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The Amazon floodplain Demonstration Site: Sustainable timber production and management of Central Amazonian white-water floodplains

Florian Wittmann[1], Jochen Schöngart[1], Helder L. Queiroz[2],
Astrid de Oliveira Wittmann[3], Auristela dos Santos Conserva[2],
Maria T.F. Piedade[3], Jürgen Kesselmeier[1], Wolfgang J. Junk[4]

[1]Max Planck Institute for Chemistry, Johann J. Becherweg 27, 55128 Mainz, Germany
e-mail: F-Wittmann@web.de
[2]Instituto de Desenvolvimento Sustentável Mamirauá,
Av. Brasil 197, 69470-000 Tefé, Brazil
[3]Instituto Nacional de Pesquisas da Amazônia,
Av. André Araújo 2936, 69060-001 Manaus, Brazil
[4]Universidade Estadual do Amazonas,
Av. Djalma Batista 3578, 69005-010 Manaus, Brazil

Abstract

Within the frame of the UNESCO Ecohydrology Program, the present Demonstration Project aims at the enrichment of degraded várzea forest patches with economically important timber species in the Mamirauá Sustainable Development Reserve (MSDR), western Brazilian Amazon. Enrichment plantations will reduce exploitation pressure in the natural environment and will contribute to the conservation of várzea forests and its ecological integrity by introducing alternative sources of income for the inhabitants. We present preliminary results from an interdisciplinary research, including data about the use and the net present values of timber trees in western Brazilian várzea; growth models and management criteria of the most exploited timber species; and germination experiments, which demonstrate that várzea timber species are easy to germinate, without requiring complicate treatments and expensive materials. These data allow for the initialization of timber species reproduction at larger scales, and provide the scientific basis to enrich degraded várzea forests with economically important timber species.

Key words: Amazon, enrichment plantations, germination, sustainable forest management, várzea, wood increment

1. Introduction

The conservation of tropical forests in the frame of climate protection and the maintenance of biodiversity and genetic resources remains one of the most important ecological challenges of our times. Due to the declining timber stocks in Southeast Asia (OECD-FAO 2005) and the opening up of the Amazon basin at the end of the 1960s (Kohlhepp 1989), the round-wood production in Amazonia increased from 4 Mio. m^3 in the year 1975 to 27.5 Mio. m^3 in the year 1997

(Nepstad *et al.* 1999). Today, more than 75% of the total Brazilian roundwood production originates from the Amazon basin, which will be the center of the tropical wood production in the 21st century (Uhl *et al.* 1998; Nepstad *et al.* 2001). As the world‘s largest remaining tropical rain forest, the Amazon basin plays a crucial role in the global carbon cycle and the conservation of biodiversity. Considering the current trends of global warming, an increasing El Niño activity, human population growth, and deforestation in Amazonia, this situation requires urgently the development of controlled and sustainable land-use systems to protect the multiple functions of the Amazonian rainforests.

Amazonian freshwater floodplains cover an area of approximately 300 000 km^2, which represents 5-7% of the area of the Amazon basin (Junk 1989). They are classified in *várzea* (periodically flooded by nutrient-rich white-waters originating from the Andes and the Andean foothills), and *igapó* (periodically flooded by nutrient-poor black- and clear-waters originating from the Archaic and Paleozoic shields of the Guiana’s and of Central Brazil, (Sioli 1954; Prance 1979). The water-level fluctuations of the major Amazonian Rivers result in the existence of an aquatic and a terrestrial phase during the year (Junk *et al.* 1989). Depending on their location on the flooding gradient, várzea forests underlie periodic inundations of 1.0-7.5 m height, corresponding to a mean waterlogged period of 30-230 days year^{-1} (Wittmann *et al.* 2002, 2004).

With more than 900 taxonomically described tree species, várzea forests are the most species-rich floodplain forests worldwide (Wittmann *et al.* 2006a). They have important functions in the Amazonian landscape like regulation of the hydrological regime, soil protection against erosion, water storage, local climate buffer, sinks and sources in biogeochemical cycles, and they represent habitats for a highly adapted, partial endemic flora and fauna (Junk *et al*. 2000).

For centuries the várzea has been settled and used, largely because of its easy accessibility, high soil fertility, and richness in natural resources (Junk *et al*. 2000). The increasing demand of nutrient-rich várzea soils for agriculture has led to a significant deforestation of primary forests especially in the more densely populated eastern part of the Amazon basin. In addition, várzea forests are endangered through timber exploitation of an expanding timber and plywood industry (Higuchi *et al*. 1994). In comparison with non-flooded forests, costs of selective logging, skidding, and timber transport in floodplain forests are low, because timber can be removed by boats and shipped to the sawmills during the aquatic phases (Barros, Uhl 1999). Thus, between 60-90% of the local and regional markets in the central and western Amazon basin are provided with timber from the várzea (Kvist, Nebel 2001; Worbes *et al*. 2001). The round-wood production in Amazonian várzea in the year 1999 amounted to three Mio. of m^3 year^{-1}, this corresponds to about 10% of the total round-wood production within the Brazilian Amazon (IBAMA 2000). Wood production in floodplains thus contributes with US$ 120 Mio. to the Amazonian gross product and actually generates about 30 000 direct employments (Bentes-Gama *et al*. 2002).

Despite high tree species richness in Amazonian várzea, only a few timber species are of commercial interest. Due to unsustainable logging practices and a lack of information about growth rates and regeneration, continuously logged timber species like *Ceiba pentandra* and *Cedrela odorata* already disappeared from local and regional markets (Higuchi *et al.* 1994), and subsequently were replaced by alternative várzea timber species such as *Hura crepitans*, *Couroupita subsessilis*, *Ocotea cymbarum* and *Sterculia apetala* (Albernaz, Ayres 1999; Worbes *et al*. 2001).

Floodplain forests are key habitats that in addition to many tree species harbor many terrestrial invertebrates at the forest floor and in the canopy, and closely interact with many species of fishes, birds and mammals. Preservation and sustainable management of the floodplain forest is the greatest challenge in várzea protection, because centuries are required to restore a species-rich mature floodplain forest. However, due to the comparatively high content of soil nutrients, which is annually refreshed by the inundations (Junk 1993; Furch, Klinge 1989), várzea trees are characterized by accelerated growth rates and elevated primary production (Nebel *et al.* 2001; Schöngart 2003) when compared to forests of the non-flooded uplands (Clark *et al*. 2001; Mahli *et al*. 2006; Chave *et al.* 2005). Therefore, the introduction of sustainable forest management programs is particularly attractive in Amazonian várzea.

In the frame of the UNESCO Ecohydrology Program VII, the present Demonstration Project aims at the sustainable timber production in Amazonian várzea forests of the Sustainable Development Reserve Mamirauá, western Brazilian Amazon. The recultivation of economical important timber species in degraded forest areas will reduce exploitation pressure in undisturbed forests by creation of an alternative source of income for the inhabitants and/or extractors, thus contributing to the protection and conservation of floodplain biodiversity and ecosystem integrity. However, successful enrichment plantations must be based on scientific data, which include information about use and values of timber species, its stocks in the natural environment, its growth and regeneration behaviors, as well as about possibilities to reproduce vital tree seedlings.

In the present study, we examine the use and the net present values of timber species within the central Amazonian várzea. We also show results about the germination and growth behavior of the most useful várzea timber trees. Aim of this study is to analyze which várzea timber species are the most appropriate for enrichment plantations in degraded forest areas, how these species can be sustainably managed, and whether vital seedlings can be produced by the inhabitants, without requiring expensive infrastructure or chemicals.

2. Materials and Methods

Study site

The present UNESCO Demonstration Site in Ecohydrology takes place in the Mamirauá Sustainable Development Reserve (MSDR), which is located at the confluence of the Solimões and the Japurá Rivers, approximately 70 km NW of the city of Tefé, in the Central Brazilian Amazon (Fig. 1). The MSDR was founded in 1990 and its focal area comprises 11 240 km^2 of várzea floodplains. Together with the Amanã Sustainable Development Reserve, the Jaú National Park, and the Biological Reserve Anavilhanas, the MSDR forms the `Central Amazon Conservation Complex´, which totals an area of about 6 10^6 ha, and which is one of the largest areas of protected tropical forests, declared to a world heritage by the UNESCO in the year 2000 with extension in the year 2003.

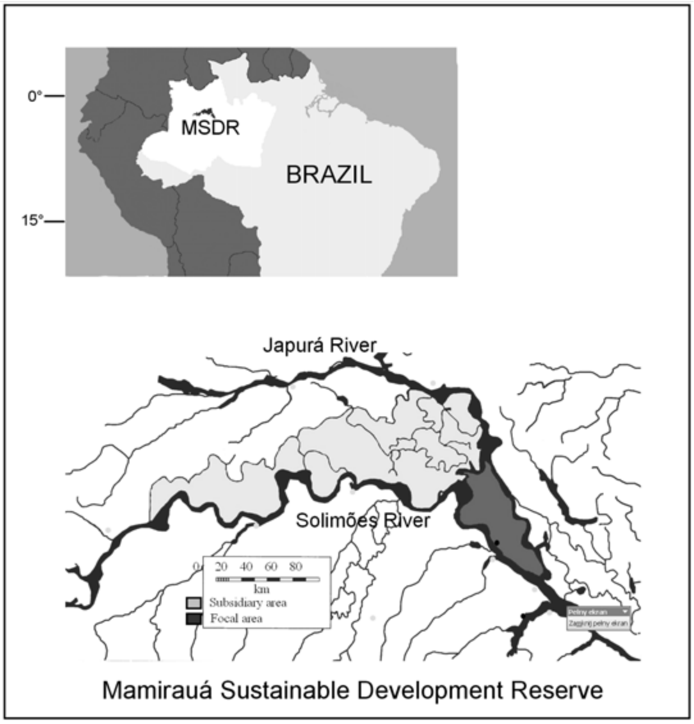

Fig. 1. Location and size of the Mamirauá Sustainable Development Reserve – MSDR.

A mean daily temperature of 26.9°C and an annual precipitation of almost 3000 mm with a distinct dry season during July-October characterize the MSDR. Mean amplitude of the annual water-level fluctuation is 11.38 m for the period 1993-2000 (Schöngart *et al.* 2005).

Prior studies conducted in the area

Since 1992, the Institute of Sustainable Development Mamirauá – (ISDM) has commenced a variety of community management systems in the focal area of the MSDR based on socio-economic and bio-ecological studies, including fishery, agriculture, agro-forestry, ecotourism, and forestry (Sociedade Civil Mamirauá 1996; Ayres *et al*. 1999). The Forest Management Program - established in 1998 - is a polycyclic selection system (Lamprecht 1989; Graaf *et al.* 2003) with a minimum logging diameter (MLD) of 50 cm, a cutting cycle of 25 years, and a maximum yield of 30 m^3 per harvest based on legal restrictions and normative instructions (e.g., Instrução Normativa Nº 5, 11th December 2006) of the IBAMA (Brazilian Environmental Institute). Endangered timber species like *Cedrela odorata, Calophyllum brasiliense*, *Ceiba pentandra*, *Platymiscium ulei*, *Xylopa calophylla* and *Virola surinamensis* are excluded from the forest management. The most important timber species logged in the year 2003 were mainly those with comparatively low wood densities [wood specific gravity (SG) <0.60 g cm^{-3}, like *Hura crepitans*, *Couroupita subsessilis*, *Maquira coriacea*, and *Ficus insipida*], but also some species with higher wood densities (SG>0.60 g cm^{-3}, like *Ocotea cymbarum*, and *Piranhea trifoliata*) (Schöngart *et al.* 2007).

A variety of socio-economic and scientific studies preceded the establishment of the present Demonstration Project in the MSDR, many of them conducted by members of the scientific agreement between the ISDM, INPA (National Institute for Amazon Research, Manaus, Brazil), and MPI (Max Planck Institutes for Limnology and Chemistry, Germany). Population censes, socio-economic activities, and income and household production of the inhabitants of the MSDR was investigated by the Sociedade Civil Mamirauá - SCM (1996).

Floristic inventories of the different forest types and taxonomical, structural, phyto-ecological, and phyto-sociological studies were performed by Ayres (1993), Queiroz (1995), Wittmann *et al.* (2002, 2004), Wittmann, Junk (2003), and Schöngart (2003). The distribution and coverage of the different forest types of the MSDR by remote-sensing techniques was investigated by Wittmann *et al.* (2002). Phenology, wood characteristics, biomass, primary production, and the growth behaviour of trees was studied by Schöngart (2003, 2008), Schöngart *et al.* (2002, 2004, 2005, 2007), and Wittmann *et al.* (2006b). Tree regeneration and establishment was investigated by Wittmann, Junk (2003), Conserva (2006), and Oliveira Wittmann *et al.* (2007a, b).

Project design and methods

The present project focuses on the recultivation of traditionally and commercially exploited várzea timber species in degraded forest areas of the MSDR, implying an interdisciplinary approach between ethno-botanic, ecological, and silvicultural methods. Here, we focus on the investigation of (1) use and values of várzea timber species, (2) species growth modeling, and (3) germination experiments that enable the production of vital timber species seedlings:

Use of várzea timber

To define suitable timber species for enrichment plantations, we preliminary investigated the traditional and commercial use of the 186 most common várzea tree species (*sensu* Wittmann *et al.* 2006a) within the western Brazilian Amazon, using information from: a) herbaria (mainly INPA, Manaus, Brazil; Missouri Botanical Garden – MBG, USA; New York Botanical Garden-NYBG, USA, Royal Botanical Gardens, Kew, Great Britain), b) literature (mostly from the Peruvian Amazon, i.e. Phillips *et al.* 1994; Kvist *et al.* 2001; Reyes-García *et al.* 2006), and c) the Forest Management Program of the ISDM. As most of the tree species are used for multiple purposes by the inhabitants, we considered timber species only those where the tree usually is cut as a whole for use destination (round wood). We separated the use destiny of timber in nine categories: house construction, heavy construction and sleepers, construction of canoes, boats, and floating houses, carpentry, furniture, floors and panels, plywood, tools (e.g. instrument shafts), and fences. The occurrence and distribution of timber species along the flooding gradient was investigated, based on the várzea forest type classification described by Ayres (1993) and Wittmann *et al.* (2002), which separates the forests in low várzea (mean inundation height >3 m, corresponding to a inundation period of >50 days year^{-1}), and high várzea (mean inundation height <3 m, inundation period <50 days year^{-1}). The net present value (NPV) of timber exploitation following the IBAMA instructions was calculated for both, low-density and high-density timber.

Growth modeling

In 1999/2000 we established a network of seven 1-ha plots in almost undisturbed várzea forests of different successional stages and of different inundation heights to monitor forest dynamics focusing on stand's vertical, horizontal and age structure, tree species diversity and composition, forest regeneration, mortality and increment rates (Wittmann *et al.* 2002, 2004; Schöngart 2003; Wittmann, Junk 2003). The plots were divided in 16 quadratic subplots with laterals of 25 m (625 m^2) where all trees above 10 cm diameter at breast height (*dbh*=130 cm height) were inventoried. Additionally we established a circular plot with 500 m² in an early pioneer stage on a recently formed sand bar at the Japurá River. The studied forest stands are annually flooded by a water column of 1.90-4.65 m. In all plots we mapped trees by *x*-, *y*-coordinates and measured *dbh* with a diameter tape (in case of buttresses the diameter was recorded directly above them) and total tree height with a Blume Leiss BL 6 (Zeiss, Jena). In the vicinity of the permanent observation plots we established circular temporal plots with 500-2000 m^2 and a sample size between 61-115 trees ≥10 cm *dbh* to determine wood densities, tree ages and increment rates based on tree-ring analyses. Therefore all trees were mapped, *dbh* and tree height was measured and two or three wood samples were obtained at *dbh* with a Suunto tree borer of 5 mm inner diameter (Vantaa, Finland). One sample was used to calculate wood density; the other samples to determine tree age and increment rates. Additionally we sampled stem disks and cores of 270 trees from the most abundant tree species in several várzea forest types of different stand age (Schöngart 2003).

Wood samples were prepared and analyzed in the dendrochronological laboratory at the INPA using standard procedures (Worbes 1995; Schöngart *et al.* 2004). All samples were progressively sanded to analyze tree-ring structure macroscopically by wood anatomical features characterized by density variations (e.g., Annonaceae, Lauraceae, Myrtaceae), marginal parenchyma bands (e.g., Fabaceae), alternation between fiber and parenchyma tissues (e.g., Sapotaceae, Moraceae, Lecythidaceae) or rarely by variations in the vessel size and distribution (Worbes 1989). Ring width was measured to the nearest 0.01 mm using a digital measuring device (LINTAB) supported by the software TSAP (Time Series Analyses and Presentation). Individual and average cumulative diameter growth curves were con-

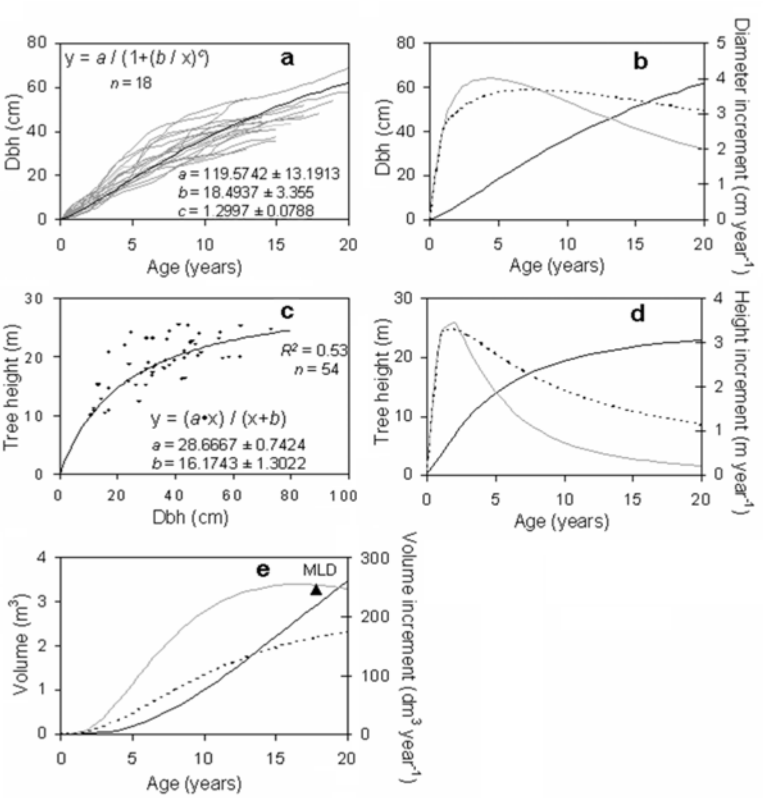

Fig. 2. (**a**) Cumulative diameter growth curves of 18 individuals of *Ficus insipida* (gray lines) and the mean curve (black line), fitted with a sigmoidal regression model. (**b**) Model of diameter growth (black line), current annual increment *CAI* (gray line) and mean annual increment *MAI* (dotted line). (**c**) Relationship between diameter and tree height of 54 individuals, fitted with a non-linear regression analysis. (**d**) Model of height growth (black line), current height increment (gray line) and mean height increment (dotted line). (**e**) Volume growth model derived from the diameter growth model combined with the height growth model (volume was estimated by the basal area multiplied with the tree height and a form factor of 0.6). The minimum logging diameter (*MLD*) is defined in the peak of the current volume increment.

structed for every tree species based on the measured annual radial increments and fitted to sigmoidal (non-linear) regression models (Schöngart 2008) (Fig. 2). Height growth of a tree species was estimated by combining the age–diameter relationship and the relationship between dbh and tree height measured in the field fitted to a non–linear regression model (Schöngart *et al.* 2007; Schöngart 2008). Thus, for every tree age over the lifespan of a species, the corresponding dbh and tree height can be derived and the cumulative volume growth of a tree species was calculated by multiplying the basal area with the corresponding tree height and a form factor of 0.6 (Schöngart *et al.* 2007).

Germination experiments

Many várzea tree species fruit during the period of highest water-levels, thus optimizing seed dispersal by water currents and aquatic organisms (Gottsberger 1978; Goulding 1983; Pires, Prance 1985; Kubitzki, Ziburski 1994). The contact with the river water is essential to break seed dormancy of many várzea species (Oliveira Wittmann *et al.* 2007a). To discover the fastest way to produce vital tree seedlings of várzea timber species suitable for enrichment plantations, we performed germination experiments restricted to varying periods of water logging of the diaspores, thus simulating the conditions in the natural environment. In the frame of the present project, germination experiments were conducted in so far eight pre-selected várzea tree species (*Ficus insipida*, *Macrolobium acaciifolium*, *Ocotea cymbarum*, *Laetia corymbulosa*, *Tabebuia barbata*, *Piranhea trifoliata*, *Mezilaurus itauba*, *Calophyllum brasiliense*). The germination experiments were conducted with respect to the following criteria: a) vital diaspores of the species available within the MSDR, and b) possibility of experiment repetition by inhabitants of the MSDR directly at the study site, without requiring expensive technical equipment or chemicals.

Mature fruits of the pre-selected tree species were collected in várzea forests of the focal area of the MSDR. To increase the possibility of genetic variety within the sampled species, fruits were collected from three individuals that were located >15 km apart from each other. Germination experiments were conducted in a greenhouse at the INPA, at 80% of natural solar radiation intensity. Air temperatures ranged between 23°C and 35°C (mean: 29.8°C), water and soil temperatures between 22.3°C and 30.1°C (mean: 28.9°C).

Seeds were separated from the fruits, mixed, and subsequently split into samples containing 25 seeds each. Samples were placed in aluminum trays with the sizes of 40 x 20 x 15 cm. The trays contained a) várzea substrate (S), b) tap water (water column: 10 cm, changed weekly) during 30 days (W30), and c) tap water during 60 days (W60). After the periods of waterlogging in the settings W30 and W60, the samples placed in tap water were removed to trays containing várzea substrate, thus standardizing the environmental conditions for all species, and simulating a restricted period of waterlogging of the diaspores (Oliveira Wittmann *et al.* 2007a).

Germination initiation and rates were determined from the emission of cotyledons, because the emission of radicles could not be monitored in the seeds placed in várzea substrate without influencing the seedling. Germination rates were recorded daily until all species germinated, for a period of 300 days. Temporal and quantitative variations in germination velocity and rates between waterlogged and non-waterlogged treatments were quantified by multivariate F-tests.

3. Results

Use of várzea timber

The investigation about the use of the 186 most common Central Amazonian várzea tree species indicates that 80 species (43%) are traditionally and/or commercially used for timber within the Brazilian Amazon (Table I). The overwhelming part of timber trees is used for multiple purposes (Table I). Quantitative most important category is that of house construction (63 species), followed by carpentry (22 species), furniture (21 species) and boat, houseboat, and canoe construction (20 species). Eighteen tree species are commercially harvested for plywood (among the most important: *Hura crepitans*, *Ceiba pentandra*, *Ocotea cymbarum*, *Couroupita subsessilis*, *Schizolobium amazonicum*, *Sterculia apetala* and *Maquira coriacea*, Table II), some of them representing none or only poor non-commercial values for the inhabitants.

Twenty-three timber species used by the inhabitants have comparatively high wood specific gravities (SG≥0.65 g cm^{-3}), whereas 37 timber species are low-density wood species (SG<0.65 g cm^{-3}) (Table II). No SG values could be achieved for 20 timber species. Wood prices of central Amazonian várzea timber vary among the timber species, but average approximately US\$ 17.50 m^{-3} for low-density wood species, and approximately US\$ 31.00 m^{-3} for high-density wood species in the year 2007 (Forest Management Programme Mamirauá). Basing on the normative instructions established by the IBAMA, the NPV from selectively logged várzea timber thus actually ranges from 13.80 to 51.36 US\$ ha^{-1} year^{-1}.

The overwhelming part of timber species (54) shows restricted distribution in high-várzea forests. Thirty timber species are restricted to low-várzea forests (inundation height ≥3 m, inundation period ≥50 days year^{-1}), whereas only 4 timber species occurred in both, high-várzea and low-várzea forests.

Growth modeling

Growth modeling is indicated for the example of *Ficus insipida* with tree ages varying between 3 and 20 years (Schöngart *et al.* 2007, Fig. 2). The relationship between tree age and *dbh* of *Ficus insipida* is statistically significant (r=0.82, P<0.001) allowing to model the cumulative diameter growth curves (Fig. 2a). After 15 years, an average tree reaches the current MLD of 50 cm. From the mean diameter growth curve, we derived the current and mean diameter increment (Fig. 2b). Trees reach their maximum current diameter increments at an age of 4–5 years with a rate averaging 4 cm year^{-1}, but the highest increment rate observed exceeded 8 cm year^{-1}. Diameters (varying between 10.9 and 73.3 cm, corresponding to ages between 3 and 20 years) and total tree heights were significantly correlated (r=0.74, P<0.001) and described by a non-linear regression model (Fig. 2c). Substituting *dbh* in the diameter growth model (Fig. 2b) by the significant relationship between *dbh* and tree height (Fig. 2c) results in a model for height growth (Fig. 2d). Current height increment peaks at an age of 2 years, with rates of almost 3.5 m year^{-1}. The combination of the regression analyses of age-*dbh* and *dbh*-height relationships results in a volume growth model for the entire life span (Fig. 2e). The optimal period to harvest the trees is at the peak of the current volume increment, when *Ficus insipida* have an average age of 17 years. The diameter at the maximum current volume increment indicates the preferred time for logging, and cor-

Table I. Timber use categories of the 186 most common tree species in Amazonian várzea (for category definition, see text). Data obtained from herbaria (mainly Instituto Nacional de Pesquisas da Amazônia - INPA, Manaus, Brazil, Missouri Botanical Garden-MBG, USA, New York Botanical Garden-NYBG, USA, Royal Botanical Garden Kew, Great Britain; information provided in literature (see text), and information provided by the Forest Management Programme of the Institute of Sustainable Development Mamirauá.

Use category	n Species (from 186)	%
Timber products	80	43.01
House construction	64	34.40
Carpentry	22	11.83
Furniture	21	11.29
Canoe, boat, and houseboat construction	21	11.29
Plywood	18	9.68
Heavy construction and sleepers	17	9.15
Floors and panels	16	8.60
Fences	9	4.84
Tools (i.e. instrument shafts, handles)	7	3.76

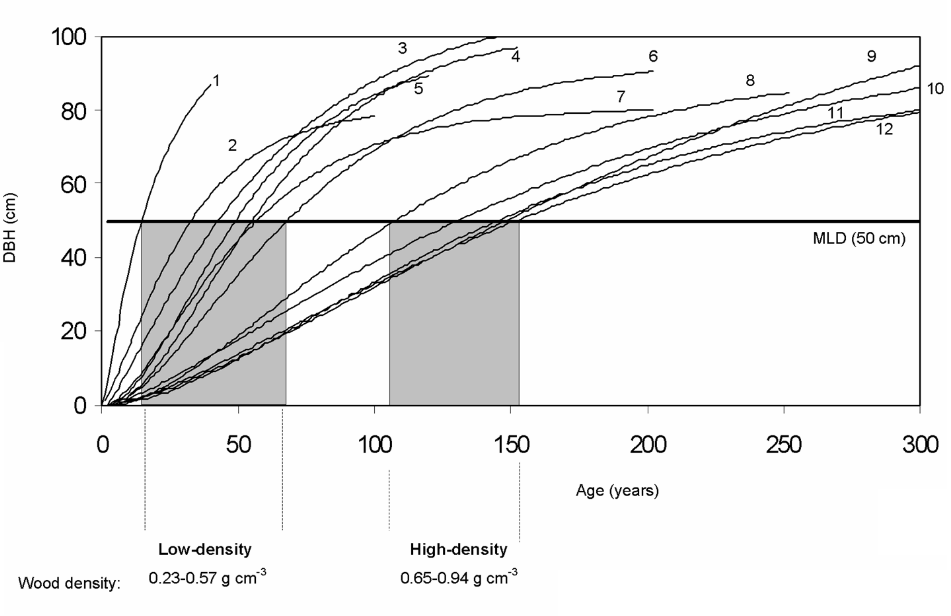

Fig. 3. Cumulative mean volume growth curves of 12 low-density (1-7) and high-density (8-12) timber species from the Central Amazonian várzea floodplain forests (1-*Ficus insipida*, 2-*Pseudobombax munguba*, 3-*Luehea cymulosa*, 4-*Ilex inundata*, 5-*Macrolobium acaciifolium*, 6-*Albizia subdimidiata*, 7-*Sloanea terniflora*, 8-*Pouteria elegans*, 9-*Piranhea trifoliata*, 10-*Chrysophyllum argenteum*, 11-*Tabebuia barbata*, 12-*Eschweilera albiflora*) (Schöngart 2008). MLD=Minimum logging diameter.

responds to a *dbh* of 55 cm, this derived from the model for diameter growth (Fig. 2b), which would be an appropriate MLD for this species. The cutting cycle, calculated by the mean passage of time through 10 cm *dbh* classes until the tree reaches the MLD of 55 cm (Fig. 2b), is 3.3 years.

Besides *F. insipda*, growth models have been established for 11 várzea timber species (Schöngart 2003). All growth models are based on significant relationships between tree age and diameter as well as *dbh* and tree height based on over 16 430 ring-width measurements. Other low-density timbers need periods of 67 years (*Sloanea terniflora*) to pass over the MLD of 50 cm; high-density woods require between 106 years (*Pouteria elegans*) and 151 years (*Eschweilera albiflora)* to reach this limit (Fig. 3) (Schöngart 2008).

Germination experiments

From the eight investigated tree species, only *F. insipida* could not be reproduced by the collected diaspores. *Macrolobium acaciifolium*, *Laetia corymbulosa* and *Tabebuia barbata* showed significant higher germination rates in at least one of the waterlogged treatments (W30 or W60), while germination rates between treatment S and waterlogged seeds were not significantly different in *Ilex inundata* and *Ocotea cymbarum* (Table III). Seeds from *Mezilaurus itauba* only germinated in treatment S.

Mean germination periods were significantly longer in waterlogged seeds than in seeds of treatment S in *Macrolobium acaciifolium* and *Ocotea cymbarum*, while in the other species, waterlogging shortened the germination periods (Table III).

Waterlogging increased the velocity of germination (protrusion of cotyledons) in the species *Macrolobium acaciifolium*, *Laetia corymbulosa*, and *Tabebuia barbata*, whereas it delayed germination in *Ilex inundata*, *Ocotea cymbarum*, and *Piranhea trifoliata* (Table III).

4. Discussion

The amount of traditionally and commercially used várzea timber species within the Brazilian Amazon is comparable to the findings of Phillips *et al.* (1994) and Kvist *et al.* (2001), which performed ethno-botanical inventories in Peruvian floodplain forests. Besides the commercial exploitation of palm fruits, both the studies described that timber for house and boat construction is the most important economic resource from floodplain forests. In the central and western Amazon basin, wood prices raised continuously during the last four years (221% in low-density wood, 204% in high-density wood; data from the Forest Management Program Mamirauá - ISDM). Furthermore, many commercially important fish species feed on the fruits, seeds and invertebrates from the floodplain forest.

Table II: Species occurrence, wood specific gravity (SG), and uses of 80 timber tree species from Amazonian várzea. Note that only use categories implying tree cutting as a whole (round wood) are listed. LV=low várzea (mean flood height>3.0 m); HV=high várzea (mean flood height<3.0 m). ISDM=Information provided by the Forest Management Programme of the Institute of Sustainable Development Research Mamirauá, Tefé, Brazil. Codes: 1=house construction, 2=canoe, boat, and houseboat construction, 3=carpentry, 4=sleepers and heavy construction, 5=furniture, 6=floors and panels, 7=tools (e.g. instrument shafts), 8=plywood, 9=fences. Ranges of SG were obtained from Fearnside (1997), Worbes *et al.* (2001), Schöngart (2003), and Wittmann *et al.* (2006b).

Species	**Occurrence**		**SG**	**Use category**									**Source**
	LV	**HV**	**(g cm^{-3})**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Acacia loretensis J.F. Macbr.	x		-	x								x	ISDM
Acosmium nitens (Vogel) Yakovlev	x		0.72-0.76	x	x		x				x		ISDM; Worbes *et al.* (2001)
Aniba riparia (Nees) Mez.		x	0.39-0.46	x								x	ISDM
Annona tenuipes R.E. Fries	x		-	x								x	ISDM
Apeiba glabra Aubl.		x	-	x	x						x		ISDM; Phillips *et al.* (1994)
Aspidosperma riedelii Müll.Arg.		x	-							x			ISDM
Batocarpus amazonicus (Ducke) Fosberg		x	0.71-0.77	x				x					Phillips *et al.* (1994); Kvist *et al.* (2001)
Buchenavia oxycarpa (Mart.) Eichler		x	0.72-0.77	x	x		x		x			x	ISDM
Byrsonima japurensis A. Juss.	x	x	-	x									ISDM
Calophyllum brasiliense Camb.		x	0.51-0.68	x	x	x		x	x	x			ISDM ; Phillips *et al.* (1994); Kvist *et al.* (2001); Santos *et al.* (2004)
Calycophyllum spruceanum (Benth.) Hook f.		x	0.74-0.81	x			x	x	x	x			ISDM; Kvist *et al.* (2001); Worbes et *al.* (2001)
Caraipa punctulata Ducke		x	-	x									ISDM
Caryocar microcarpum Ducke		x	0.58-0.64	x	x				x		x		Worbes *et al.* (2001); Kvist *et al.* (2001)
Cedrela odorata L.		x	0.48-0.60	x	x	x		x	x				ISDM; Parotta *et al.* (1995)
Ceiba pentandra (L.) Gaertn.		x	0.21-0.34		x	x					x		ISDM; Parotta *et al.* (1995); Kvist *et al.* (2001)
Chrysophyllum argenteum Jacq.		x	0.70-0.75	x						x			ISDM; Kvist *et al.* (2001)
Copaifera officinalis (Jacq.) L.		x	-			x		x			x		ISDM
Couroupita subsessilis Pilg.		x	0.45-0.55			x		x	x		x		ISDM
Cynometra bauhinifolia Benth.	x		0.78-0.82	x									ISDM
Duguetia spixiana Mart.	x		-	x								x	ISDM; Phillips *et al.* (1994); Kvist *et al.* (2001)
Endlicheria anomala (Nees) Mez.	x	x	-	x				x					ISDM
Endlicheria formosa A.C. Sm.		x	-	x									Phillips *et al.* (1994)
Erythrina fusca Lour.		x	0.31-0.33		x	x							ISDM
Eschweilera albiflora (DC.) Diers	x	x	0.66-0.83				x						ISDM
Eschweilera ovalifolia (DC.) Nied	x		-	x	x								ISDM
Etaballia dubia (Kunth) Rudd.		x	0.62-0.66	x									ISDM
Euterpe precatoria Mart.			-	x									ISDM; Henderson *et al.* (1995); Kvist *et al.* (2001)
Ficus insipida Rich. ex DC.	x		0.35-0.38								x		ISDM; Phillips *et al.* (1994)
Garcinia brasiliensis Mart.		x	0.58-0.64	x									ISDM
Genipa americana L.		x	0.57-0.66	x		x	x	x	x	x		x	ISDM; Kvist *et al.* (2001)
Guarea guidonia (L.) Sleumer		x	-	x			x	x					ISDM; Phillips *et al.* (1994)
Guazuma ulmifolia Lam.		x	0.49-0.52			x							ISDM
Heisteria acuminata (Humb. & Bonpl.) Engl.		x	-	x									ISDM; Phillips *et al.* (1994)
Hevea brasiliensis Müll. Arg.		x	0.52-0.64	x		x		x					Worbes *et al.* (2001)
Hura crepitans L.		x	0.36-0.42	x	x	x		x	x		x		ISDM; Phillips *et al.* (1994); Albernaz, Ayres (1999); Kvist *et al.* (2001)
Ilex inundata Poepp. ex Reissek	x		0.39-0.43	x									ISDM
Laetia corymbulosa Spruce ex Benth.	x		0.61-0.67	x									Kvist *et al.* (2001)
Lecointea amazonica Ducke		x	0.97-1.03	x			x			x			ISDM, Kvist *et al.* (2001)
Lecythis pisonis Camb.		x	-	x			x			x			ISDM

Species	Occurrence		SG	Use category									Source
Licania apetala (E. Mey.) Fritsch	x		0.64-0.78	x									ISDM; Kvist *et al*. (2001)
Licaria armeniaca (Nees) Kosterm.	x		0.44-0.51	x	x								ISDM; Phillips *et al*. (1994); Kvist *et al*.. (2001)
Luehea cymulosa Spruce ex Benth.	x		0.38-0.48		x	x					x		ISDM, Worbes *et al*. (2001)
Maclura tinctoria (L.) D. Don. ex Steud.	x		0.69-0.73	x	x								ISDM
Macrolobium acaciifolium (Benth.) Benth.	x		0.43-0.49	x		x		x					ISDM; Worbes (1997); Kvist *et al*. (2001); Santos *et al*. (2004)
Macrolobium bifolium (Aubl.) Pers.	x	x	-	x								x	ISDM
Maquira coriacea (H. Karst) C.C. Berg		x	0.45-0.49	x		x		x			x		ISDM; Kvist *et al*. (2001); Worbes *et al*. (2001)
Mezilaurus itauba (Meisn.) Taub. ex Mez.		x	0.65-0.75		x		x	x	x				ISDM
Minquartia guianensis Aubl.		x	0.76-0.88	x			x						ISDM; Silva (1977); Phillips *et al*. (1994); Kvist *et al*. (2001); Santos *et al*. (2004)
Mouriri acutiflora Naudin		x	0.77-0.82				x						ISDM
Mouriri grandiflora DC.		x	-	x									Kvist *et al*. (2001)
Nectandra amazonum Nees	x		0.38-0.47	x									ISDM
Ocotea aciphylla (Nees) Mez.		x	0.58-0.63	x									ISDM; Marques (2001)
Ocotea cymbarum Kunth		x	0.58-0.62	x	x	x		x	x		x		ISDM; Albernaz, Ayres (1999); Worbes *et al*. (2001)
Oxandra riedeliana R. E. Fries	x		0.47-0.51	x									ISDM; Phillips *et al*. (1994)
Pachira insignis (Sw.) Sw. ex Savigny		x	0.43-0.47								x		Phillips *et al*. (1994)
Paramacherium ormosioides (Ducke) Ducke		x	0.37-0.42	x				x					ISDM
Parinari excelsa Sabine		x	0.64-0.68	x	x		x						ISDM; Worbes *et al*. (2001)
Piranhea trifoliata Baill.	x		0.86-0.94	x		x	x						ISDM; Worbes *et al*. (1992)
Platymiscium ulei Harms		x	0.73-0.77	x	x		x	x	x				ISDM; Worbes *et al*. (2001)
Pouteria procera (Mart.) T. D. Penn.		x	0.65-0.73	x									ISDM; Phillips *et al*. (1994); Kvist *et al*. (2001)
Pseudobombax munguba (Mart. & Zucc.) Dug.	x		0.21-0.29			x			x				ISDM
Pseudopiptadenia suaveolens (Miq.) J.W. Gr.		x	-	x							x		ISDM; Phillips *et al*. (1994)
Pterocarpus amazonum (Mart. ex Benth.) Amsh.	x		0.33-0.38	x	x								Phillips *et al*. (1994); Santos *et al*. (2004)
Schizolobium amazonicum Huber ex Ducke		x	0.58-0.64	x							x		ISDM; Brienza-Junior *et al*. (1991)
Sloanea terniflora (Sessé & Moc.) Standl.	x	x	0.63-0.71	x		x							ISDM; Phillips *et al*. (1994)
Spondias lutea L.		x	0.31-0.41			x		x			x		Worbes *et al*. (2001); Santos *et al*. (2004)
Sterculia apetala (Jacq.) H. Karst		x	0.33-0.36	x	x	x		x			x		ISDM; Worbes *et al*. (2001)
Tabebuia barbata (E. Mey) Sandwith	x		0.65-0.79	x			x						ISDM; Albernaz, Ayres (1999)
Tabebuia serratifolia (Vahl) G. Nicholson		x	0.87-1.01	x	x	x	x		x				ISDM
Terminalia dichotoma G. Mey.	x		0.64-0.68	x	x								ISDM
Trichilia lecointei Ducke		x	0.70-0.88	x			x						ISDM
Triplaris surinamensis Cham.	x		0.51-0.63	x		x		x					Worbes *et al*. (2001)
Unonopsis guatterioides (A. DC.) R.E. Fries		x	0.42-0.48								x		ISDM; Worbes *et al*. (2001)
Vatairea guianensis Aubl.	x		0.70-0.75	x				x	x				ISDM; Worbes *et al*. (2001)
Virola calophylla (Spruce) Warb.		x	-	x									ISDM; Phillips *et al*. (1994)
Virola surinamensis (Rol. ex Rottb.) Warb.		x	0.37-0.42	x		x		x	x		x		ISDM; Phillips *et al*. (1994); Anderson *et al*. (1999); Worbes et *al*. (2001); Santos *et al*. (2004)
Vismia baccifera (L.) Triana & Planch.	x		0.54-0.60	x								x	ISDM
Vitex cymosa Bert. ex Spreng.	x		0.56-0.59	x									ISDM
Vochysia guianensis Aubl.		x	-	x									ISDM
Xylopia calophylla R.E. Fries		x	0.33-0.37						x			x	ISDM; Phillips *et al*. (1994)

Destruction of the forest will drastically reduce the stocks of these species. Due to their importance as sources of construction material and food, Amazonian várzea forests are more useful than other Amazonian forest types, and therefore subject to overexploitation (Phillips *et al.* 1994). On the other hand, the high nutrient status of the várzea soils and the periodic nutrient input by the floods makes the area very attractive for crop and timber plantations. Várzeas are probably the only habitats in Central Amazonia which allow long term sustainable timber production with high yield, when adequately managed. The combination of non-timber products, timber and fishes is probably the most efficient sustainable productive system in the várzea, which in addition maintains biodiversity and stores large amounts of carbon in its standing biomass.

The overwhelming part of commercially exploited várzea timber species and in particular the high-density wood species show restricted distribution patterns at high-várzea late-successional forests. These are the most species-rich forests within Amazonian floodplains (Ayres 1993; Cattanio *et al.* 2002; Wittmann *et al.* 2006a). The highly geo-hydrologic dynamic of the Amazonian white-water rivers results in natural habitat fragmentation of long-term developing forest stands, implying that high-várzea forests occur on only 10-15% of the várzea landscape (Wittmann *et al.* 2002). The high várzea is, on the other hand, the area where inhabitants settle and where conversion of forests into agricultural areas and pastures concentrates. High-várzea timber species are species with natural low abundances (Nebel *et al.* 2001, Wittmann *et al.* 2004). In addition, these species need a relative long period to reach maturity and to develop stems of exploitable diameters and heights. Overexploitation affects populations of these late-successional species to a larger extend than those of earlier successional stages, and may lead to species extinctions at regional scales.

One of the biggest difficulties for sustained management of tropical forests is to get reliable data on growth and yield of trees. Nevertheless, these data are prerequisites for determining harvesting volumes and cutting cycles. In this respect, there is much scepticism about growth rates being used for managing many forests in the region. The established time and diameter limitations of these management concepts are estimations or based on legal restrictions rather than being derived from scientific data. Amazonian várzea species can be divided in fast growing low-density species and slow growing high-density species (Schöngart 2008). Both groups show discrepancies to the currently practiced forest management in the Mamirauá Reserve, which bases on the IBAMA instructions. A cutting cycle of 25 years is inappropriate and inefficient to manage the timber resources of fast-growing low-density species, as shown by the growth model for *Ficus insipida* but it also does not correspond to slow-growing high-density timber species. The same holds also for other polycyclic management systems in the tropics worldwide, which operate with only one cutting cycle for several timber species. The varying growth strategies of low-density and high-density timber species require a species-specific management of the timber resources also considering varying site conditions to achieve sustainable yields. Based on timber stocks and lifetime growth rates of both species groups, Schöngart (2008) created a new concept (GOL – Growth-Oriented Logging) as an aid to improve forest management in the Central Amazonian várzea.

Table III: Germination rates, mean period of germination, and velocity of seedling protrusion in the investigated várzea timber species. With treatment S=seeds placed on várzea substrate; W30=seeds placed in tap water during a period of 30 days, and afterwards placed on várzea substrate; W60=seeds placed in tap water during a period of 60 days, and afterwards placed on várzea substrate. Each treatment represents 25 seeds with 4 repetitions = 100 seeds. Letters following the numbers vary at significance-levels of 0.05 (t-test). *CV*=coefficient of variation; *MSD*=minimum significant difference; ^{ns}=not significant.

Species	**Germination rate (%)**			**Mean germination period (day)**			**Velocity of protrusion (seedlings day^{-1})**		
	S	**W30**	**W60**	**S**	**W30**	**W60**	**S**	**W30**	**W60**
Macrolobium acaciifolium	14 B	63 A	73 A	48 A	41 A	66 A	0.34 A	0.41 A	0.30 B
Mezilaurus itauba	32 A	0	0	62 A	0	0	0.15 A	0	0
Ilex inundata	9 A	3 A	6 A	95 A	75 A	70 A	0.03 A	0.01 A	0.01 A
Laetia corymbulosa	21 A	23 A	9 B	39 B	18 A	15 A	0.16 B	0.46 A	0.17 B
Ocotea cymbarum	28 A	23 A	29 A	57 A	146 C	105 B	0.41 A	0.07 B	0.08 B
Piranhea trifoliata	13 A	7 B	0 C	27 B	14 A	0	0.22	0.13	0
Tabebuia barbata	8 B	7 C	47 A	30 B	18 A	19 A	0.09 B	0.10 B	0.70 A
	CV=92.62% *MSD*=46.83 *F*=2.81 (p<0.01)			*CV*=77.49% *MSD*=70.86 *F* =3.04 (p<0.01)			*CV*=117.62% *MSD*=0.32 *F*=2.02^{ns}		

The results of our germination experiments show that the majority of the investigated várzea timber species can be reproduced by simple germination treatments. We obtained germination rates of up to 73% (*Macrolobium acaciifolium*), indicating that there is no need for expensive infrastructure (i.e., climatic chambers) or chemicals (i.e., H_2SO_4) to begin the production of vital várzea timber seedlings suitable for enrichment plantations. The results also indicate that rates and velocities of germination can be influenced by the use of different germination treatments, which, dependent on the species, may lead to higher germination rates and faster germination, or to lower germination rates and decelerated germination. Both cases may be advantageous when vital seedlings of a species should be produced. High germination rates and short germination periods may have advantage when species fruit at the end of the aquatic phase and/or the beginning of the terrestrial phase, thus allowing for a rapid re-cultivation of seedlings in emerging forests. On the other hand, delayed germination can be advantageous when species fruit early, at the beginning of the aquatic phase, thus requiring a relative long period until seedlings can be planted at the beginning of the terrestrial phase. The period of germination and the formation of a seedling in a given species can be monitored to establish an optimal species production schedule.

With the acquired knowledge about utilization, wood prices, and germination and growth behaviour, we are now able to start enrichment plantations of economically important timber species in degraded várzea forest areas. Along with previously obtained data about tree species distribution patterns in dependence of habitat preference (i.e., Junk 1989; Ayres 1993; Wittmann *et al.* 2002, 2004, 2006; Schöngart 2003), population ecology and regeneration behaviour (i.e., Wittmann, Junk 2003; Conserva 2006; Oliveira-Wittmann *et al.* 2007b; Assis 2008; Marinho 2008), these data will contribute to ascertain optimal species-specific sites suitable for enrichment plantations. With support from the present UNESCO Demonstration Project in Ecohydrology, the inhabitants of the MSDR initialized enrichment plantations and its monitoring starting in 2008. Depending on the timber species and growth rates obtained, we expect first yields of these species after 17-45 years. Besides the creation of an additional source of income to the inhabitants, we argue that these plantations locally reduce exploitation pressure in still undisturbed forests, and thus contribute to the conservation of biodiversity and ecological integrity of Amazonian várzea.

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