Improving conservation values of managed forests: the Dendrogene Project in the Brazilian Amazon

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Tools for species identification, predictive modelling and scenario analysis are being designed to facilitate adoption of new policy and practices in managed forests in the Brazilian Amazon.

As human influences on natural systems extend to the furthest reaches of the planet, a challenge for the twenty-first century is how to reconcile resource use with an equitable and just quality of life for current and future generations of people, while also conserving the millions of other species with which we share the planet. This is especially relevant for tropical regions known to be biodiversity rich. The question is how, exactly, this should be accomplished, and what measurements can be used to establish whether the goal has been reached.

This article describes the Dendrogene Project, an initiative developed to provide tools for improving conservation values in managed forests in the Brazilian Amazon and to contribute to the sustainable development of the region's natural resources. Such a blend of conservation and management is seen by many as the lasting solution to the region's problems of poverty and inequality.

The project, hosted at the Eastern Amazon research station of the Brazilian Agricultural Research Corporation (Embrapa), focuses on providing skills and tools to forest users so that knowledge-based management systems can be applied in practice. A forest simulation model is being developed to analyse alternative scenarios of forest use. The simulation modelling approach makes it possible to test criteria and indicators for the sustainability of genetic and ecological processes in managed forests.

BIODIVERSITY AND EVOLUTIONARY HEALTH

Biological diversity (or biodiversity) refers to the natural variety and variability among living organisms, the ecological complexes in which they naturally occur and the ways in which they interact with each other and with the physical environment (OTA, 1987; Noss, 1990; Redford and Richter, 1999). Biodiversity can be partitioned into three levels - ecosystem diversity, species and within-species diversity, and genetic diversity - all of which are essential to environmental health and to human well-being.

Dendrogene Project

Hosted at the Embrapa Eastern Amazon research station in Belém, Pará, Brazil, the Dendrogene Project depends on a multidisciplinary approach and multi-institutional participation. The Department for International Development (DFID) of the United Kingdom supports the project (2000 to 2004) through the Brazil-United Kingdom Technical Assistance Programme. Many of the initiatives in Dendrogene are based on earlier activities in the Rainforest Silviculture Research Project (1993 to 1998), also supported by DFID.

Further information is available on the Dendrogene Web site:
www.cpatu.embrapa.br/dendro/index.htm

Biodiversity is the result of evolutionary and historical processes. The genetic architecture of a species is also the result of these processes. Thus, genetic diversity is fundamental to biodiversity, and may also be thought of as the ultimate constituent of ecosystem health. The maintenance of biodiversity is threatened when natural events, human interventions or alterations of habitat erode genetic make-up in such a way that the evolutionary future of a species is likely to be compromised.

To conserve biodiversity in a particular habitat it is crucial to know how many species there are, and how many individuals of each must be maintained to avoid putting the long-term survival of the community at risk.

Most assessments of biological diversity concentrate on ecological measures of population or species health. They measure population sizes, reproductive rates, biogeographical distributions and similar ecological parameters that describe the size and range of a population. Such data are relatively easy to acquire and have an important role in interventions to prevent species extinctions.

The crucial condition for long-term survival, however, is the evolutionary potential of the population. Is enough variation within and between populations maintained that the species can respond to local stresses, competitors or diseases? Population size has a crucial role in predicting genetic variability, and maintaining it is thus an important component of maintaining biodiversity. But numbers alone are not the only requisite. The real measure of successful biodiversity conservation is the maintenance of reasonable levels of genetic variation within populations, and the conservation of the ecological and genetic processes that support that genetic make-up (Namkoong and Koshy, 2000).

Collection of botanical material - L. PROCÓPIO

CONSERVATION OF TROPICAL FORESTS

Tropical forests are among the "superstars" of biotic diversity. They are reservoirs of huge numbers of species of birds, mammals and reptiles, with species numbers well exceeding those found in temperate climate zones. They are likely to be the home to thousands, if not millions, of yet-undescribed species in less well studied taxonomic groups such as vascular and non-vascular plants, insects, nematodes and protozoans. Thus, it is of special interest to protect the immense diversity of these equatorial habitats. At the same time, tropical forests, savannahs and aquatic habitats are under immense human pressures. Forests, in particular, are of great importance in the ecology, economy and social interactions of tropical peoples, but growing human populations and development pressure put these forest habitats at serious risk.

Large tracts of land in the tropics have been set aside for conservation. But even if these areas were adequately protected from conflicting uses (which many are not), reserving forests alone cannot guarantee the protection of tropical biodiversity. Most tropical habitats are used by humans. The key is to establish management systems that will be most effective in conserving the critical elements of biodiversity in complex landscapes with different land uses. Clearly, managed or exploited habitats will undergo changes. But if the effects of alternative land use patterns can be predicted effectively, this information can be used as the basis for negotiating measures to reduce or mitigate potential negative impacts or to balance these effects over larger areas. It should be possible to improve the value of managed landscapes in supporting conservation goals - or at least to see more clearly the trade-offs in resource use and biotic conservation.

ABSENCE OF BIODIVERSITY INDICATORS

Forest management and conservation programmes are often based on ecosystem and community attributes, with little attention given to species and genetic diversity. This is particularly true in tropical rain forest ecosystems, where the high biological diversity and its complexity pose immense challenges to managers, scientists and policy-makers.

To date, no effective indicators have been developed which provide solid measures of ecological or genetic sustainability. While forest management may include a variety of measures intended to minimize the impact of extraction on the biodiversity of the forest (such as directional felling, vine cutting, and diameter and volume limits on harvest), they are generally based on guesses about what levels of extractive activity might prevent damage to both the resources and the economic returns, and there is as yet no clear evidence of their effectiveness in conserving biodiversity. The lack of measurable indicators for estimating the impacts of different management options on important variables for biodiversity is a problem, for example, for certification schemes intended to assure buyers that forest goods have been sustainably produced. The Forest Stewardship Council's guidelines for certification state that "Ecological functions and values shall be maintained intact, enhanced, or restored, including genetic, species, and ecosystem diversity" (Criterion 6.3b, cited in Bass *et al*., 2001). The reality, however, is that there are today virtually no analytical tools by which to measure whether such critical goals are being met by the management practices used.

THE DENDROGENE PROJECT

The goal of the Dendrogene Project is to contribute to sustainable tropical land use in the Brazilian Amazon region by developing the capacity to predict the impacts of management of the landscape (e.g. fragmentation of forests) or of the forest area on the genetic make-up of tree species potentially at risk from commercial use and exploitation. The central output of Dendrogene is a set of tools being developed for scenario analysis and impact prediction for policy and management. A basic assumption is that the elements of planned and controlled forest management exist or are being implemented.

The project uses a variety of approaches to address specific problems in resource inventory and decision-making concerning management of forest resources and land use. Through collaboration with key stakeholders, the project seeks to promote policies and management practices based firmly on scientific evidence, and to address some of the critical operational constraints to the application of such policies and practices.

The project focuses on four fundamental areas:

- enhancing user capacity to identify species reliably;
- developing a reliable predictive model for analysing genetic structure in tropical tree species;
- applying scenario analysis to guide policy and management decisions;
- facilitating adoption of new policy and management practices.

Reliable identification of species

The correct naming of things is the basis of science (Wilson, 1998) and a prerequisite for their proper use and conservation (Helgason *et al.*, 1996). The forestry sector in the Amazon region does not currently have the capacity to identify many trees to the level of species. Yet correct scientific identification is essential for obtaining available information on species properties. Common names, often locally specific but not unique over larger areas, are often inaccurately associated with scientific names (see Box on p. 28). In forest management, inadequate identification compromises the ability to plan for species regeneration as well as incurring risks of more direct losses. Because of the scale and diversity of the Amazonian tropical forest, reliable identification may seem an impossible dream. However, there has been progress in building on existing resources such as the "Ducke Guide", a guide to the flora of the Ducke Reserve (Ribeiro *et al.*, 1999), which uses a visual approach based largely on vegetative traits such as leaf and stem characters.

Dendrogene addresses the problem of species identification at the operational level. Through cooperation with other institutions including the Society for Research and Conservation in the Amazon (SAPECA, a non-governmental organization formed by many of the authors of the Ducke Guide), the project is developing identification sheets, including botanical and wood anatomical information, for more than 50 of the principal commercial timber species. Dendrogene runs training courses (and improves them on a continuous basis) for botanical and wood identification. The botanical course includes practical testing of the Ducke Guide. The project also encourages and trains private industries to maintain their own reference collections and to develop links with the Embrapa herbarium for verification or provision of new tree species identifications. The project is studying how industry currently groups tree species (consciously and unconsciously) in processing and sales in order to learn more about the consequences of misidentification and to suggest more suitable groupings. It is also supporting the computerization of Embrapa's herbarium and xylarium (an archive of wood samples for anatomical identification) which will facilitate its management and use. More than 100 000 specimens (70 percent of the collection) have now been entered into the herbarium's database.

At the strategic level, Dendrogene promotes cooperation among the national herbaria and xylaria through the use of a common platform for information management, BRAHMS (www.brahms.co.uk). All the major Amazonian herbaria have now adopted BRAHMS, and it is being installed in herbaria in Brasilia and Rio de Janeiro. Dendrogene is also seeking to build strategic alliances to stimulate the participation of stakeholders concerned with tree species identification to build consensus on practicable solutions. For example, the recent Workshop on the Relevance of Botanical Identification for Sustainable Forest Management in the Amazon recommended that priority should be given to developing a defined parataxonomist profession, as the lack of professional recognition was seen as the main obstacle to the development of region-wide identification capacity.

Development and validation of a predictive model

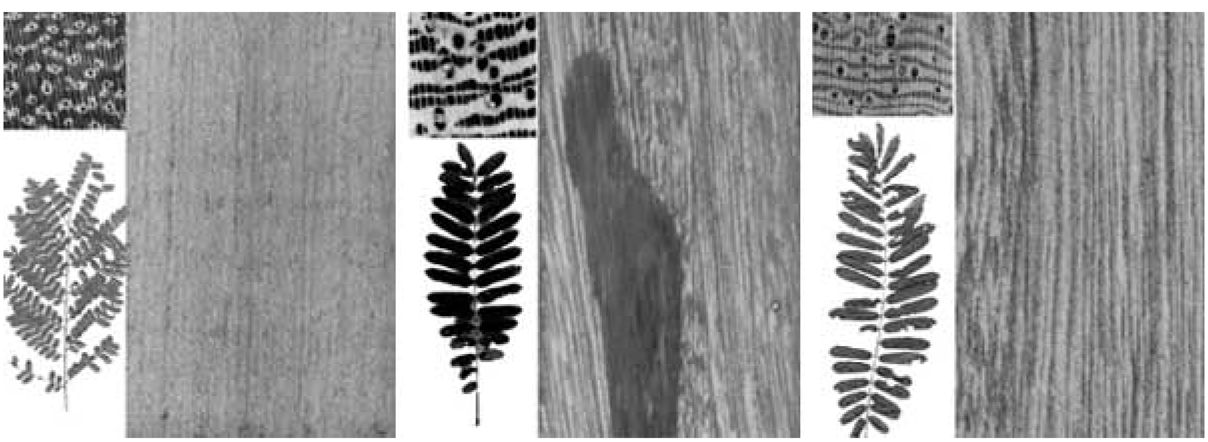
Modelling approaches are advantageous where decisions must be informed by expensive data collection procedures. The modelling approach is particularly useful where there are many different variables contributing to the final outcome of interest (in this case, genetic diversity). A simulation model provides a means of integrating phenology, pollination, seed dispersal, recruitment and growth into a framework in which the individual effects of each variable on genetic diversity can be studied using sensitivity analysis. Since the costs of genetic inventories are prohibitively high for routine forest management, the assessment of the impact of forest management decisions on genetic processes demands a modelling approach.

Dendrogene is working in collaboration with the French National Institute for Agricultural Research (INRA) through Silvolab (French Guiana) to develop the Ecogene model (Degen, Gregorius and Scholz, 1997) for tropical forest management applications. The model employs a database of genetic and ecological data for neotropical tree species (Dendrobase), combined with a data generation engine being developed to supply necessary missing data so that the model can be applied to tree species for which complete ecological or genetic data are not yet available.

Identification problems hinder commerce

For commercial timber companies, different names of tree species often make it difficult to equate species, product and market:

- **An importer from Germany wanted to buy more "cedrinho". The exporter from southern Brazil had been supplied from the lower Amazon and was informed that it was difficult to obtain. If it had been identified as *Erisma uncinatum*, the exporter might have known that large volumes could be purchased from the Eastern Amazon - where it is commonly known as "quarubarana".**
- **A study by a botanist for a timber company found that trees sold as "louro amarelo" included two previously undescribed species.**
- **Studies undertaken by Dendrogene in different companies found that four species of *Manilkara* were all managed as "massaranduba" and three species of *Couratari* and one of *Cariniana* were managed as "tauari".**
- **A Dendrogene study found that 32 different species from 13 genera were sold as "angelim".**

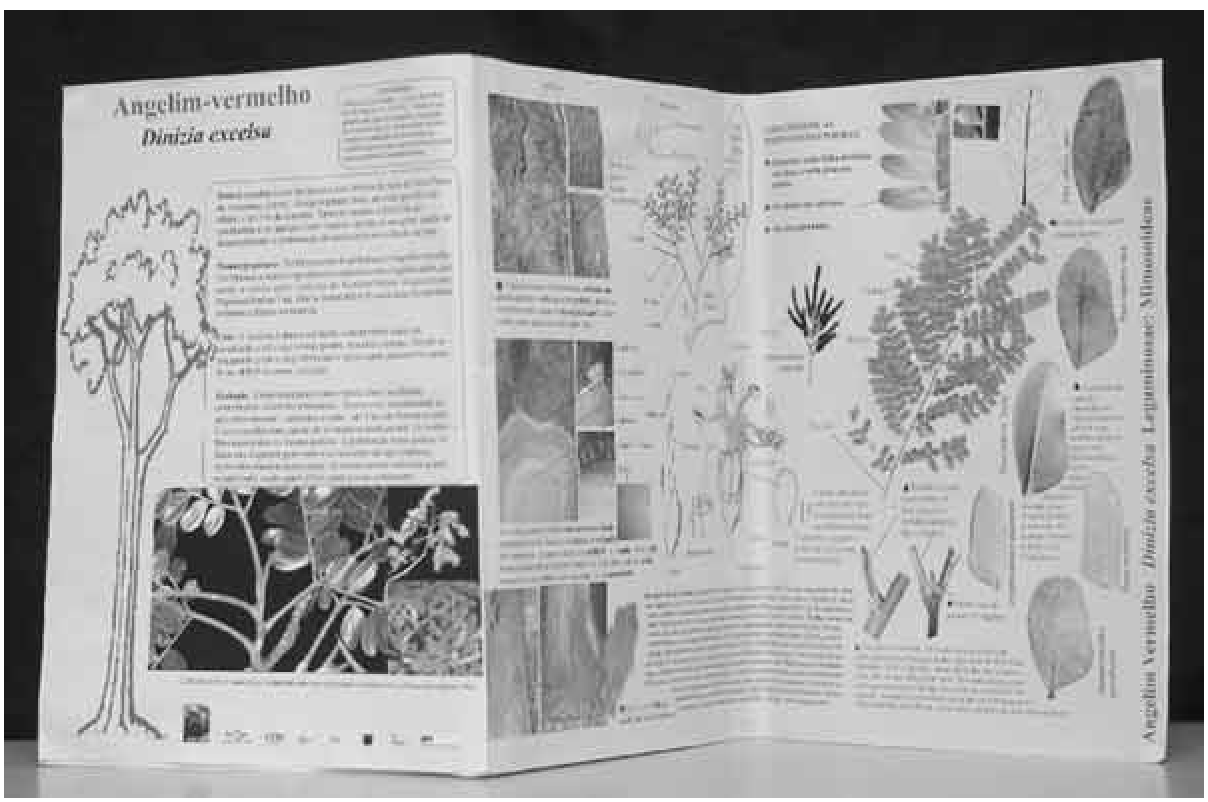


Three species (from left to right, **Dinizia excelsa, Hymenolobium excelsum** ***and*** **Hymenolobium pulcherrimum*) all known under the name "angelim"***

The Ecogene model will be validated through comparison with real data collected on an intensive study plot (500 ha) in the National Forest of Tapajós (see Box on

p. 30). Dendrogene is carrying out this work in cooperation with the project "Sustainable Forest Management for Timber" of the Brazilian Institute for Environment and Natural Renewable Resources (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, IBAMA) and the International Tropical Timber Organization (ITTO). Studies on the genetics, reproductive biology and ecology of seven timber species are under way and will continue after the area is logged in 2003. Growth, recruitment and mortality will be modelled in a spatially explicit way. Elements of a yield simulation model, SYMFOR (Phillips and van Gardingen, 2001), will be specially modified and adapted within Ecogene and parametrized with long-term permanent sample plot data collected by Embrapa Eastern Amazon (Silva and Lopes, 1984; Silva *et al*., 1995).

Using the Ecogene model, the project seeks to project the impacts of management alternatives on the genetic make-up of tree populations 50 to 100 years into the future. Modelling is the most effective way to attempt to predict the interactions of complex processes in this time frame. However, modelling clearly has limitations. It inevitably uses simple relationships to describe complex systems. Validation of the model is resource intensive, and can be carried out for only a few species. Application of the model to other tree species, to other forests and over different time frames requires additional assumptions, with subsequent risks of error. The output of the model will only be as good as the data entered. Thus the current lack of reliable field identification of tree species is a source of error in modelling population processes. Given that the model works transparently, however, it can be a valuable tool, especially for strategic decision-making. It can help to evaluate the limits within which populations are likely to experience genetic impacts as a result of various management choices, and it can help to improve today's management decisions while limitations such as tree identification capacity are gradually improved.



The Dendrogene Project is developing identification sheets, including botanical and

wood anatomical information, for more than 50 of the principal commercial timber species in the Brazilian Amazon - L. PROCÓPIO

Dendrogene runs training courses on botanical identification for forest workers and other persons involved in forest inventory and management - J. SOLER

Scenario analysis to inform policy and management

The Ecogene model will be used to predict the sustainability of alternative forest management scenarios to support decision-making in the development of public policies that concern forest resources. Some possible uses include testing of:

- the use of alternative criteria for the selection of trees for harvesting;
- the impact of incorrect identification of species;
- the impact of different intensities of logging;
- the impact of different spatial distributions of logging;
- the impact of different layouts of felling coupes within the management unit;
- the impact of riverside buffer zones and permanent reserve areas;
- the impact of different scales of management, from small community forest holdings to large holdings and landscapes;
- the impact of fragmentation of forest areas;
- the usefulness of different management indicators, such as percentage of commercial tree stock retained;
- species vulnerability to harvesting practice and possible species-specific controls.

Intensive study plot at Tapajós - field validation of the Ecogene model

Seven model tree species, occupying a variety of ecological niches and exhibiting different life history strategies, are being studied in populations large enough for gene flow to be documented (200 to 400 mature individuals). The commercial tree inventory was extended downwards in the study site to include all individuals of the model species of diameter at breast height (DBH) greater or equal to 20 cm. In a 100 ha subplot the inventory was further extended to DBH of 10 cm.

Before species-level studies can be performed, field checks of the commercial inventories are essential. Although the study focuses on trees considered easy to distinguish, consistent field identification errors are still found for over half the model species; in the worst case, 16 percent of trees in one species were misidentified.

Genotyping of all the individuals in each of the tree populations is being done from cambium collections, using DNA amplification and microsatellite analysis. These data are then coupled with field inventory maps to produce population maps for each species which document spatial and genetic patterns. Genetic microsatellite analysis of seeds collected from chosen "trap trees" within each population can be used to determine paternal (pollen) gene flow distributions. Collecting and analysing trap-tree seed genotypes before and after logging should provide detailed information on the impact of logging (especially alterations in adult density and spatial distribution) on gene flow, outcrossing rates and changes in genetic diversity in seedling genotypes produced after a logging event. Collecting seed from 30 trap trees each year will provide good estimates of between-tree gene flow, while collecting 30 or more seeds from each tree will provide a measure of within-tree variability in pollen movement.

Phenology is an important component of tree reproductive behaviour, because patterns of flowering may constrain gene flow. Pollen movement between trees is restricted to those individuals that flower at the same time. Temporal differences in flowering can thus limit or even prevent gene flow between individuals. Detailed phenological observations are made on all trap trees and occasional monitoring is carried out for the entire adult tree populations under study. It has therefore been necessary to open over 45 km of phenology trails for access to these widely dispersed study trees. Studies on pollinators and on seedling and juvenile tree distribution are also being undertaken.

Database management is automatically linked to a geographical information system (GIS) to provide easily interpreted spatial information that can be instantly updated.

A "trap tree" in the study forest, from which seed is collected for genetic analysis - M. KANASHIRO

The results of the tests can be used in refining legislation, best management practices and the certification process. While the use of the model to analyse scenario outputs will remain a specialized task, the overall analysis will be a participative process. Forest managers, local communities and others interested in the outcome will be involved in designing the questions, interpreting the results and formulating proposals for policy or management response. The modelling process will identify potential impacts of land-use alternatives on tree genetic diversity, a critical element in conserving plant biodiversity. It is, of course, only one potential indicator of the conservation value of managed forests, and other indicators may be required to assess other important ecosystem impacts.

An example of the application of the Ecogene model to management

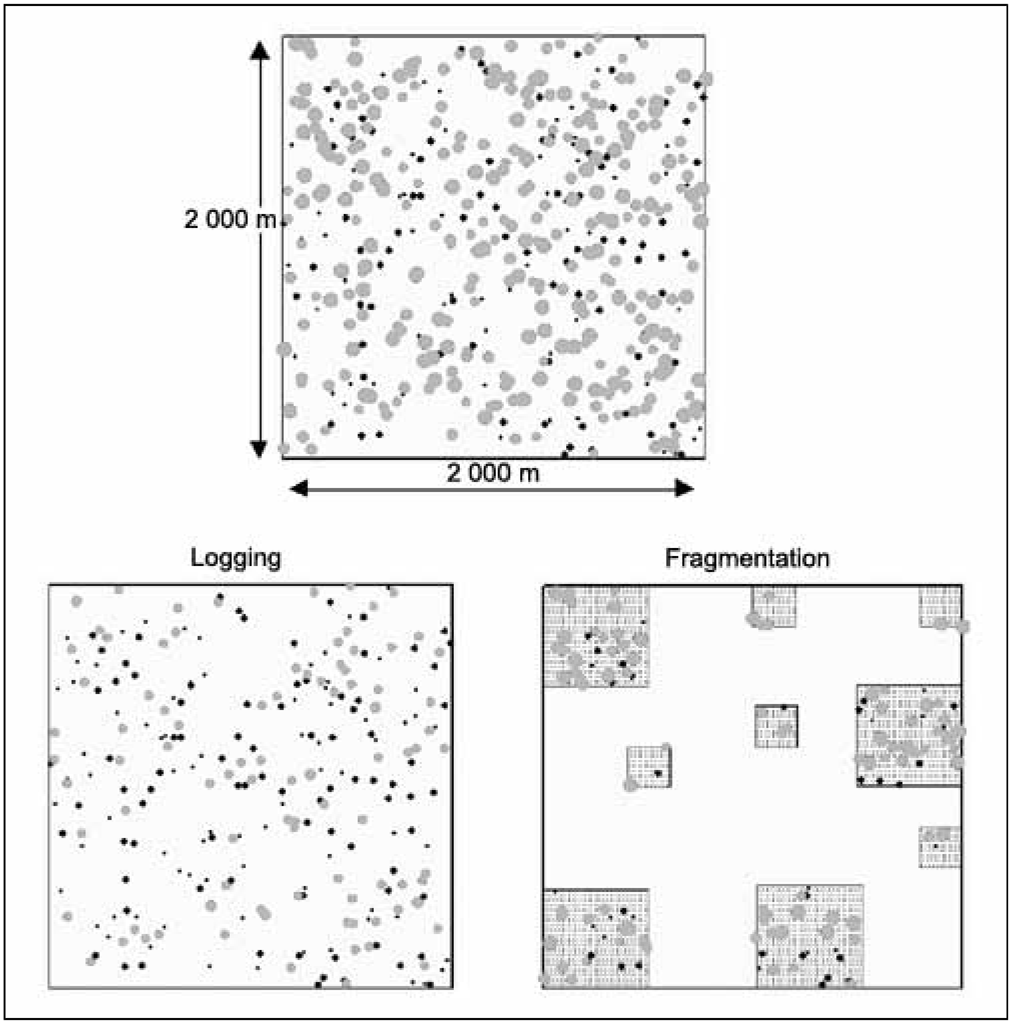
Degen, Roubik, and Loveless (2002) used field data on tree spatial distribution in the intensive study plots in the Tapajós National Forest to examine the effects of logging

and of fragmentation on genetic diversity in *Jacaranda copaia*, one of Dendrogene's seven focal species. They created populations with different densities and spatial patterns, representing:

- **a control, using inventory data for one 400 ha block;**
- **logging (removal) of all individuals greater than 31 cm DBH;**
- **fragmentation to give the same residual population size (90 flowering trees greater than 20 cm DBH) as in the logging scenario, reducing the area of the forest habitat to 140 ha (35 percent of its original size).**

Flowering phenology, pollinator movement patterns and seed dispersal distributions were identical in all three simulations.

The seeds produced from one episode of mating in these populations were then analysed for 13 standard genetic measures, including effective population sizes, fraction of selfing, mean pollen dispersal distance, observed and expected heterozygosities and allelic diversity. Each simulation was run 30 times, and means and standard deviations (sd) were used to compare the results between the control population and the two different treatment scenarios. In both treatments, 11 of 13 indices of genetic diversity were significantly different from those of the control population. Effective population size was most severely affected by alterations in tree spatial distribution; it was estimated at 161.81 (sd = 7.34) individuals in the control population, 59.22 (sd = 4.16) individuals in the logged population and 44.80 (sd = 4.84) individuals in the fragmented population. Self-pollination increased significantly in the treatment scenarios, and mean pollen dispersal distance also increased. Expected heterozygosity (also known as gene diversity) was significantly reduced in the treatment simulations. The results also suggest that some genetic variables are more sensitive than others in demonstrating genetic differences under different management regimes.



Maps showing control and treatment scenarios in the Ecogene simulation study of **Jacaranda copaia*****; black dots indicate trees of*** **Jacaranda copaia** ***greater than 10 cm DBH, and grey dots indicate individuals flowering in each scenario (308 trees in the control and 90 trees in each of the treatment scenarios)***

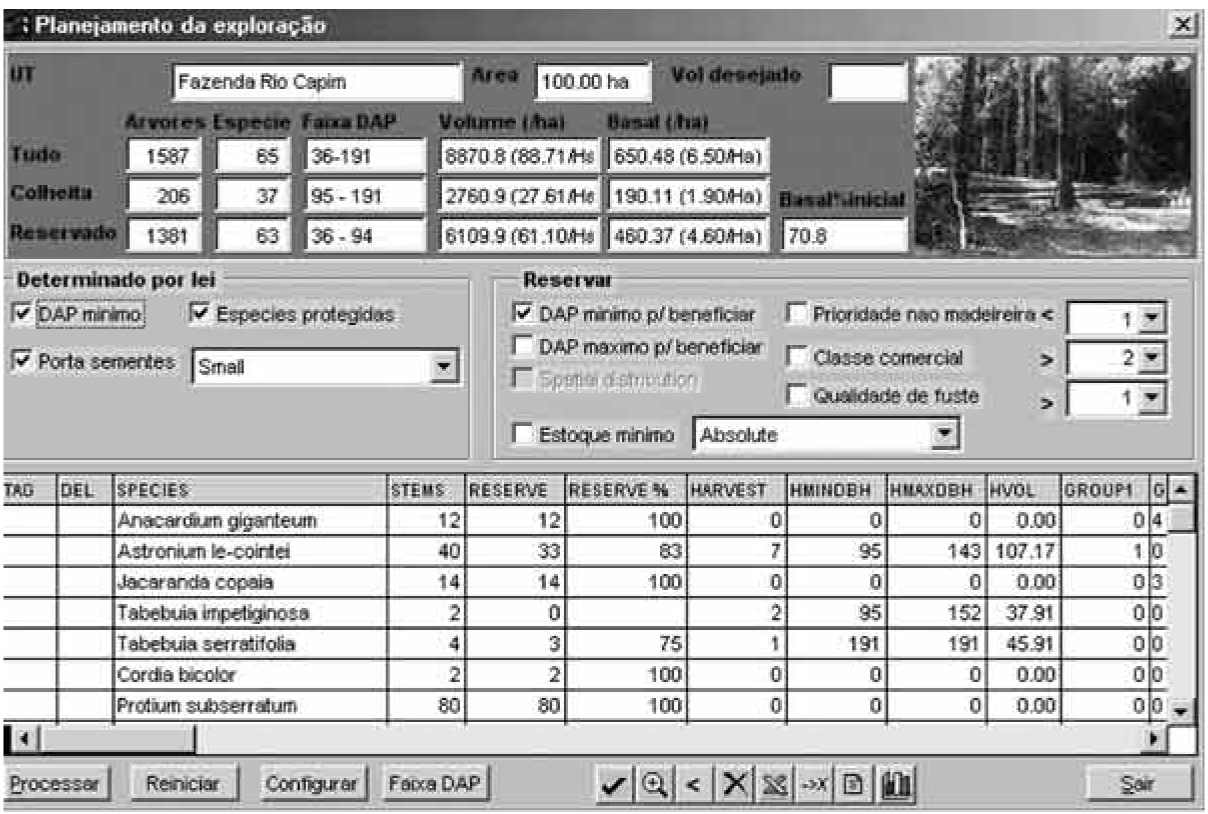
Facilitating adoption of new practices

A common barrier to change in management practice or to compliance with new legislation or policy is the difficulty of modifying operational routines. This is especially true when new procedures are more complex than current ones - as would be the case, for example, in adopting forest harvesting planning that takes into account each tree species, its inherent characteristics and the characteristics of the population to be managed. The Dendrogene Project has been supporting the development of the Tree Management and Mapping database, Trema, in order to facilitate adoption of new management practices.

Trema includes functions to facilitate the control of species nomenclature and to produce species lists, stand tables and maps as required for forest management planning and control. It contains information on key species characteristics, and stores the population data for the trees in the specific forest unit. It also includes automated routines to apply criteria for the selection of the trees to be felled. The criteria and their thresholds can be adjusted to take account of recommendations arising from the genetic impact modelling. Economic criteria of trees to be harvested, such as current market acceptability and presence of defects, are also included so that the final selection is commercially realistic.

The commercial sector may fear that applying genetic conservation criteria to harvest selection will threaten the economic viability of management. Dendrogene does not seek to set limits that define acceptable management in terms of genetic impact only, but rather seeks to provide analytical tools that will help stakeholders identify the trade-offs between economic, social and environmental values. Local forest dwellers may also have different perceptions of biodiversity values. These issues will be explored through participatory impact assessment of the logging carried out in the study area.

The conceptual framework used in Dendrogene could be applied to other forest ecosystems and regions. Basic elements such as the gathering and application of existing information, the development of capacity for correct identification of species, the development of forestry decision support software and the development of policy and management practice based on best available evidence, add value independently of the success of the simulation modelling component. This framework could readily be assimilated within ongoing forest sector development programmes.



The Tree Management and Mapping database, Trema, is being developed to facilitate adoption of conservation-oriented management practice; it contains information on key species characteristics and stores population data for the specific forest unit

CONCLUDING REMARKS

The Dendrogene Project builds on multidisciplinarity and multi-institutional alliances. It seeks to gather appropriate new data and to apply existing research information to the development of efficient new management tools. It supports accurate identification of species, documentation of forest ecological processes and modelling of forest dynamics (including genetics of forest tree species). It is a pioneer test of the use of simulation modelling to integrate genetic and ecological processes on a relevant scale in studying the impacts of tropical forest management on genetic processes. The project uses scenario analysis and participatory methodologies to influence policy and management practices.

The authors believe that this scientific approach to assessing the impacts of harvesting on genetic processes in tropical forests of the Amazon region, while not eliminating uncertainty, will help forest managers, industry and policy-makers make better decisions and move closer towards sustainable development of tropical forest resources.

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