011. GenRiver and FlowPer: Generic River and Flow Persistence models. User manual version 2.0. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. http://www.worldagroforestry.org/sea/publication?do=view_pub_detail&pub_no=MN0048-11.

# 31 | Rainfall simulator (RainyDay) and spatial rainfall (SpatRain)

**Meine van Noordwijk, Lisa Tanika, Desi A. Suyamto, Rachmat Mulia, Betha Lusiana and Ai Farida**

Rainfall Simulator (RainyDay) generates daily rainfall based on annual rainfall characteristics and an assumption that rainfall patterns follow statistical distribution functions, such as Weibull and Gamma. The model takes into account day-to-day variations in rainfall events as well as different patterns of rainfall across time or seasons. The model operates in MS Excel.

Spatial Rainfall (SpatRain) is a statistical tool to generate event-level rainfall maps across a watershed that represent the observed partial spatial correlation between daily rainfall at multiple locations. The results can be used by hydrological models that assess the influence of rainfall at watershed level on the scaling of river flow and its degree of buffering and flow persistence.

## Introduction

Most hydrological and ecological models need daily rainfall data as input. Such a dataset is, however, not always readily available because, for example, the high cost of buying daily data from a weather-recording institution, human error in reading the daily rainfall amount from installed equipment in the field or a rainfall record that tends to produce rainfall data over several days so wet and dry days tend to be clumped together. Some studies can also need an extrapolation of rain events, for example, for simulations of hydrological process over 100 years into the future. An appropriate method to generate daily rainfall data is thus necessary.

RainyDay generates daily rainfall based on two main steps: 1) simulating rainfall occurrence, that is, determining whether or not a day is a rainy day; and 2) if rainfall occurs, determining the amount of rainfall on that wet day. Rainfall occurrence is simulated using a Markov chain model, while amount of rainfall is determined using Weibull and Gamma distribution functions.

Variations in river flow tend to decrease with an increasing area of consideration, partly owing to a decrease in temporal correlation of rainfall events across space. Patchiness of rainfall can contribute to an increase of crop-yield stability over space. To what degree does rainfall variability enhance stability of river flow? How do land cover and spatial patterns of rainfall interact in preventing flashiness of river flow? Being able to answer these questions is important for watershed management. The answers can determine how much changes one can expect from land rehabilitation efforts improveme watershed functions.

A hydrological model can answer these questions. However, a model requires the availability of rainfall data based on a dense network of rain gauges across a watershed. In the absence of such data, which is usually the case, especially in developing countries, a rainfall generator that can produce realistically resampled rainfall maps across a watershed is essential. Existing rainfall simulators, such as the ones included in WaNuLCAS and GenRiver, focus on station-level time series, not on the space/time autocorrelation that matters at higher scales.

## Objectives

The objective of RainyDay is to generate daily data from monthly rainfall data.

The objective of SpatRain is to generate time series of rainfall that are fully compatible with existing station-level records of daily rainfall but yet can represent substantially different degrees of spatial autocorrelation. Using semivariance as as a function of increasing distance between observation points, SpatRain is also able to characterize the resulting rainfall patterns accumulated over specified lengths of time (days, weeks, months, years).

## Steps in RainyDay

1. Prepare a minimum of one year's daily rainfall data as an input. These data are used to extract the characteristics of rainfall, that is, the wettest month, the month with the highest daily rainfall, the number of wet days, the monthly wet fraction, the monthly relative wet persistence and parameters for Weibull distribution.
2. Parameterize the model.
3. Generate daily rainfall data that has the closest characteristics to actual rainfall data.

## Steps involved in SpatRain

Calculations start from the assumed spatial characteristics of a single rainstorm pathway, with a trajectory for the core area of the highest intensity and a decrease of rainfall intensity with increasing distance from this core. The model can derive daily amounts of rainfall for a grid of observation points by considering the possibility of multiple storm events per day but not exceeding the long-term maximum of observed station-level rainfall. Options exist for including elevation effects on rainfall amount.

SpatRain adheres to the following rules.

1. The simulated rainfall for any point in the landscape must be consistent with existing data on the frequency distribution of daily rainfall.
2. SpatRain must allow for spatial trends in the rainfall average (mean), for example, due to elevational effects.
3. SpatRain analyzes semivariance as a function of increasing distance between observation points as a way to characterize the resulting rainfall patterns accumulated over specified lengths of time and identify the storm-level parameters that lead to specified degrees of spatial correlation.
4. For use in combination with a hydrological model, SpatRain should allow for the
   a. identification of sub-catchments in a watershed area and allow averaging the point grid; and
   b. pattern to derive the daily average rainfall per sub-catchment.

The following steps are carried out prior to running SpatRain.

1. Calculate assumed storm (rain) properties.
2. Synchronize spatial pattern with temporal pattern.
3. Generate multiple storm events.
4. Calculate storm events probability.
5. Calculate patchiness indicator using semivariogram.

## Case study: RainyDay in Sumberjaya

We applied RainyDay in Sumberjaya catchment, Lampung, Indonesia. Land use in the area was mostly (70%) coffee plantations. A reservoir for a hydroelectric plant was located downstream. The plant's management were concerned that the coffee plantations, which had been converted from forests, would disrupt the stability of river flow. They were interested in using a model to assess the hydrological function of the watershed. However, multi-year rainfall data were not available and so we used RainyDay to generate the data for the area. We tested the performance of RainyDay in generating rainfall by comparing its results with actual observations for a 1-year period.

Analysis of the rainfall data was carried out to create input parameters required to generate rainfall (tables 31.1 and 31.2). In general, the rainfall of Sumberjaya has one peak event. Thus, we could use uni-modal parameters. The offset value was smaller than -1 because in Sumberjaya there were no dry months (monthly rainfall is always larger than 0). The high Weibull value showed that the daily rainfall tended to be uniform.

**Table 31.1**. List of parameter inputs for RainyDay in Sumberjaya

| Parameters | Value |
|---|---|
| Uni or bimodal? | 1 |
| Wettest month of rainy season | 1 |
| Peakiness of season | 1 |
| Probability | 0.5 |
| Offset (influence number of dry months) | -30.00 |
| Weibull value | 0.93 |
| Average of wet fraction | 0.81 |

**Table 31.2.** Monthly time series input for RainyDay in Sumberjaya

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Agt | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of wet days | 29 | 27 | 30 | 26 | 26 | 22 | 22 | 16 | 20 | 23 | 26 | 29 |
| Montly rainfall | 334 | 297 | 321 | 306 | 208 | 153 | 103 | 119 | 163 | 239 | 273 | 315 |
| Relative wet per-sistence | 1.01 | 1.00 | 1.00 | 1.02 | 1.07 | 1.15 | 1.19 | 1.45 | 1.27 | 1.15 | 1.08 | 1.01 |

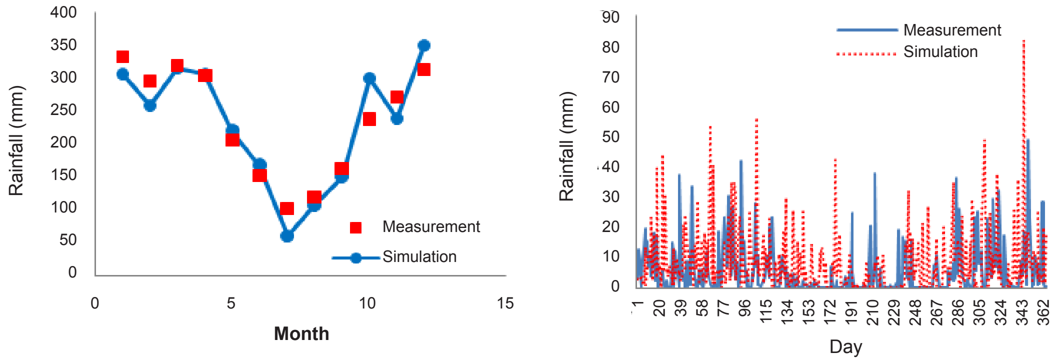


**Figure 31.1.** Comparison of simulated and observed rainfall data, total monthly rainfall (upper figure) and daily rainfall data (lower figure)

The comparison between simulated and actual rainfall showed that RainyDay was able to generate rainfall similar to actual rainfall with correlation above 80% and bias smaller than 8 mm.

## Case study: SpatRain in Sumberjaya

SpatRain was used together with GenRiver to simulate the river flow of Way Besai River in Sumberjaya watershed, Lampung, Indonesia. The study tested the hypothesis that spatial variability of rainfall becomes increasingly important with increasing size of catchment areas in influencing the volume, seasonality and regularity of river flow.

A series of spatially explicit daily rainfall patterns was constructed that matched the monthly mean as derived from rainfall records on the site (Figure 31.2) with differences in pattern, homogeneity, intermediateness and patchiness (Figure 31.3). The fractal dimension (Bian 1997) of each rainfall type was 1.44, 2.34, and 2.90, for H ('homogeneous'), I ('intermediate') and P ('patchy'), respectively.

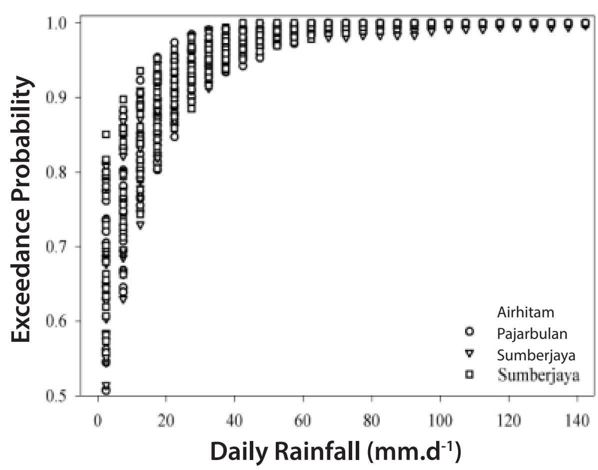


**Figure 31.2.** Probability of rainfall in Sumberjaya based on three rainfall stations

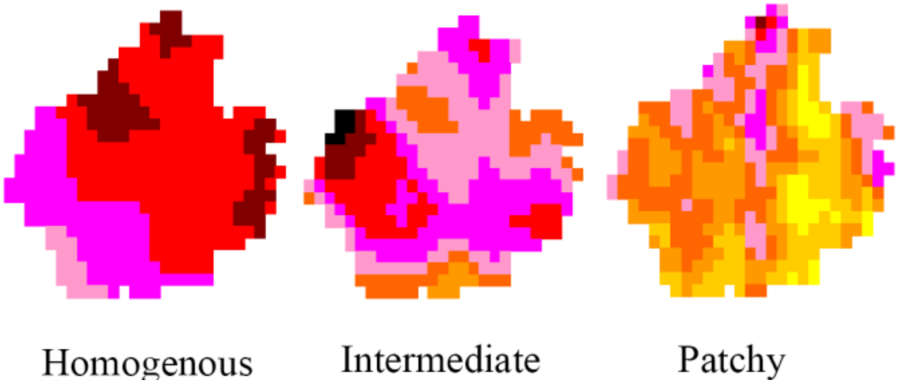


**Figure 31.3.** Example of the spatial distribution of rainfall on a single day for settings that are indicated as 'homogenous', 'intermediate' and 'patchy'

Using the rainfall patterns of SpatRain, we simulated river flow for the Way Besai River over 20 years to reveal the way annual rainfall is partitioned over evapotranspiration, groundwater discharge, surface and soil quick flows, showing some changes in response to land-use changes (Figure 31.4).

The difference between the three rainfall patterns, however, was larger than the land-use change signal, with an increasing surface quick flow fraction for more patchy rainfall events. The latter was due to higher local rainfall events in parts of the landscape exceeding infiltration capacity during the time available. The frequency distribution of river flow clearly corresponded with the simulations for 'patchy' rainfall much more closely that it did with those for homogeneous or intermediate rainfall types (Figure 31.5).

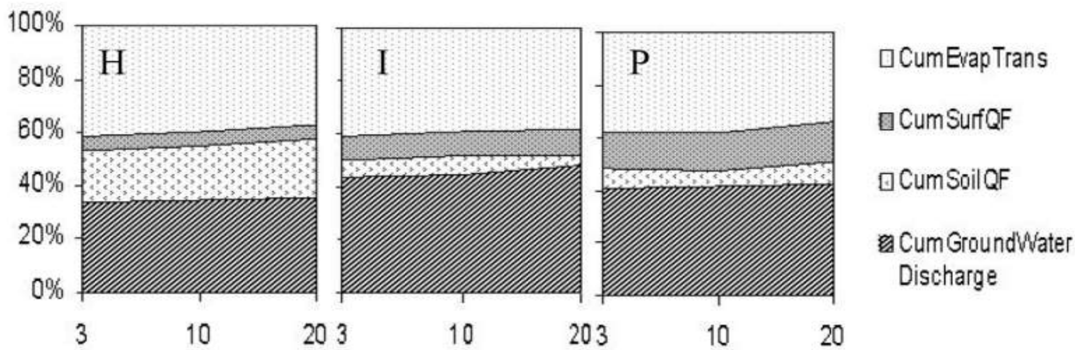


**Figure 31.4.** Water balance for homogenous (H), intermediate (I) and patchy (P) rainfall type

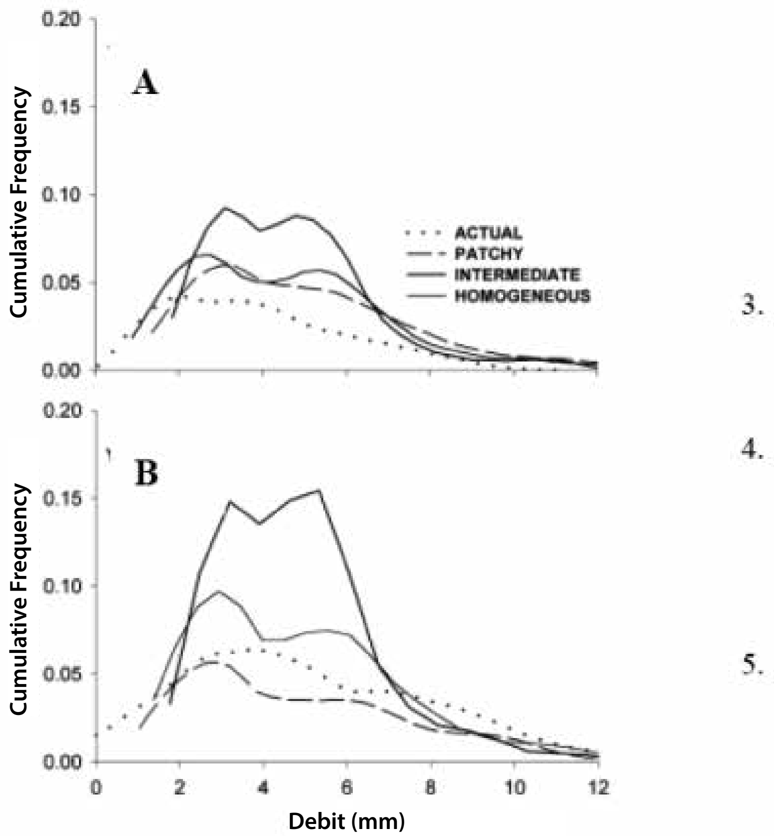


**Figure 31.5.** Probability/frequency distribution of the river debit

**Note:** Actual and as simulated by GenRiver driven by homogenous, intermediate or patchy rainfall patterns for year 3 (A) and year 20 (B)

## ■ Key references


Van Noordwijk M, Widodo RH, Farida A, Suyamto D, Lusiana B, Tanika L, Khasanah N. 2011. *GenRiver and FlowPer: Generic River and Flow Persistence models. User manual version 2.0*. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. http://www.worldagroforestry.org/sea/publication?do=view_pub_detail&pub_no=MN0048-11.

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# 32 | Land-use change impact assessment (LUCIA)

**Carsten Marohn, Georg Cadisch and Betha Lusiana**

The Land-Use Change Impact Assessment (LUCIA) model can be used to assess impacts of land-use changes on soil productivity and fertility, biomass production, watershed functions and environmental services. It operates at high spatial and temporal resolution but can so far only handle small mountainous catchments. It help scientists and land-use planners simulate mid- to-long-term effects of land-use management and changes on environmental degradation and rehabilitation. It is explicit in the consequences of plot-level decision making by farmers and thus operates between the reach of detailed tree–soil–crop interaction models and models that operate at more aggregated watershed scale.

## Introduction

Peoples' decisions with respect to agricultural land use and management have a major impact on natural resource degradation. Soil degradation is largely caused by the activities of land-use decision makers and has substantial feedback effects on both human and environmental systems. Particularly in mountainous areas, degradation is largely due to flow of matter from upstream to downstream areas in the form of water (runoff) that also brings along soil (erosion, deposition) and nutrients. The use of a simulation model such as LUCIA can help land-use planners to assess the impact of landscape management in order to reduce soil degradation.

LUCIA integrates different processes related to soils, water and plants thus allowing a user to assess the benefits and trade-offs of land-use changes and management. These processes are represented in a spatially explicit way so that the effects of positioning of each land use and activity in the catchment are taken into account and can be considered when designing management strategies. Applications of the model encompass the decline and recovery of soil fertility, changes in the water balance, surface runoff, erosion and sedimentation processes, yield levels, as well as food security, biomass and carbon stocks. Scenarios can represent the consequences of local farmers' short-term management decisions (such as fertilization, ploughing or burning), land-use and land-cover changes, or longer-term changes such as climate.

## Objectives

LUCIA was designed to represent processes of water balance, erosion and sedimentation as well as nutrient balance and yield formation in a small catchment responding to plot-level management decisions.

## Steps

LUCIA combines daily time steps for crop growth and hourly sub-time step for infiltration, runoff and erosion. It is a spatially explicit landscape model written in PCRaster, a combination of dynamic modelling language and GIS developed at the University of Utrecht.

LUCIA consists of five main modules: 1) Hydrology/soil water; 2) Soil nutrients; 3) Organic matter and decomposition; 4) Plant growth; and 5) Land-use and management options. The soil water, organic matter and plant modules are built on concepts of established models, namely KINEROS (Woolhiser et al 1990) and SPAW (Saxton and Rawls 2006), CENTURY (Parton et al 1987) and the Crop Growth Monitoring System CGMS (Supit 2003), which is based on the World Food Studies (WOFOST) model.

Input parameters required and outputs produced by LUCIA are provided in the user manual (Hörhold and Marohn 2012) and theoretical background in the documentation (Marohn and Cadisch 2011). An online distance learning course is offered that includes lectures and exercises with the model (https://openilias.uni-hohenheim.de).

The LUCIA model has been successfully coupled with MP-MAS, a model that simulates farm decision making, to explore the impacts of several soil conservation measures on erosion and yields in northern Viet Nam. Currently, LUCIA-Choice is also being developed: a decision-making module, which can be coupled with LUCIA. LUCIA-Choice contains a decision algorithm based on household resources, crop preferences and plot quality. The latter includes top-soil carbon contents and other indicators of soil fertility and it is up to the farmers (as parameterized by the user) how much importance they attribute to these factors. This will allow a reflection of farmers' levels of local knowledge on plot-specific characteristics in terms of their land. A simple tool for building land-cover-change scenarios is the rule-based LUC generator.

## Case study: LUCIA in Viet Nam

Soil degradation is largely caused by the activities of land-use decision makers and has substantial feedback effects on both human and environmental systems. To capture these feedback effects and the resulting human–environment interactions, LUCIA was used to assess the potential impact of low-cost soil conservation methods on maize cultivation in upland areas. The study was carried out in Chieng Khoi in Son La province, Viet Nam, an area which represents the ongoing trend toward intensified maize-based agriculture in parts of northwestern Viet Nam. The combination of heavy rain and mostly steep terrain makes soils highly susceptible to erosion once permanent vegetation cover is removed. With increasing population in the area and stronger market integration, fallow periods have shortened or even disappeared, leading to severe soil degradation.

Average crop yields were calibrated using a household survey of 490 farms (Quang 2010) and validated based on field data by Schmitter et al (2010) and Rathjen (2010) for paddy rice, maize and cassava, respectively. Pixel size in the Chieng Khoi model was set at 25 by 25 m, which corresponds to the size of an average smallholding plot. Maize fields in Chieng Khoi are slashed and burned between November and March; fields are ploughed at the start of the wet season (April to October) and maize is sown in May. Model scenarios were based on the above data, comparing farmers' practices as a baseline scenario to three alternative scenarios (Table 1). Under these scenarios, the introduction of different soil conservation options in the maize fields was tested.

**Table 32.1.** Scenarios tested for plots under maize cultivation

| Scenario | Management options | | | |
|---|---|---|---|---|
| | Burning | Tillage | Cover crop | Description |
| Baseline: current practice | Yes | Yes | No | Fallow vegetation or crop residues are slashed and burned in the dry season prior to ploughing and sowing |
| B: Zero tillage without cover crop | No | No | No | Fallow vegetation is not burned but mulched; maize is planted in untilled soil |
| C: Zero tillage with cover crop | No | No | Yes | Same as (B), but a perennial legume is inter-planted with maize to reduce erosion; suppress weeds and fix atmospheric nitrogen |
| D: Cover crop plowed under | No | Yes | Yes | Same as (C), but the cover crop is ploughed into the soil to improve soil fertility and ease planting |

**Source:** Marohn et al 2013

Three fertilizer levels were implemented for each scenarios: 1) zero fertilizer; 2) farmers' practice which is 75/50/75 kg of N/P/K per hectare; and 3) levels recommended by the fertilizer manufacturer (double the farmers' practice). Fertilizer levels per pixel were not varied between scenarios and years. Legumes were implemented as soil cover not competing with the crop for nutrients.

The objective of the study was to assess 1) whether soil conservation measures under maize were able to directly reduce soil degradation and indirectly reduce it under other land uses on lower slope positions; and if so 2) how far yield levels would be positively affected by soil conservation measures in the long run.

It was found that soil conservation effectively reduced erosion. After the first year, soil conservation on maize plots under no tillage (Scenario B) resulted in 0–7.3 Mg $ha^{-1}$ less sediment loads per pixel as compared to the baseline, while the legume scenarios C and D achieved between 0 and 18.8 Mg $ha^{-1}$ less sediment loads (Figure 32.1). Land uses other than maize showed only minor differences between scenarios. After 25 years, reduced sediment loads on maize plots reached up to 365 Mg $ha^{-1}$ for Scenario B and 1680 Mg $ha^{-1}$ for Scenario C and Scenario D. The most substantial reduction was found in the lowland areas, which receive sediment from the entire catchment. Cumulative reduction ranged from 0 to 780 Mg $ha^{-1}$ for Scenario B and from 0 to 2,150 Mg $ha^{-1}$ for scenarios C and D. Topsoil depth after 25 years was analysed as well. On a few of the pixels (approximately 20% of the entire catchment), topsoil thickness was slightly greater in the baseline as compared to the other scenarios. In all other cases, topsoil was up to 5.3 cm thicker under Scenario B and up to 20 cm under scenarios C and D, as compared to the baseline. Separating these effects between maize and other land covers showed that other land uses were hardly affected, revealing that top-soil loss affected mainly the source cells and that sediments travelled through the lowlands but did not cause a major entrainment of soils under other land-cover types.

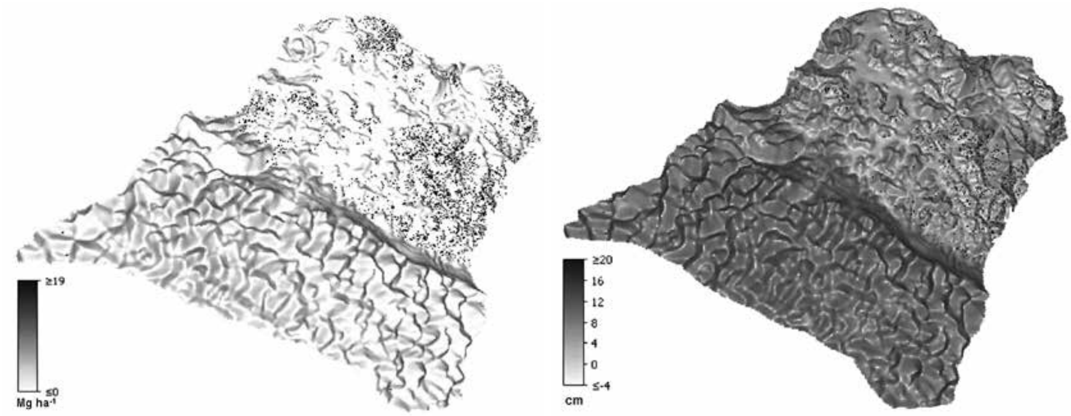


**Figure 32.1.** Difference in sediment loads and topsoil depth

**Note:** Baseline minus scenario D after year 1 (left) and difference in top-soil depth scenario D minus baseline after year 25 (right)

**Source:** Marohn et al 2013

The analysis of yields after 25 years showed that it was mainly maize that was affected by soil conservation measures, as expected (Figure 32.2 ). Owing to landscape-related factors, both maize-derived erosion rates and maize yields showed large spatial variability, as shown in Table 32.2.

**Table 32.2**. Descriptive statistics of yields

| Descriptor | Maize yield F0, year 5 | Erosion, year 1 |
|---|---|---|
| Mean [Mg ha$^{-1}$] | 4.20 | 13.6 |
| St.dev. [Mg ha$^{-1}$] | 2.40 | 30.2 |
| Coeff. Var. [%] | 57 | 222 |

**Note:** On unfertilized (F0) maize pixels for the fifth year of simulation, and erosion across all maize pixels for the first year of simulation, baseline, (n = 3,665)

**Source:** Marohn et al 2013

Clear differences in average maize yields appeared between fertilizer levels, regardless of the soil conservation measures used. Under farmers' practice of continuous fertilizer inputs (F1 treatment in Figure 32.2, left chart) average maize yields started around 6 Mg ha$^{-1}$ and then increased up to 7 Mg ha$^{-1}$ under the baseline and no tillage scenarios, while yields of maize combined with legumes slightly decreased and dropped below the baseline in year 8. As nutrient competition between crop and legume was not modelled, this might have been caused by indirect nutrient insufficiency owing to water stress in the crop (caused by the higher water demand of crop plus legume). Yields under high fertilizer input (F2 treatment; Figure 32.2, right chart) came close to potential yields during years without water stress. Under soil conservation and high fertilizer inputs, yields remained clearly above the baseline at all times, however, during years of extreme weather (for example, 7 and 17) the difference in yields between legume and non-legume treatments shrunk.

Significant effects of ploughing between the two legume treatments were not observed in the simulations.

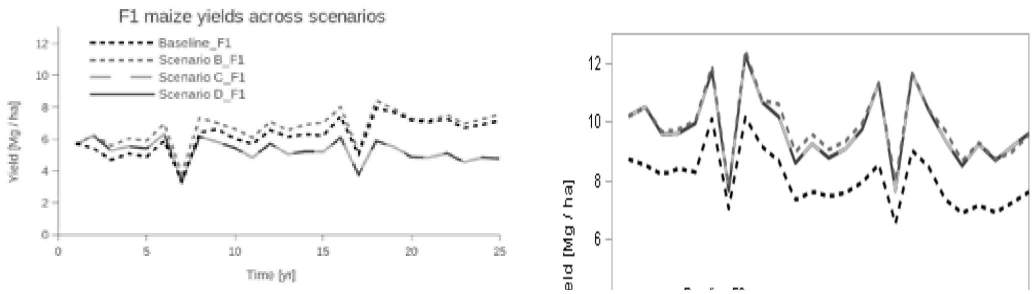


**Figure 32.2.** Average maize yields

**Note**: At farmers' practice (left) and high fertilizer levels (right) under all scenarios over the 25 years of simulation

**Source:** Marohn et al 2013

At the plot level, the magnitude of soil eroded from maize plots (Table 32.2) was in the range of that found in the reference experiments carried out on similar slopes and soils in Chieng Khoi (Tuan, personal communication). Simulated soil conservation measures on maize plots were effective at reducing soil erosion on these plots and also on other plots downstream. The reduced erosion rates had a positive effect on maize yields in the first years after implementation of the measures.

In combination with the MP-MAS model, LUCIA maize yields led to two different land-use and management strategies by farmers: 1) Intensification, that is, adding more fertiliser when maize yields decreased; and 2) extensification, that is, omitting fertiliser on plots that were not profitable. Consequently, a sensitivity analysis showed that fertiliser prices had a strong impact on soil conservation measures: where fertiliser was cheap, waning yields were compensated by increased fertiliser levels, else soil conservation was practised.

At the landscape level, soil conservation measures in maize fields had limited effects on the sediment loads leaving the entire catchment, as deposition accounted for filtering and delayed delivery. Although absolute quantities of eroded soil at the catchment outflow differed clearly between scenarios, these differences remained small in relative terms, owing to the fact that the large areas under forest and tree plantations that contribute little to erosion remained unchanged between scenarios. Seemingly larger erosion reduction effects in paddies, as compared to maize plots, stemmed from the fact that the model simulated sediment loads and thus did not distinguish between eroded soil originating from a pixel and such passing through a pixel (except for pixels without an inflow, for example, next to a ridge). As sediment from the entire catchment passed the lowland and outflow cells, total amounts were always higher than in the upland source cells.

The LUCIA standalone model captured the spatial variability in erosion and crop yields observed in the field (Lippe et al 2011). The high temporal and spatial resolution of the model allowed identification of erosion hotspots (in terms of reduced topsoil thickness), distribution of sediment loads and patterns of soil fertility (for example, high fertility along previously forested footslopes, outputs not shown) and their development over time. The unchanged land cover and management practices over 25 years, even though not a necessarily realistic scenario, facilitated the tracing back of causal relationships between variables.

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# 33 | Polyscape

**Fergus Sinclair and Timothy Pagella**

Polyscape is a GIS framework designed to explore spatially explicit synergies and trade-offs amongst ecosystem services to support landscape management (from individual fields through to local landscapes of 1000 $km^2$ scale). Polyscape currently maps the impacts of land-cover change on surface runoff, habitat connectivity, erosion, carbon sequestration and agricultural productivity. The tool also incorporates trade-off algorithms that allow visualisation of the impact of different land management decisions and, thus, can be useful for land-use planning at local landscape scales.

## Introduction

Bagstad et al (2013) recently reviewed 17 ecosystem services' tools against eight evaluative criteria that gauged their readiness for widespread application in public- and private-sector decision making. There is scope for further exchange of concepts and algorithms between these models, while there is a clear need for greater user-friendliness and options for exchange between models based on common definitions and concepts. Most of the models are currently framed as 'decision support', aiming for a best-current-science representation of the likely consequences of actions. As discussed before in many of the tools herein, it is relevant to complement such models with approaches that are more directly cognizant of the negotiation context, where knowledge, aspirations and skills are not (yet) shared between the various stakeholders.

The Polyscape approach provides a spatially explicit framework for different stakeholders to explore impacts of land-use options for a range of ecosystem services and to identify synergies and trade-offs amongst them. Negotiation of ecosystem services is likely to involve interaction at the plot, farm and local landscape scale and the tool was designed to work at these scales (typically 10 to 1000 $km^2$). Stakeholders are engaged from the outset, with the representation of ecosystem services' maps iteratively developed and drawing heavily on local and expert stakeholders' knowledge and feedback. This ensures local legitimacy of outputs. This participatory mechanism facilitates in the negotiation of land-use options and in the evaluation of their impact on the provision of ecosystem services. The core of the Polyscape approach is a GIS toolkit that uses generally available data to map:

1. where interventions are most and least desirable with respect to single ecosystem services (currently, agricultural production, water flow, sediment flow, biodiversity conservation and carbon storage; these layers would need to be customised for each landscape);
2. trade-offs and synergies amongst impacts of land-use change on a range of ecosystem services, pinpointing win-win options and areas where incentives may be required to manage trade-offs; and
3. how changes in landscape structure have an impact on the provision of ecosystem services.

Given the emphasis on participation and the difficulties of operating in data sparse environments, the process of developing the maps is likely to be more important than the final maps.

## Objective

The objective of Polyscape is to represent the basic physical structure of a landscape along with the key spatial processes that influence ecosystem functions and create spatial dependencies between cause and effect. This is to be done in a way that is intuitive and communicates well with local stakeholders. The tool captures additional information and insights into the current situation before exploring future changes.

## Steps

1. Obtain a working version of the model and the software needed to run it. Polyscape is in the proof-of-concept phase. Initial development used Python scripts that were hardwired into the tools. Polyscape runs in ESRI™ ArcMap™ 9.2 (or 9.3) with Spatial Analyst™ and Arc-Hydro extension. The tool is currently being ported to QGIS.
2. Develop specifications for the ecosystem services being considered (see Figure 33.1) Parameterize the model with existing spatial information.
3. Present the initial model version to a group of stakeholders, obtain their suggestions for refinement and improvement and observations on how realistic the model is; adjust to the degree possible.
4. Bring the adjusted model to further meetings of landscape actors (including farmers) and explore with them how a wide range of alternative future configurations would affect the performance measures in agronomic, economic and environmental perspectives.
5. Capture the main contrasts, trade-offs and choices that emerge from the 'what if' scenarios of local stakeholders, and bring them into local negotiations.
6. Validation with local stakeholders and experts.

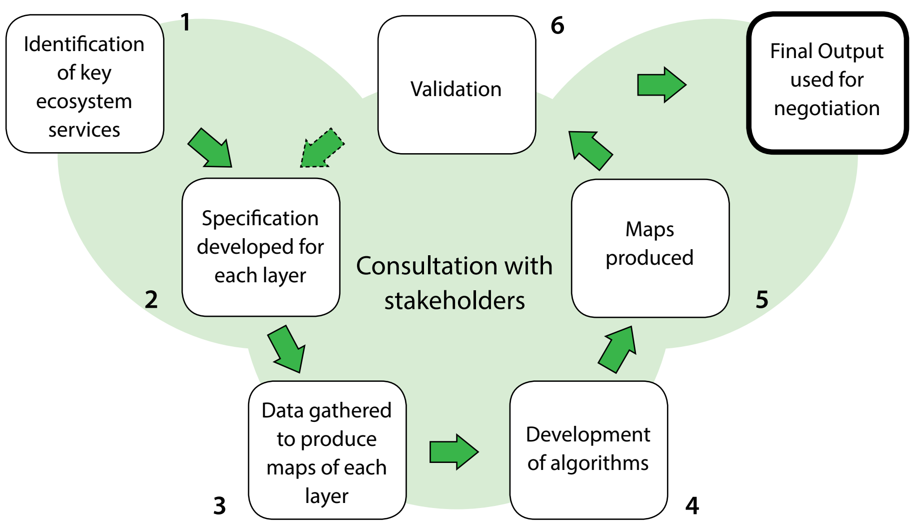


**Figure 33.1.** Iterative cycle of map development for Polyscape

## Example of application

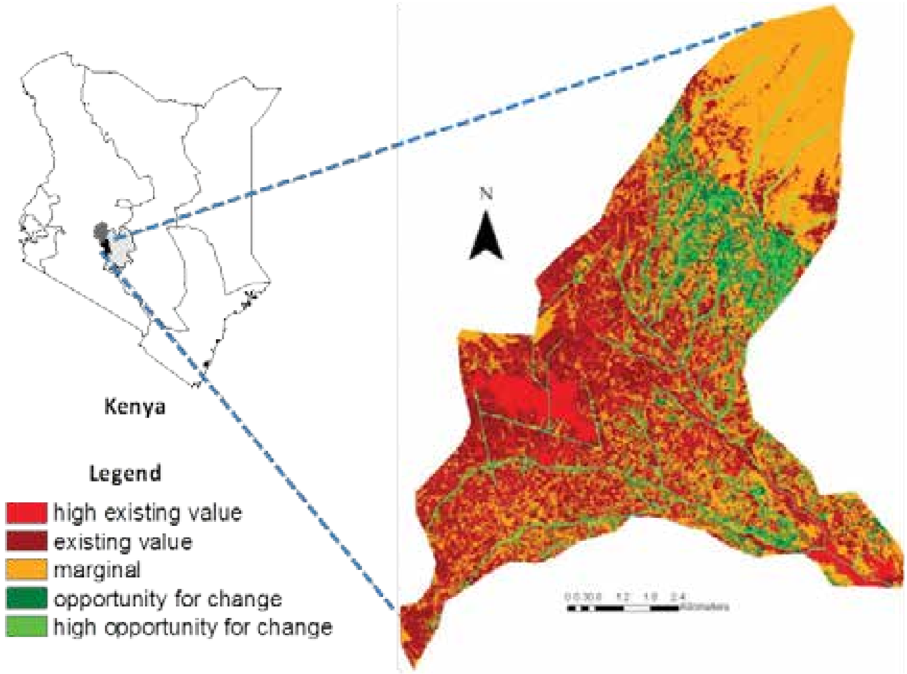


**Figure 33.2.** Example of Polyscape output for the Sasumua watershed in Kenya, trading-off flood mitigation and agricultural productivity services

Polyscape produces spatially explicit outputs in the form of maps showing areas where different ecosystem services either show a trade-off or have synergies at landscape scale. Polyscape was applied in the Sasumua watershed in upland Kenya. The trade-offs shown explore interactions between two separate ecosystem services (flood mitigation and farm productivity). The research interest here was to explore where best to place trees in the landscape (Figure 33.2). Areas where tree planting did not interfere with agricultural production but would intercept surface runoff are shown as light green; areas where a single ecosystem service is good and another ecosystem service is neutral are shown as dark green. The areas coloured red or maroon show where there was a trade-off between agricultural production and hydrological regulation, possibly requiring incentives to promote tree planting.

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# 34 | Forest, agroforest, low-value landscape or wasteland (FALLOW)

**Desi A. Suyamto, Rachmat Mulia and Betha Lusiana**

Forest, Agroforest, Low-value Landscape or Wasteland (FALLOW) is a spatially explicit model that simulates the consequence of agents' land management decisions on overall landscape dynamics. It is useful for exploring how the changes in the landscape have an impact on carbon sequestration, biodiversity and watershed functions. FALLOW is particularly suited to simulate rural or peri-urban landscapes where land-based activities (that is, agriculture, forest extraction) are still the main livelihood. FALLOW proceeds in annual time steps at watershed scale.

## Introduction

Growing populations and market-based development accelerate changes in parts of the developing world. In areas where new land is no longer available and accessible, intensification may lead to conflicts. Trade-off analysis of the impact of land-use changes on livelihoods and environmental services can help evaluate options for current land-use and future management. If scenario analysis is based on a credible landscape simulation model, we can assess various options and their consequences for livelihoods, carbon stocks and water flows, with various incentives and rules to enhance environmental service provisioning.

FALLOW can be used to explore the likely trajectories and impacts of development strategies. FALLOW simulates the dynamics of land-use and land-cover changes that are local responses to external drivers, with various feedback loops (Figure 34.1), and assess the consequences of the resulting land-use mosaics on economic utilities (welfare and food security) and environmental services (for example, carbon stocks).

### FALLOW PORTRAYS SEVERAL LOCAL RESPONSES.

- How farmers adjust their expectations about the economic utility of each available option on land-based and non-land-based investments through learning.
- How farmers allocate their capital (labour, money and land) to each available option of investment.
- How farmers perceive the attractiveness or otherwise of a plot to expand a particular land-use system, with regard to some spatial factors determining potential benefits (soil fertility, suitability and attainable yield) and potential costs (transportation, maintenance and land clearing).
- Succession, growth, fire and land conversion.
- Laws of diminishing and increasing marginal utilities on soil fertility and land-use productivity.

The main external drivers incorporated in the model include:

- market mechanisms and relevant regulation interventions, articulated through commodity prices, costs and harvesting labour productivities;
- development programs, articulated through extension, subsidies, infrastructure (settlements, road, market, processing factories) and land use productivities; and
- conservation programs, articulated through forest reserves as prohibited zones for farmers.

## Objectives

FALLOW can be used to project landscape dynamics and the consequence of changes on ecosystem services and people's livelihoods.

## Steps

1. Installation of FALLOW, PCRaster and NutShell programs to run the model.
   a. The FALLOW model can be obtained from http://worldagroforestrycentre.org/regions/southeast_asia/resources/fallow-forest-agroforest-low-value-landscape-or-wasteland.
   b. PCRaster is open source environmental modelling software developed by Utrecht University, The Netherlands, targeted at the development and deployment of spatio-temporal environmental models: http://pcraster.geo.uu.nl/downloads/.
   c. NutShell is a Windows shell for PCRaster that facilitates the running of PCRaster commands and edits and runs PCRaster models (scripts): http://nutshellqt.sourceforge.net/.
2. Preparation of data
   a. FALLOW input data are categorized into three types: 1) spatial data; 2) arrays; and 3) time series . The spatial data required by FALLOW are information on initial land cover, information to differentiate qualities, such as soil fertility, slope, distance to market, roads and rivers and, if they exist, a suitability map for each agricultural system/livelihood option. FALLOW also requires information on profitability, input (labour and cash) and output (yield) for each livelihood option, which can be based on a farm survey. Landscape-level information, such as size of population, percentage of labour force and income per capita, are initial information required to run the model.
3. Development of scenarios
4. Run the model

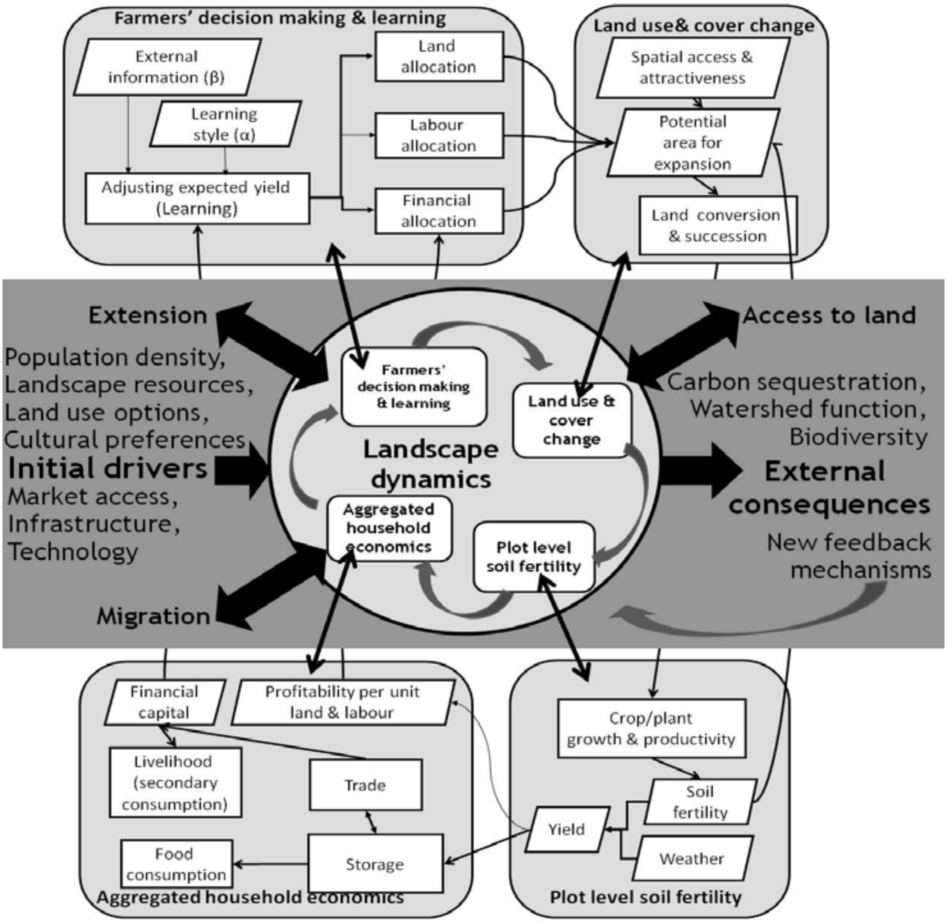


**Figure 34.1.** The four core modules of FALLOW that simulate dynamic changes in land-use and land-cover due to local responses to external drivers, with various feedback loops

## Case study: FALLOW in Upper Konto catchment

FALLOW model was used to explore the effect of land zoning on farmers' livelihoods and aboveground carbon sequestration in the Upper Konto catchment, East Java, Indonesia. The watershed presents a landscape of mixed agroforests and rice fields with forest remnants, which is typically found in Southeast Asia, where horticulture in a peri-urban setting lead to rapid land-use change and forest conversion. Conflicts over access to land have occurred in the past as two-thirds of the land was allocated as forests for production and conservation purposes. Thus, farmers could access only a third of the watershed for settlement and agricultural activities. We explored 1) the impacts of changes to the forest zone policy; 2) the potential of further integration of fodder production in forest areas; and 3) the impact of open access to all land on farmers' welfare and aboveground carbon sequestration in the entire landscape. We developed five scenarios representing the current situation ('business as usual' or BAU) and four hypothetical questions related to changes in land zoning, including access to harvest fodder (Table 34.1).

The FALLOW simulation was run for a 20-year period. We evaluated how the model performed in simulating the BAU scenarios. The spatial validation showed good results and we are confident the model can be used to explore scenarios (not depicted here, refer to Lusiana et al 2012). The model projected that under the current policy, forest cover will be maintained with intensive agriculture (horticulture) dominating the agricultural system. However, in terms of contribution to income, dairy cattle was the highest contributor, followed by agriculture and agroforestry.

**Table 34.1.** Scenarios (business-as-usual and prospective) of landscape dynamics in the Upper Konto catchment developed for FALLOW

| Scenarios | |
|---|---|
| I | Business as usual |
| II | Agroforestry access to plantation forest |
| III | No fodder harvesting allowed in plantation forest |
| IV | No planting of monoculture Napier grass |
| V | Open access to land |

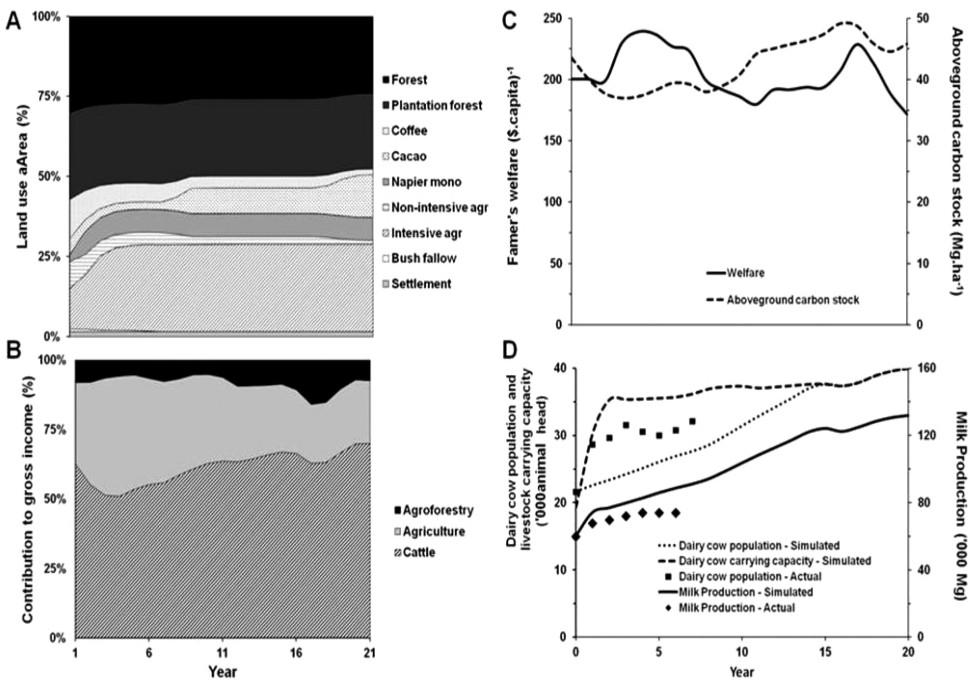


**Figure 34.2.** Business-as-usual scenario from FALLOW for the Upper Konto catchment

**Note:** (A) landscape dynamics (% area); (B) contribution of main livelihood options on catchment gross income (%)

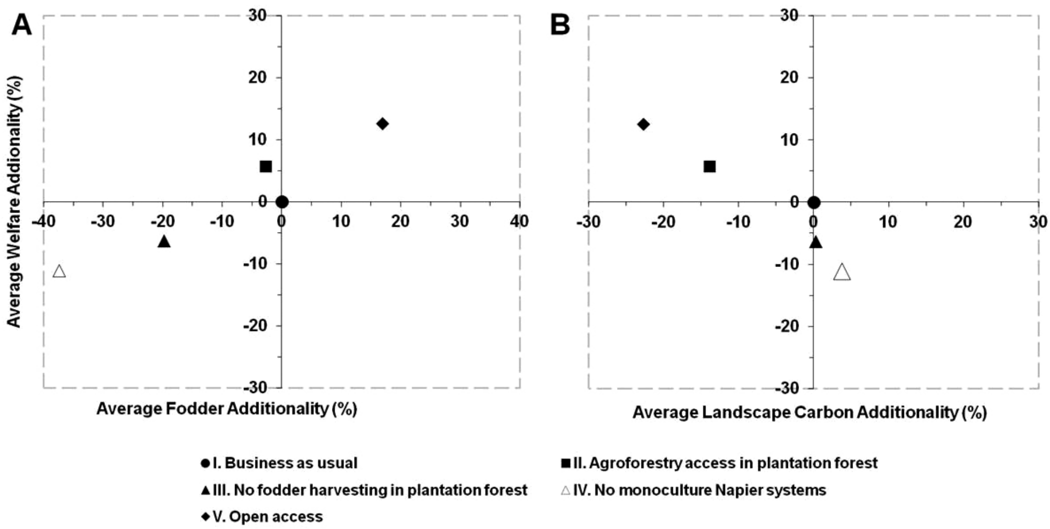


**Figure 34.3.** Trade-offs

**Note:** A) average fodder additionality versus landscape aboveground carbon stocks; and B) farmers' welfare versus landscape aboveground carbon stocks relative to business as usual. Results of prospective scenarios (I–V) of the FALLOW model averaged over 20 years

Comparing the four scenarios (II – V) with BAU (I) showed that welfare/income are positively correlated with availability of fodder. Increases in welfare were projected to be obtained through the open-access scenario (Figure 34.3A). However, the model suggested that the current policy appeared to be the best for balancing livelihoods and environmental objectives (Figure 34.3B). Although open access would increase welfare by around 33%, carbon stocks would be decline in the landscape by 23%.

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# 35 | Ecological corridors (ECor): a distributed population model with gender specificity

Meine van Noordwijk, Rachmat Mulia and Sonya Dewi

To counteract the effect of habitat fragmentation, the concept of restoring ecological corridors is popular in conservation circles. The expected effectiveness of such corridors depends strongly on the dispersal characteristics, which for species such as orangutan are strongly dependent on gender. A distributed population model allows ex ante impact predictions of various corridor designs.

## Introduction

Habitat fragmentation is a major cause of loss of biodiversity, as populations of plants and animals may get too small to survive and recover from the shocks that tend to occur with climate variability and other stress factors. Reconnecting remaining small habitat fragments through 'ecological corridors' through which plants and animals can disperse is a response to the fragmentation challenge. However, the effectiveness of such corridors must be weighed against the costs and alternative uses of conservation funds so an ex ante impact predictor is needed. We found that existing tools did not handle gender-specific dispersal yet male and female individuals of a species such as orangutan have very different dispersal distances.

The ECor model MetPop001 was developed by the Ecological Modeling Unit of the World Agroforestry Centre Southeast Asia Regional Program in September 2010 to provide options to analyze ecological connectivity in landscape mosaics, as the next step in dynamic land-use-change models such as FALLOW. This is a beta version of a landscape mosaic and corridor meta-population model. It is based on simple principles of population dynamics in a number of separate populations that are linked through dispersal. The default application is for orangutan (OU) population dynamics in a small forest patch with or without active corridors to a 'stable reservoir' population in a large protected area. Other species can be added to the database and then evaluated. The model is initially described for discrete (default: yearly) time steps and a continuous variable population density rather than discrete individual counts.

Meta-populations can be described through local birth rates and mortality plus an annual transfer coefficient matrix. Corridors can play a significant role through the transfer coefficient matrix even if their mortality exceeds birth rates. Within the confines of this model, habitat quality can be translated into a carrying capacity concept, capping off local population increase. Connectivity with corridors implies both gains and losses and the net effects depend on access to (relatively) large source areas. For an organism such as orangutan, the dispersal behavior differs between males and females and this affects corridor effectiveness. The following life-history traits have to be provided as parameters to the model: sex ratio at birth, average inter-birth interval, litter size, juvenile mortality multiplier, pre-productive years, adult annual mortality rate (%/year), male dispersal and female dispersal. These jointly determine the natural increment rate feasible for the population in the absence of disturbance.

## Objectives

Objective of the model is to allow details of life history at species level, including male and female dispersal traits, to be related to a land-use mosaic with time-dependent habitat types to explore effects on sub- and total population size. The tool can be used to explore the likely effectiveness of alternative ecological corridor designs.

## Steps

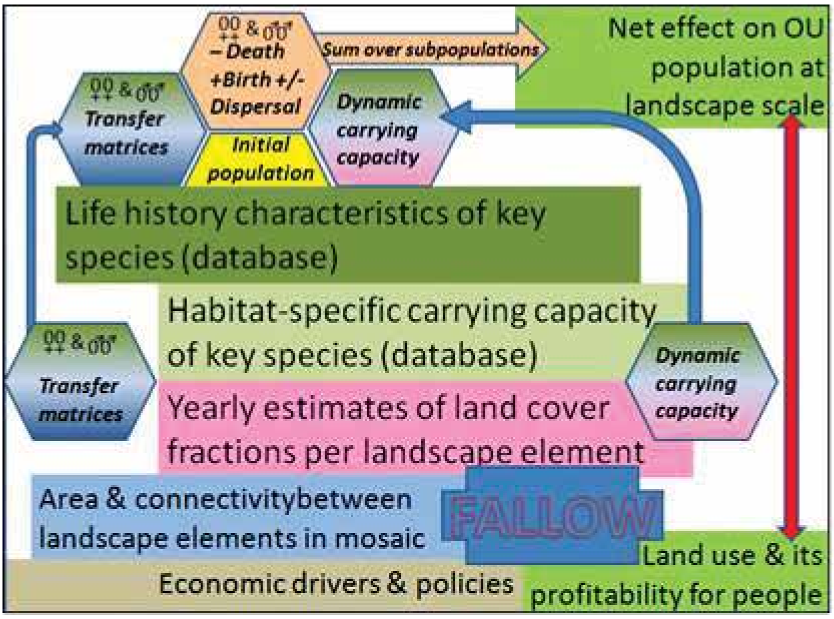


**Figure 35.1.** Logical flow of the MetaPop model

## Case study: ECor in Indonesia

In line with broader efforts to restore ecological connectivity in landscape mosaics, the potential relevance of restoring connections between the habitats of (sub-) populations of Sumatran orangutan is expected to support survival of the species. One of the last chances to do so may be in the Tripa swamp where a (sub-) population of over 100 individuals has become separated from the main population in the Gunung Leuser National Park as a result of the conversion of peat swamp-forest into oil-palm plantations. While there may be opportunities to use funding mechanisms linked to the United Nations-mandated mechanism for Reducing Emissions from Deforestation and Degradation plus conservation (REDD+) for both protecting remaining forest and restoring (ecologically) the surrounding landscape, the effectiveness of such efforts on orangutan survival forms a key argument for seeking broader investment beyond the issues of avoided carbon-dioxide emissions and net carbon sequestration. The expected functionality of landscape corridors must be weighed against their costs and local acceptability.

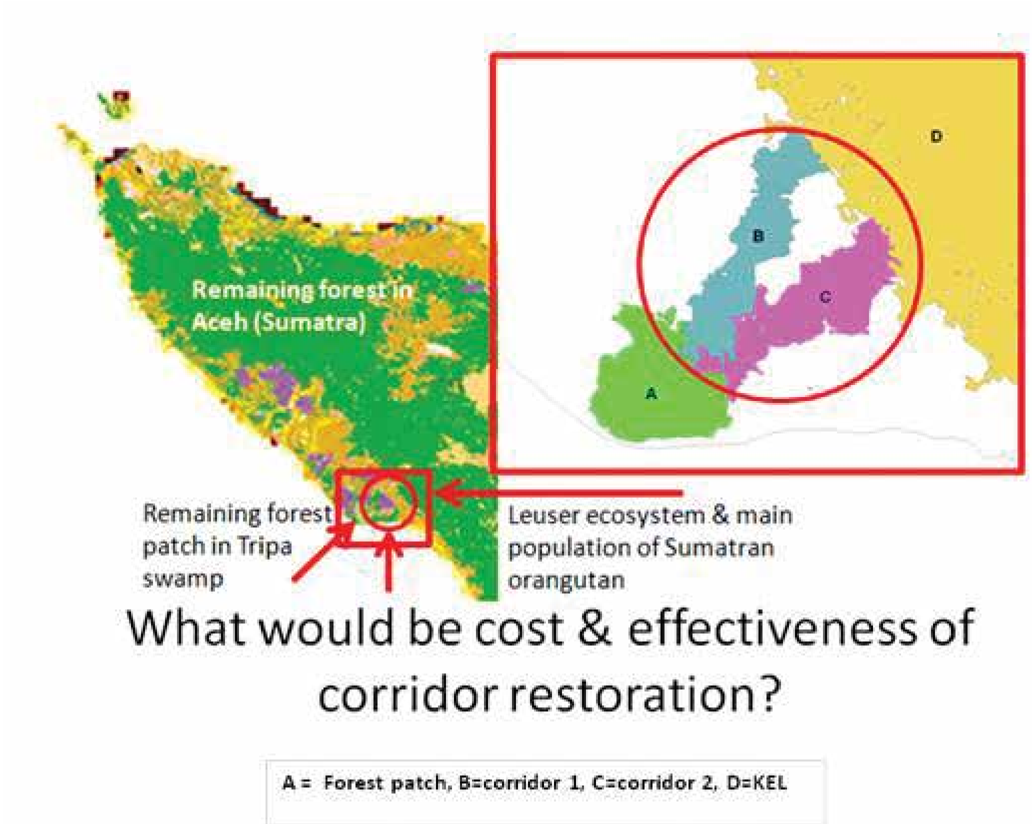


**Figure 35.2.** The model explored potential corridors B and C, singly or in combination, between forest remnant A and the national park

## Key references

Tata MH, van Noordwijk M, Mulyoutami E, Rahayu S, Widayati A, Mulia R. 2010. *Human livelihoods, ecosystem services and the habitat of the Sumatran orangutan: rapid assessment in Batang Toru and Tripa*. Project Report. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

Download ECor: http://www.worldagroforestry.org/sea/files/MetaPop001BV.zip.

# 36 | REDD abacus SP

**Degi Harja, Sonya Dewi, Meine van Noordwijk, Andree Ekadinata, Arif Rahmanulloh and Feri Johana**

REDD Abacus SP is the short name for Reducing Emissions from Deforestation and Forest Degradation Abatement Cost Curves and Simulator for Scenarios of Policies, a tool to estimate emissions from land-use and land-cover changes, which takes into account the dynamic heterogeneity of soil types, elevations, climate and other biophysical characteristics in a landscape. The tool can easily produce abatement cost curves and the resulting opportunity cost analysis of trade-offs between emission reduction and economic benefits.

## Introduction

Carbon emissions' reduction and storage incentive schemes, such as the United Nations-mandated Reducing Emissions from Deforestation and Forest Degradation plus Conservation (REDD+), are part of climate-change mitigation in the agriculture, forestry and other land-uses sector. Implementing such schemes has been high on the agenda of many forest-rich developing countries. Some countries, like Indonesia, have made specific emissions-reduction commitments. As the mechanism takes shape, the question of how to relate national commitments to local contexts and effective implementation is more important than ever. Implementation at the sub-national level needs to be equipped with an appropriate planning platform. The platform must allow development of a multiple stakeholder decision-making process to establish land-use plans for sustainable development, which can reduce greenhouse gas emissions from land-based activity while simultaneously maintaining economic growth.

REDD Abacus SP can assist such a platform by simulating emissions-reduction scenarios within specific zones or across an entire landscape in order to produce ex ante emissions-reduction and opportunity-cost forecasts. REDD Abacus SP is one suite of tools that can analyze emission-related components, including historical and projected emissions and economic trade-offs. In REDD Abacus SP, intermediate and final results are easily extracted so that the process is not a 'black box' and information can easily be traced. The tool uses Java programming language and can be run in any operating system (Windows, Mac, Linux etc). The user interfaces can be easily translated into other languages.

## Objectives

- Estimate emissions from land-use and land-cover changes allowing for dynamic heterogeneity of soil types, elevations, climate and other biophysical characteristics in the landscape.
- Analyze trade-offs between emissions and financial gain (opportunity-cost analysis) and produce abatement cost curves to project ex-ante emissions and financial gain of business-as-usual scenarios for setting the reference emission level.
- Simulate zone-specific policies and other emissions-reduction scenarios within landscapes and estimate the potential reductions and opportunity costs.

- Project ex-ante emissions and financial gain of business-as-usual scenarios for setting the reference emission level.

REDD Abacus SP can serve as the main tool for

- developing land-use plans for low-emissions development strategies at provincial or district levels;
- assessing carbon efficiency of a large-scale, land-based enterprise; and
- estimating the abatement cost of emissions from land-use and land-cover changes at a regional level.

## Steps

The tool performs four steps.

1. Converts differences in carbon stocks into estimated emissions.
2. Constructs a table of opportunity costs for every type of land-use change from the differences in net present value and carbon stocks.
3. Determines the actual emissions for each cell in the matrix from the area involved and the emissions per unit area.
4. Presents the cumulative emissions total after sorting by opportunity cost.

Together these four steps lead to a two-dimensional graph charting the opportunity costs of avoiding deforesting land-use changes against the volume of carbon-dioxide equivalent emissions.

REDD Abacus SP requires four types of data.

1. A legend that represents land-use changes from the perspectives of economic ('land use') and carbon storage ('land cover') and which allows land-use change data to be compiled by a combination of land-cover-change detection and economic constraints (for example, labour requirements in relation to human population density).
2. Typical carbon-stock data for each legend unit (RaCSA).

   Net present value for each land-use type, typically using private or social accounting (LUPA).
3. A matrix of land-use-change values, which are internally consistent and represent either historical change or a forward-looking scenario (ALUCT).

## Example of application

REDD Abacus SP has been used extensively within LUWES activity. It was applied in Tanjung Jabung Barat district, Jambi province, Indonesia, to estimate opportunity-cost curves during the periods 1990–2000, 2000-2005 and 2005-2009 (figures 36.1–3). Using the threshold of USD 5 as the potential price of 1 ton $CO_2$ equivalent, the curves showed how much emissions could have been compensated or abated. During 1990–2000 (Figure 36.1), emissions below the threshold of USD 5 were 4.49 ton $CO_2$e/ha/year and increased to 10.28 ton $CO_2$e/ha/year for 2000–2005 (Figure 36.2) . The increase of eligible emissions demonstrates the higher emissions from conversion to lower net present value land uses. During 2005–2009, the amount of emissions below the USD 5 threshold decreased slightly to 9.53 ton $CO_2$e/ha/year (Figure 36.3). From the total annual emissions, the proportion of emissions that could have been avoided in Tanjung Jabung Barat district increased over the period of analysis. For 1990–2000, the proportion was 42%, for 2000–2005 it was 58% and for 2005–2009 the proportion was 64%. These increasing figures demonstrate that emissions reduction efforts could have been successful. A higher proportion of emissions could have been avoided with a similar price of carbon. This also shows potential for future emissions reduction in Tanjung Jabung Barat district.

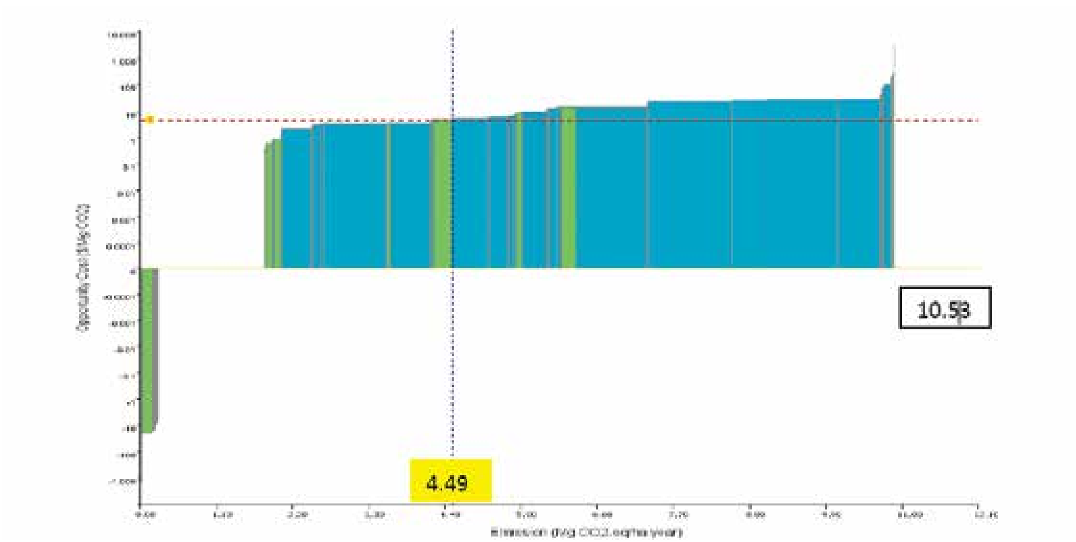


**Figure 36.1.** Opportunity-cost curve for Tanjung Jabung Barat, 1990–2000

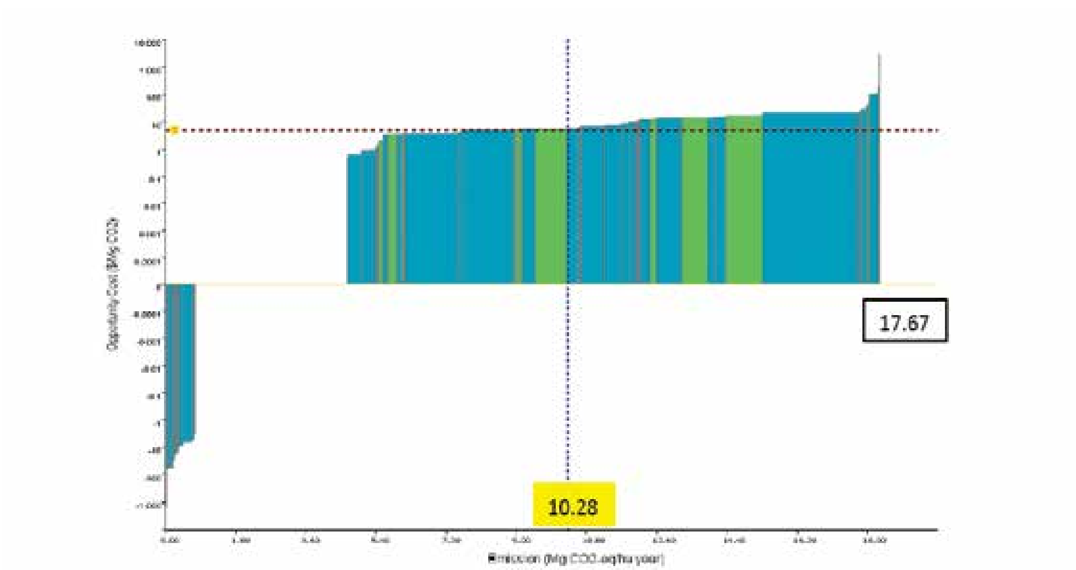


**Figure 36.2.** Opportunity-cost curve for Tanjung Jabung Barat, 2000–2005

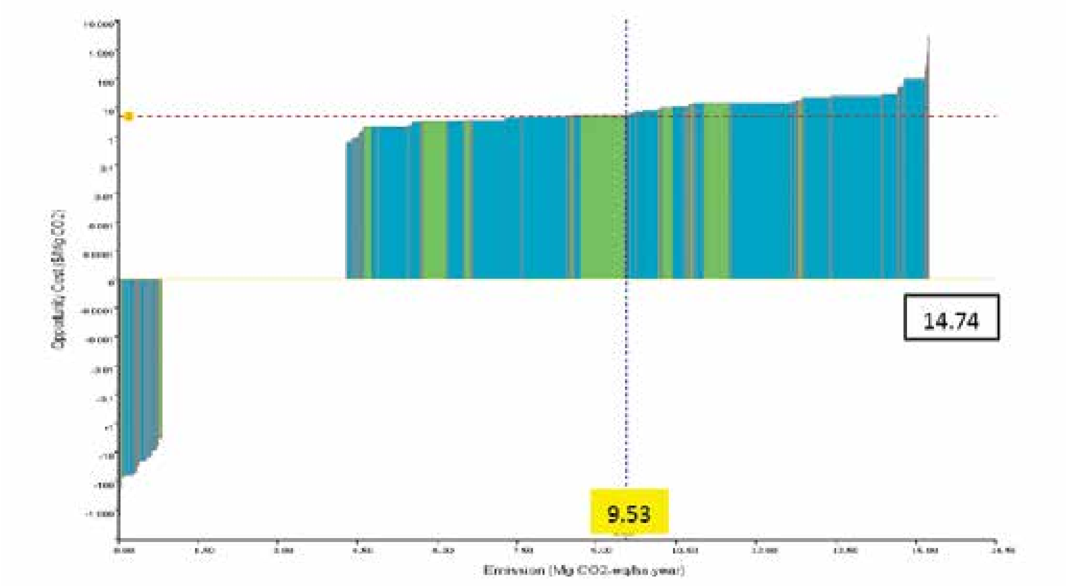


**Figure 36.3.** Opportunity-cost curve for Tanjung Jabung Barat, 2005–2009

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Widayati A, Suyanto S, van Noordwijk M. 2011. *Towards reduced emissions in a high-stake district. REALU project design for Tanjung Jabung Barat (Tanjabar), Jambi, Indonesia.* Version 2.0. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program.

Tool download: http://worldagroforestrycentre.org/regions/southeast_asia/resources/redd-abacus-sp