INTRODUCTION

The conservation of Tropical Forests in connection with the protection of the atmosphere and the conservation of biodiversity is one of the most important ecological challenges of our times. Tropical forest ecosystems play an important role in carbon exchange with the atmosphere and in global water cycles. It is assumed that the worldwide deforestation in the tropics (and elsewhere) affects global climate change which feedback on the growth of trees and forests.

Two major questions were recently discussed in this context.

1. A global forest convention and certification of sustainability of forest production became priorities on the United Nations Conference on Environment and Development in 1992 (Brünig 1996). The idea is to improve the protection of tropical forests by the transformation of restricted areas into sustainable managed forests following ecological criteria to preserve biodiversity and soils. Concepts for sustainable managing of tropical forests were discussed in national and international commissions. Indicators and criteria for sustainable management were developed by CIFOR (Center for International Forestry Research) and other international organisations. These indicators include easy measurable parameters like species composition, structure and timber storage, exploitation systems and others.

2. At the conference of Kyoto in 1997 a worldwide reduction of Carbon Emissions was discussed. Industrial countries obligated themselves to reduce the carbon emissions. On the other hand the tropical countries were obligated to protect their forests as a carbon stock and maybe partially a carbon sink. In the future a financial compensation by the industrial countries for the loss in timber production is very likely. Information on carbon stocks and fluxes therefor are required by all countries under the terms of the Climate Convention.

The key-indicator for the functioning of sustainable management and the estimation of carbon uptake is the wood increment of trees and forest stands. The knowledge on growth rates of tropical trees is extremely poor. Estimates are vague and vary considerably in dependance of the site, the used measurement method and the political interest. Some figures were discussed below.

METHODS TO ESTIMATE FOREST PRODUCTION IN THE TROPICS

Since decades several methods were tested to measure the growth rates of tropical trees. These methods are generally either very complicated and time consuming or not very exact. Actually, there are one direct and three indirect methods of dating ages and growth rates of tropical trees.
and two attempts to give a rough calculation of biomass production of forest stands: Age estimation, by repeated diameter measurements (e.g. Lieberman et al. 1985), by radiocarbon dating (e.g. Camargo et al. 1994) and by a mathematical approach based on the estimations of mortality rates (e.g. Condit et al. 1995) and finally our new attempt, the annual tree ring counting (e.g. Mariaux 1969).

- Repeated diameter measurements only give information about the growth during the measured period. Upscaling of the data to the whole life span of the tree allows only rough estimations because tree growth changes considerably depending on age and environmental conditions (Worbes 1989).

![Graphs](image)

**Fig 1:** Diameter/age estimations derived from repeated diameter measurements. The curves represent so-called growth trajectories. Measured are the increments in different diameter classes as the base for passing through times through consequently following diameter classes. In graph a individual growth curves, in graph b calculations for lowest, mean and fastest increments are shown.

- The interpretation of radiocarbon datings can be problematic. Ages of wood samples older than 50 years and younger than 350 years can not be dated due to the Suess Effect (Stuiver & Becker 1986). During this period the increasing burning of fossil fuel emitted “old” carbon into the atmosphere and changed the natural 14C/12C relation considerably. This is shown clearly in a calibration curve which was estimated analysing the 14C-concentration in exactly dated tree rings from different species. The time span from 1640 to 1950 covers the ages of the most interesting timber trees in natural forests. Direct radiocarbon age datings therefor do not help at all in the investigation of tropical forest dynamics.

- The estimation of a hypothetical age of 2000 years on the basis of mortality rates in a tropical tree population (*Swartzia simplex* in Panama) is a mathematical exercise which was never confirmed by direct measurements (Condit et al. 1995). Assuming a constant mortality rate the maximum age is calculated by

\[ L = (\ln No)/m \]
$L = \text{longevity}, \; N_0 = \text{population size}, \; m = \text{mortality rate until the population is reduced to one individual.}$ Problems are that large populations provide high longevity values and mortality is never constant in a rain forest.

![Graph showing mortality rates and population sizes over time.](image)

**Fig. 2** Left graph: Hypothetical mortality curves starting from different population size (240/400) and results from age estimations with different methods in a Mexican rain forest (right graph, Martinez-Ramos & Alvarez-Buylla 1998)

The most accurate estimation of the exact tree age and wood increment is the use of tree ring analysis. One of the many myths on tropical forests is the assumed absence of annual tree rings. In fact the existence of annual rings in tropical trees under seasonal precipitation conditions is proven since the beginning of our century (Geiger 1915) and meanwhile confirmed in numerous publications (Worbes & Junk 1989, overview Worbes 1992, 1995). The trigger for the annual growth period is either a periodical inundation as it occurs in the annually flooded areas of great streams or periodical dry periods of two or three months as they occur in most non flooded areas in the tropics, even close to the equator. The seasonal climate type with one distinct dry season is widely distributed in the humid tropics (Worbes 1996), e.g. in Central Amazonia tree ring analyses give information on individual growth rates and growth conditions during the whole life period of the individual. The competition behaviour of tree species, the growth history of the stand and the variation of climatic conditions in the past can be derived from tree-ring time series.

Since the beginning of our century the existence of annual rings in tropical trees is proven many times (Ursprung 1900, Geiger 1915, Coster 1927, 1928, Berlage 1931, Mariaux 1967, 1969, 1981) despite the fact that in textbooks this knowledge is ignored consequently (e.g. Whitmore 1991). One reason for the ignorance of annual rings in the tropics is that the occurrence of annual rings was detected and described the first time in the temperate zones (Hartig 1856) and the related science: the tree ring analysis (Dendrochronology) was developed in the temperate zones as well (overview in Schweingruber 1988).

The base of the tree ring analysis is the reaction of woody plants to seasonal varying growth conditions throughout the year. Under unfavourable conditions deciduous tree species shed their leaves but the majority (evergreen as well!) stops the wood growth, because of a cambial...
dormancy. The cambial activity (cell division) is reduced almost to zero in that periods. The result of a declining cambial activity is the production of late wood. The new vegetative period starts with increasing cambial activity and the production of early wood. This alternation between early wood and late wood becomes visible as a growth ring.

CLIMATE AND GROWTH PERIODICITY IN THE TROPICS

The precondition for the existence of annual growth rings is the annual (!) saisonality of climate.

Seasonality in the tropics

In general three different types of climatic seasonality effect annual tree growth:

- The variation of the annual temperature with a temperature near or below the freezing point in winter. The small variation between “winter” and “summer” temperature in the tropics never causes annual growth periodicity (s. fig. 2).
- The annual occurring floodings of the great river systems in the tropics (Rio Negro, Amazon River) which rise up to five meters above the forest floor and last up to six or seven months per year (Worbes 1985, 1997) cause anoxic conditions in the soil. Root respiration and water uptake is hindered, many species shed their leaves and have a cambial dormancy. This is reflected by annual rings in the wood.

![Fig. 2: Variation of the water level of the Rio Negro close to the confluent with the Amazon River. The dotted line marks the lower limit of closed forest growth. The higher the elevation of a site the shorter is the length of inundation.](image)

- The variation of the precipitation with a change between a rainy season and a dry season. The dry season may last two or three months with a precipitation beyond 50 mm. This climate type covers the major part of the tropics (Worbes 1995), see example below.
Periodical tree growth is indicated in many tree species by phenological rhythms. The phenological events are triggered by climatic variations but patterns are related to specific genetic conditions. So at one site different ecological phenotypes (Borchert 1999) may occur (evergreen, stem succulent, deciduous, brevi-deciduous) under equal climatic conditions but with distinct different reactions to drought stress.

**Fig. 4:** Climate diagram of Piracicaba, Brazil with the temperature curve of Göttingen, Germany. The line at 50 mm precipitation indicates the limit between arid (precipitation below) and humid conditions (left). Climate diagram following the conventions of Walter & Lieth (1967) from Caparo Venezuela (right side). The flat line indicates the temperature curve, the second line is the monthly precipitation. When precipitation curve is under the T-curve climate is arid (dotted area) above but below 100 mm the climate is humid and above 100 mm it is perhumid (black period).

**Fig 5:** Distribution of principal climate types in the tropics.
**Seasonal tree growth in the tropics**

Seasonal climate is reflected by various features and growth responses of trees. The annual cycle is divided into a vegetation period and a dormancy period. This growth rhythm is visible in variation of:

- **Cambial activity**
  Cambial activity can be measured directly by repeated sampling of anatomical cross sections, where the relative number of cambium cell rows indicate the dividing activity. Usual staining procedures of the slides with astra blue and safranine make the active cambium visible under polarization light (Dünisch et al. 1999).

- **Diameter increment**
  Dendrometer bands serve to measure the diameter increment, which is a derived feature of the cambial activity. Best results are to reach with metal bands instead of textile bands, which often react to foreign influences or do not fit exactly on rough barks. During drought periods stems often show a “negative growth” what is in fact stem shrinking as a result of water loss. Monitoring periods should not exceed four weeks.

- **Leaf phenology**
  Different tree species at one site do not necessarily react uniform to changes in climate. The different leaf fall behaviour of dry forest species is classified by Borchert (1999) into:
  - Stem succulent
  - Deciduous
  - Brevideciduous
  - Evergreen
  This functional ecotypes differ in tolerance strategies against drought events in terms of leaf structure, water potential and stem water content, pattern of leaf fall and flushes.

The relation between precipitation, stem increment and leaf fall behaviour of one species (*Terminalia superba*, Combretaceae) at different location in Africa is shown in figure 6. The observations origin from north (Ivory Coast) and south of the equator (Congo). Growth is bound to the wet season independently from the calendar month (Mariaux 1969).

**Fig. 6:** Growth responses of *Terminalia superba* to climate variation in Africa.
WOOD ANATOMY

The high species diversity in the tropics is reflected by the diversity in wood structural features. At microsections of the wood or at carefully prepared macro-sections of stem discs and core samples (see section sample collection and preparation) the principal dendrochronological analysis will be carried out. The knowledge of anatomical structures, cell types and it’s variation is a necessary prerequisite for tree ring analysis especially in the tropics. At the ring boundaries of tropical woods structures are to be find as they are common for wood from other climate zones, too.

The basis of all far leading investigations and interpretations is a precise description of the visible wood structure with it’s basic patterns and variations. The dendrochronological analysis however requires a useful classification without simplification. The following classification is based on the observations of Coster (1927) of 63 tropical and 22 from the temperate zones introduced woody species in Java. The scheme is modified by Worbes (1989) with additional observations from Neotropical floodplain and terra firme (non flooded) forests. The growth zones and it’s ring borders are characterised by:

- **Type 1: Density variations** occurring in tropical Gymnosperms as a unique feature and in broad leaf trees together with one or more of the following features. The anatomical background is the variation of fibre dimensions between early wood and late wood. Cell
wall thickness becomes greater and cell lumen becomes smaller from early- to late-wood (Annonaceae, Verbenaceae, Lauraceae and many other families, Fig 7a)

- **Type 2: Marginal parenchyma bands:** The most frequent and helpful feature is the occurrence of marginal parenchyma bands. The bands run around the entire cross section and consist usually only of one or few cell rows. Dünisch et al. (1999) show for Amazonian *Swietenia macrophylla* that the bands are formed readily before the cambial dormancy period and should named therfor a terminal band. (Annonacea, Bignonoceae, Leguminosae, Meliaceae a.o., fig. 7b)

- **Type 3: Tissue pattern:** The most complicated and frequently misinterpreted structure is to be found in Euphorbiaceae, Moraceae, Sapotaceae, Bignoniaceae and others. Rings are characterised by periodical patterns of parenchyma and fibre tissue. The bands usually become narrower towards the end of a growth zone (fig. 7c)

- **Type 4: Vessel distribution:** The ringporousness is widely distributed in the temperate zones but occurs only with few examples in the tropics (e.g. *Tectona grandis*, and some Meliaceae, fig. 7d). In the mangrove tree species *Rhizophora mangle* rings are distinguishable through periodically varying vessel density (Menezes et al. 2001)

Many species combine several of the four growth zone features. The structures at the growth zone boundaries principally indicate a cambial dormancy (Roth 1981) induced by increasing environmental stress factors (drought, flooding, freezing). A further differentiation of growth zone structure into 20-30 subdivisions is carried out by Carlquist (1988), but not useful for dendrochronological purposes.

In many cases the wood structure and the growth zone definition is not so clear as in these cases:

- Species with heartwood-formation often show distinct rings of dark substances. These rings were formed years after the wood formation and have nothing to do with annual rings, even when they are clear and distinct. This is obviously, when bands cross the wood structure (fig. 7c).
- Density variations within the annual rings point to climatic variations during the rainy season (fig. 7f,g). They are clearly visible in tropical Gymnosperms, but occur also in broad leaf species.
- In some cases clear rings cannot be matched with annual periodicity as in the case of *Quercus costaricensis* from mountain sites in Costa Rica (Worbes & Junk 1989). In the mountains climate is characterised bylow temperatures combined with relatively high precipitation. So severe dry periods do not occur every year but are in the mean biannually. Rings are formed consequently also every second year.
Fig. 11: Wood structure of *Pinus caribaea*, Pinaceae (Sao Paulo), *Tetramerinia bifoliolata*, Caesalpiniaeeae (Cameroon), *Piranhea trifoliata*, Euphorbiaceae (Amazon floodplain, Brazil) and *Tectona grandis*, Verbenaceae (historical wood sample from India). *Microberlinia*, Sclerobium sp., *Pinus caribaea*, *Quercus costaricensis*
THE PROOF OF ANNUAL TREE RING FORMATION

To proof the annual nature of any visible growth ring several independent methods exist:

- **Cambial wounding** (Mariaux 1967). The wounding (destruction) of a small cambial section (“Mariaux’s window”) results in a scar, soon covered by reaction wood. This scar remains in the wood and is visible after felling or coring the tree. The number of rings between the dated scars or between a scar and the outermost ring at the bark (date of felling) show in comparison with the number of years between the dates wether rings are annual in nature or not (fig. 7).

- **The Radiocarbon Dating** of single growth zones. On the base of the atomic weapon effect (the $^{14}$C-content in the atmosphere almost doubled between 1950 and 1964 in consequence of the 404 atomic bomb explosions in the atmosphere) single (isolated) growth zones can be dated by comparing their radiocarbon content with that of the atmosphere (Worbes & Junk 1989). Radiocarbon estimations can be carried out by using “Proportional Count Tubes” (which count the radioactive pulses) or Accelerator Mass Spectrometer (AMS) which directly measure the content of different isotopes. The latter enables the measurement of very small samples (below 500 mg) and provides a higher accuracy. This is necessary in most cases when individual tree rings must be dated. Precondition of an exact dating is the avoidance of contamination through foreign carbon sources as chain saw oil, fuel and others. Ideal is a chemical pre-treatment of the wood sample removing mobile substances which are formed earlier or later as the corresponding wood structure (Hua et al. 1999).
Climatological analysis of tree ring curves. The statistical comparison between measured tree ring curves and precipitation data (Berlage 1931). Individual ring curves where combined to a mean chronology for a species and a site. A concurring shape of annual climate (precipitation) curves and tree ring curves point to the existence of annual rings (Worbes 1995). Precondition of the analysis is a statistical trend removal of the tree ring curve resulting in an index ring curve. The values of index ring curves vary around zero and are normal distributed (as the climate values do). Trend removal is described in Schweingruber (1988) and various other sources. Curves may compared visually or better with tree ring statistics (Gleichläufigkeit, t-value, correlation: Schweingruber 1988).

The general observation is, that ring-widths are correlated positively with the amount of precipitation in the rainy season (Stahle et al. 1999, Worbes 1999) or in the transition months between the rainy and the dry season (Berlage 1931). The latter variable is a proxy for the length of the rainy season (= vegetation period).

In the floodplain forests of the great tropical streams like Amazon and it’s tributaries tree growth is related to the length of the flooding period ("flood pulse") resp. to the length of the flood free period. This may vary considerably in dependence of the climatic situation in different years in the catchment area of the Amazon. In years with high precipitation, when terra firme forest trees grow well, the flood period is comparably long and trees in the floodplains show only small increments.

One application of the climate analysis is the reconstruction of EL Nino-Southern oscillation effect in pre-instrumental record periods. The first who detected El Nino in tree rings was Berlage (1931). He constructed a chronology from teak on Java and showed a very strong relation between tree ring width and the length of the monsoon rainfall.
Fig. 9: The Java Teak-Chronology of Berlage (1931) in Jacoby (1989) shows the concurrence between tree ring width and precipitation. The periodical pattern of recurring minima and maxima reflects the influence of the El Nino-Southern Oscillation effect. Berlage was the first who detected El Nino in tree rings.
For many different reasons the deforestation in the tropics does not stop or lower down since many years. Annual deforestation rates are between 0.5% in Brazil and about 3% in Philippines. Deforestation hot spots in SEA (e.g. in Malaysia) are concentrated in regions with the highest forest cover, in SA at the margins of the Amazon basin. In total the annually deforested area in the tropics equals the forest area in Germany. There is strong evidence that the official figures published by FAO were surpassed by the real situation. In Brazil mainly the Amazon forest is affected by deforestation (2,000 of 2,500 km² nation wide annually). Additional 1,000 to 1,500 km² were damaged every year by logging activities and further areas are affected by extended surface fires, which usually are not documented and multiply the official figure of deforested area by 1.5 (Nepstad et al. 1999).

Deforestation is to be traced back to the following reasons (among others):

- Plantations (timber, oil palms, pulp production)
- Agricultural used area (migration programs Indonesia, Brazil etc.)
- Lakes through hydroelectric power plants, where huge areas were flooded
- More or less degraded areas through
  - Mining
  - Road constructions
  - Timber exploitation, what often is followed by other land use systems

### Tab. 1: Decrease of Forest Cover in the Tropics
All Data in 1000 Hectare, from FAO (1999) State of the World's Forests

<table>
<thead>
<tr>
<th>Land/Region</th>
<th>Forest Cover 1995</th>
<th>Annual Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central America</td>
<td>80.000</td>
<td>- 1.037</td>
</tr>
<tr>
<td>South America</td>
<td>830.000</td>
<td>- 4650</td>
</tr>
<tr>
<td>Oceania</td>
<td>41.000</td>
<td>- 151</td>
</tr>
<tr>
<td>SO Asia</td>
<td>280.000</td>
<td>- 3.000</td>
</tr>
<tr>
<td>Africa</td>
<td>504.000</td>
<td>- 3.600</td>
</tr>
<tr>
<td>Summ Tropics</td>
<td>1,735.000</td>
<td>- 12.438</td>
</tr>
<tr>
<td>Germany</td>
<td>10.740</td>
<td>0</td>
</tr>
</tbody>
</table>
In this situation the discussion raised up since the late 1970s to stop or decrease deforestation rates. Two contrasting ways for protection of tropical forests were discussed: The conservation through total protection in national parks vs. the preservation through silvicultural use. Different actors, motivations and problems are presented in table 2.

Main motivation for protection is the conservation of the enormous biodiversity and the concerns on global warming, if the carbon stock of the tropical forests is emitted to the atmosphere. Some figures to illustrate the biodiversity of the tropics are given in table 3.

Tab. 2: "Save the tropical rainforest"

<table>
<thead>
<tr>
<th>Path</th>
<th>Preservation through Protection</th>
<th>Preservation by silvicultural Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Action</strong></td>
<td>Demarcation of reserves</td>
<td>Sustainable forest management</td>
</tr>
<tr>
<td><strong>Groups of interest</strong></td>
<td>Indigenous population, local and international NGO’s</td>
<td>Wood industry, local producer, consumers</td>
</tr>
<tr>
<td><strong>Motivation</strong></td>
<td>Preservation of habitats, ethnic reasons, protection of world’s climate</td>
<td>Economic benefit, political circumstances</td>
</tr>
<tr>
<td><strong>Questions</strong></td>
<td>Who defends the borders? Who supports the reserves?</td>
<td>Is the maintenance of the ecosystem secured? Is an economical use possible?</td>
</tr>
</tbody>
</table>

It must be stated that biodiversity of higher plants are of course only one aspect. Especially in the crown region of tropical moist and mountain cloud forests additionally an enormous animal diversity is documented. The estimations speak of several million arthropods in the tropics (Adis 1990). It is important to consider that many of these species are restricted to relatively small areas (endemism) where the destruction of the habitat and the vegetation means the extinction of endemic species.

In total in the Neotropics occur around 80,000 vascular plants, in Central Europe only 3,000. Two thirds of the world wide 250,000 plant species are to be find in the tropics. In one of the most divers tropical forest in a lowland forest in eastern Ecuador 333 tree species were counted in two hectares (Balslev 1988). The total number of indigenous tree species on the British Islands is 35.
During the discussion on exploitation of the wood resources of tropical forests the demand raise to implement (again) sustainable management systems in the tropics. To ensure that tropical timber origin from sustainable management systems a certification of wood producing companies was developed and in many countries admitted. The principles of the certification were summarised to the Forest Stewardship Council. (see e.g. [http://www.fsc-deutschland.de](http://www.fsc-deutschland.de)). Main principles are given in table 4. Under point 7 many criteria and indicators which must be fulfilled are listed. One of them is the existence of a consistent management plan, where the estimation of the maximum allowable yield is one precondition. This is relatively unproblematic in the temperate zones on the background of long experience in sustainable forestry and huge databases on site conditions and growth of forests. In the tropics however the knowledge on growth of trees and forests is extraordinary poor. Estimations are time consuming, rare and expensive and usually available exclusively in the frame of long term research projects. So the estimation of the maximum allowable yield should be one of the key indicators for sustainability in tropical forests.

### Tab. 3: Plant Biodiversity in the tropics

<table>
<thead>
<tr>
<th>Country</th>
<th>Total diversity</th>
<th>Endemism</th>
<th>Endemism as % of global diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>~ 50,000 - 56,000</td>
<td>~16,500 - 18,500</td>
<td>6.6-7.4</td>
</tr>
<tr>
<td>Indonesia</td>
<td>~37,000</td>
<td>14,800 - 18,500</td>
<td>5.9-7.4</td>
</tr>
<tr>
<td>Colombia</td>
<td>45,000 - 51,000</td>
<td>15,000 - 17,000</td>
<td>6.0-6.8</td>
</tr>
<tr>
<td>Mexico</td>
<td>18,000 - 30,000</td>
<td>10,000 - 15,000</td>
<td>4.0-6.0</td>
</tr>
<tr>
<td>Australia</td>
<td>15,638</td>
<td>14,458</td>
<td>5.8</td>
</tr>
<tr>
<td>Madagascar</td>
<td>11,000 - 12,000</td>
<td>8,800 - 9,600</td>
<td>3.5-3.8</td>
</tr>
<tr>
<td>China</td>
<td>27,100 - 30,000</td>
<td>~10,000</td>
<td>~4.0</td>
</tr>
<tr>
<td>Philippines</td>
<td>8,000 - 12,000</td>
<td>3,800 - 6,000</td>
<td>1.5-2.4</td>
</tr>
<tr>
<td>India</td>
<td>&gt; 17,000</td>
<td>7,025 - 7,875</td>
<td>2.8-3.2</td>
</tr>
<tr>
<td>Peru</td>
<td>18,000 - 20,000</td>
<td>5,356</td>
<td>2.1</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>15,000 - 21,000</td>
<td>10,500 - 16,000</td>
<td>4.2-6.4</td>
</tr>
<tr>
<td>Equador</td>
<td>17,600 - 21,100</td>
<td>4,000 - 5,000</td>
<td>1.6-2.0</td>
</tr>
<tr>
<td>United States</td>
<td>18,956</td>
<td>4,036</td>
<td>1.6</td>
</tr>
<tr>
<td>Venezuela</td>
<td>15,000 - 21,070</td>
<td>5,000 - 8,000</td>
<td>2.0-3.2</td>
</tr>
<tr>
<td>Malaysia</td>
<td>15,000</td>
<td>6,500 - 8,000</td>
<td>2.6-3.2</td>
</tr>
<tr>
<td>South Africa</td>
<td>23,420</td>
<td>16,500</td>
<td>6.6</td>
</tr>
<tr>
<td>Dem.Rep. Congo</td>
<td>11,000</td>
<td>3,200</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Tab. 4: FSC’s Principles

1. Compliance with Laws and FSC Principles
2. Tenure and Use Rights and Responsibilities
3. Indigenous people’s Rights
4. Community Relations and Worker’s Rights
5. Benefits from the Forest
6. Environmental Impact
7. Management Plan
8. Monitoring and Assessment
9. Maintenance of High Conservation Value Forests
10. Plantations

Allowable Yield
The base for a allowable yield calculation is the measurement of annual increment related to an area usually one hectare or more of forest. The calculation needs a complete structural analysis with diameter and height of all trees (above 10cm DBH), number of individuals and species. Since for tropical tree species the bole form usually is not known, the volume of the bole is calculated as product of basal area and height divided by two. For a better comparison of productivity of species and sites the biomass and the biomass production is necessary. This requires the knowledge of the wood density of at least the main species either derived from tables or better measured directly. Density measurement can be performed on samples taken with a wood corer or on parts of stem discs. The exact volume must be measured and the sample must be oven dried. Age and increment estimations can be carried out with tree ring analysis, as described above, with core samples. In cases where the wood structure of new investigated species is unknown additional wood samples of stem discs or thick branches are valuable to clarify the nature, borders and shape of tree rings.

Then the annual aboveground wood biomass production ($AWBP$) can be calculated as follows:

$$AWBP = \frac{BA \cdot H \cdot SD}{A \cdot 2}$$

BA = Basal area (m$^2$)
H = Height (m)
SD = Specific Wood Density (g/cm$^3$)
A = Age (year)

The result is a measure for the mean production of a tree or a site estimated for long periods. This is reasonable since rotation periods and felling cycles assesses for at least 20 years.

In addition to the wood production losses during exploitation are to be regarded. Due to not appropriate exploitation methods losses in the tropics are high during a) felling, when a great proportion of the residual stand is damaged, b) skidding and transport, when stems remain long time in the forest etc. Only a certain proportion of the species can be used as timber. Bruenig (1996) amounts this to 40-80%. Especially in the Amazon region this proportion is usually lower. Finally the maximum allowable yield in a rough estimation using own data and Bruenig’s figures
(Tab.5) is under realistic conditions below 1 t/ha*yr that equals 1-2 cm³ timber. A comparison of different concessions in the tropics show that some lie under and some considerably above the yield which provide a long term sustainable use of the forest. (Tab.6).

**Tab 5.: Maximum allowable yield.**
Net primary production (NPP), aboveground biomass production, losses and maximum allowable yield and from general assumptions on productivity in the tropics (1Bruenig 1996), and from case studies in different forest types (2Biakoa, Cameroon and floodplain, Várzea, Brazil: Worbes 1997, Worbes et al. 2001, Worbes et al. in press). All figures in t/ha*yr.

<table>
<thead>
<tr>
<th></th>
<th>Pessimistic¹</th>
<th>Optimistic¹</th>
<th>Biakoa²</th>
<th>Várzea²</th>
<th>Várzea: 20% timber²</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPP</td>
<td>20</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(-) litter</td>
<td>10</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(-) crown/bark = stemwood</td>
<td>6</td>
<td>12</td>
<td>4,1</td>
<td>6,5</td>
<td></td>
</tr>
<tr>
<td>amount timber 40-80%</td>
<td>2,4</td>
<td>4,8</td>
<td>4,8</td>
<td>9,6</td>
<td>1,6</td>
</tr>
<tr>
<td>Losses exploit., transport ~50%</td>
<td>1,2</td>
<td>2,4</td>
<td>2,4</td>
<td>4,8</td>
<td>0,8</td>
</tr>
<tr>
<td>Maximum allowable yield</td>
<td>1,2</td>
<td>2,4</td>
<td>2,4</td>
<td>4,8</td>
<td>0,8</td>
</tr>
</tbody>
</table>

**Tab 6.: Annual yield** and additional features of different concessions and exploitation companies in the tropics: Size of the project, yearly managed area, yearly removed volume, cutting cycle and mean of removed volume (Worbes et al. 2001).

<table>
<thead>
<tr>
<th>Konzession, Projekt</th>
<th>Betriebsgröße (ha)</th>
<th>Erntefläche (ha)</th>
<th>Erntevolumen (m³/ha)</th>
<th>Nutzungzyklus (Jahre)</th>
<th>Durchschnittliche Holzentnahme m³/ha/Jahr</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT Indonesien Kalimantan*</td>
<td>601.750</td>
<td>13.000</td>
<td>57</td>
<td>35</td>
<td>1,6</td>
</tr>
<tr>
<td>North Queensland* Australien</td>
<td>160.000</td>
<td>3.000</td>
<td>20</td>
<td>40</td>
<td>0,5</td>
</tr>
<tr>
<td>Nigeria*</td>
<td>90.000</td>
<td>1.715</td>
<td>35</td>
<td>50</td>
<td>0,7</td>
</tr>
<tr>
<td>Celos Surinam* Indonesian</td>
<td>20.000</td>
<td>750</td>
<td>30</td>
<td>25</td>
<td>1,2</td>
</tr>
<tr>
<td>Mil Madeireira Brasilien (terra firme)</td>
<td>67.718</td>
<td>2.000</td>
<td>35-40</td>
<td>25</td>
<td>1,4</td>
</tr>
<tr>
<td>Gethal Brasilien (terra firme)</td>
<td>71.000</td>
<td>2.372</td>
<td>21-151</td>
<td>30</td>
<td>2,8 (0,7-5,0)</td>
</tr>
<tr>
<td>Gethal Brasilien (várzea)</td>
<td>43.000</td>
<td>1.445</td>
<td>37-78</td>
<td>30</td>
<td>1,7 (1,2-2,6)</td>
</tr>
<tr>
<td>RDSM, Brasilien</td>
<td>20.000</td>
<td>800</td>
<td>38</td>
<td>25</td>
<td>1,2</td>
</tr>
</tbody>
</table>
Figure 13: Time to reach the minimum logging diameter at 45 cm (dotted line) for different species in mature forest (right below) and early secondary (left above) of the Amazonian floodplains.

Fig. 14: Different growth strategy types in a natural mature forest in Biakoa, Cameroon.
This rough estimation points to the need for a more detailed analysis of tree and stand growth in managed forests. An example from the Amazonian floodplain forest is given in figure 12, where time is plotted against diameter in different species and at different sites. Pioneer trees grow faster than mature forest species, which show however much better wood quality (density). Under mature forest light conditions *Tabebuia barbata* grows slower than in a younger secondary forest. Different life strategy types of tree species are shown in figure 14. Species may survive in the understorey, grow slowly into the main canopy or do not have recruits as in the case of *Triplochiton scleroxylon*, Sterculiaceae. According to the classification of Hallé et al. (1976) this types also could be named as species of the present, the future and the past.

**OBJECTIVES OF THE COURSE**

**Lectures**
In several introducing lectures information will be given on
- Site conditions, climate and vegetation mainly in tropical South America
- History and development of tree ring research in the tropics
- Methods of tree ring analysis in the tropics
- Modern techniques of sample preparation and data measurements
- Forest growth and stand dynamics in the tropics

The results of different case studies of tropical forest research were presented during the week.

- The age of old grown tropical trees with special regards to the La Selva forest research station in Costa Rica
- Dynamics of a West African forest (Cameroon, Triplochiton scleroxylon-forest)
- The Forest Management in the Mamirauá-Project for Sustainable Development of an Amazonian flood plain region

In some additional lectures, hopefully prepared by interested students, far leading information on deforestation in the tropics, timber trade pathways and management systems for sustainable use of tropical forests will be presented.

**Practical course**
On wood samples from different locations in the tropics (mainly Costa Rica, Venezuela and Namibia) some small investigations can be carried out, further methods will be demonstrated.

The practical course will deal with the following objectives:

**Identification of wood species and characterisation of growth zones**

The base of all dendro-ecological work is the correct knowledge and identification of the wood species, the principle elements, the composition and the structure of the wood, it’s different species and the characterisation of the growth zones and its boundaries (Worbes 1989, Vetter &
Botosso 1989). Samples will be demonstrated from different taxa: (Pinaceae, Euphorbiaceae, Leguminosae, Moraceae, Myrtaceae, Verbenaceae, Sapotaceae, Rhizophoraceae). On behalf of image analysis a quantitative description of the wood structure shall be carried out.

Estimation of radial growth, dating of tree’s age and dendroclimatological investigations
From a natural forest stand in Namibia samples from Terminalia sericea, Combretaceae samples will be investigated. On the prepared wood samples the number of rings will be counted and the ring widths will be measured. Climatological data will be prepared for the comparison with increment curves. Tree ring curves will be standardised with special statistical tree ring programs. Statistical comparison between ring curves and climate data will be carried out (Fritts 1976, Schweingruber 1988).

STEPS OF ANALYSING (TROPICAL) TREE RINGS

1. HYPOTHESIS
   - Tree rings in the tropics are of annual nature
   - The wood structure of a species is genetically fixed
   - The wood structure is strongly influenced by external factors
   - The variation in annual precipitation is reflected by tree ring widths
   - Dynamical development is visible in tree ring patterns
   - Diameter and age of trees correlate significantly with each other
   - Understorey trees have small, emergents have large tree rings

2. SAMPLE AND DATA COLLECTION
   - Site description
     - Geographical position
     - Elevation of the site
     - Soil conditions
     - Vegetation type and structure
   - Sample origin
     - Tree species
     - Height of tree
     - DBH of tree
     - Tree (sample) number
   - Sampling
     - Coring (increment corer)
     - Cutting (discs)
     - Density measurement (Resistograph)
• Labelling of the sample with reference number

3. SAMPLE PREPARATION
• Anatomical slides
• Gluing core samples on supports
• Polishing
• Ultra-cutter
• Isolation of growth zones for radiocarbon datings

4. DATA MEASUREMENTS
• Macroscopical (and/or anatomical description)
• Image analysis
  - Vessel area and distribution
  - Density variations
• Predating of samples
• Radiocarbon datings
• Measuring ring width
  - Rough estimation („Skeleton Plot“)
  - Hand lens
  - Measuring device

5. DATA TREATMENT AND COMPARISON
• With measuring program TSAP or others
  - Cross dating
    * mathematical
    * optical
  - Indexing
  - Correlation with climate data
• Output from measuring program
  - Correlation with any statistical program
  - Graphical presentation (e.g. EXCEL)

6 INTERPRETATION OF THE RESULTS IN THE FRAME OF THE HYPOTHESIS

METHODS AND TECHNIQUES WHICH ARE REQUIRED AND WHICH WILL BE DEMONSTRATED, ORGANISATION OF THE COURSE

➢ Use of modern PC’s and knowledge of usual standard programs (Word, Excel, any Graphic-Program) is necessary.
Demonstration of sample preparation with a recently developed method.

- The use of microscopes, the tree-ring measurement devices, image analysis and statistical programs for the preparation of data will be demonstrated.

- All students will be involved in all points of the program. A short report will be carried out by every student but only on one or two of the topics, depending on the number of participants.

The time schedule is prepared as an extra sheet

References


