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La importancia de estrategias de regeneración y influencia anthropica por la expansión de bosques en el ecosistema del Bosque Montano del este de África - un modelo.

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The meaning of regeneration strategies and anthropogenic influence for the forest expansion in East African montane forest ecosystems - a modelling approach.

Abstract

During a two year field study the regenerations strategies of East African montane and submontane forests have been investigated. The compositions of growth forms and the floristic composition were recorded with the Relevée-method and with frequency analysis. From this data diversity indices were derived and completed by the point quarter method. These studies were carried out mainly on gaps, some data were collected from undisturbed forest patches. For a further classification of the disturbed patches the shadow distribution was measured with a data logger and an array of 16/32 light sensors. To measure the potential anthropogenic influence an energy survey was conducted. Interviews with the local communities shows how high the demand for products from the forest can be. This gained data shall be brought to a raster based model to simulate the changes of the forest expansion in time. With this model it will be possible to simulate the influence of human impact on the forest and to support the decision makers while making managing plans for forests in East Africa. With slide changes the model should be adaptable to other regions as well. Key Words: Regeneration Strategies, Modelling, Anthropgenic Influence

Resumen

Durante dos años de trabajo de campo se investigaron las estrategias de regeneración de bosques montanos y submontanos en el este de Afrecha. La composición florística y formas de crecimiento se registraron en releves con análisis de frecuencia. Para esta diversidad de datos de elaboran índices y se completo por el método point-quarter. Estos estudios se concentraron en claros del bosque, con unas parcelas no perturbadas como control. Para una clasificación futuro de perturbaciones la distribución de sombra ha sido medido con un logger de datos y 16/32 sensores para luz. Para medir el impacto antropico se conducía entrevistas para evaluar el uso de recursos para energía. Las entrevistas en comunidades locales indican una demanda muy alta por productos del bosque. Los datos se incorporaran en un modelo raster para simulación de los cambios en el bosque por el tiempo. Se puede simular también el impacto humano en el bosque. El modelo puede soportar los administradores en sus decisiones de manejo en el Este de África. Con pequeñas modificaciones se puede usar el modelo en otras regiones también. Palabras Clave: Estrategias de Regeneracion, Modelos, Influencia Antropica

Introduction

In the literature, regeneration of Forests is usually directly linked to a cycle from disturbance to maturity (Watt 1947; Whitmore 1989). It is widely accepted, that disturbances (gaps or openings) are one key factor for Biodiversity, especially concerning shade-intolerant species (sensu Whitmore). Without openings, their diversity would be noticeably diminished (Brokaw et al. 1989; Whitmore 1989). It can be assumed, that shade-intolerant tree species plays a key role in the expansion of the forest, because they have the ability to form a forest at the edge of the forest. In this way, they create the conditions for the establishment of a forest of climax tree species (sensu Whitmore).
Since the 1980’s much work has concentrated on gap ecology. Most studies were conducted in South America and South East Asia as well as in North America. Based on these results, the hypothesis is made, that the basic strategies of forest regeneration are applicable on all latitudes, and therefore in all forests. (Runkle 1989). One missing factor in these studies is the influence of human activities, because most studies are carried out under natural conditions. This means, in this context, without anthropogenic influences. In reality, anthropogenic influences in forests are hardly negligible, especially in equatorial countries, with the highest extension of highly divers rain forests. These forest communities represent the most vulnerable forest type, and are also believed to be the

key factor for climate regulation. These forests are also one of the major economic resources of tropical countries (Amelung 1992). Timber extraction, however lead to a vast deforestation in the last two decades, and left huge areas of damaged or degraded land (ITTO 2002). Human beings are an underestimated factor in forest regeneration. For these reasons, it is of paramount importance to take this most important factor for determining forest expansion, especially in tropical countries, into account.
For Kakamega, an East African Montane Forest, the paradigm of gap phase regeneration is applied and combined with the influence of human activities. The severity of human activities is part of the regeneration mechanism. The need to recognize human beings as an important factor in the regeneration cycle, and as part of the ecosystem, is evident. Moreover, there are mainly remnants of forests left, which are under high pressure, in particular in highly populated areas. A modeling approach seems to be a necessary step to manage these observations.

Materials and Methods

The Study Area
Kakamega Forest, situated in the Western Province of Kenya, close to the Ugandan border, is believed to be the easternmost remnant of the Guineo-Congolian rain forest belt stretching from West Africa to as far as Uganda (Kokwaro 1988; KWS, 1994). It can also be seen as a transition zone between lowland rain forests of the Guineo-Congolian type and the highland Afromontane forests, containing species of both regimes (KIFCON, 1994). Kakamega forest lies at altitudes of 1500 to 1700 m on a mainly flat to slightly undulating terrain. With high variations in rainfall, it covers all ranges from semi deciduous to moist rain forest (1325 mm (Chapman et al. 1996) to 3500mm (Tsingalia 1988)).
Kakamega forest was gazetted with 19.792 ha in 1933 (personal communication with forest department). Actual estimates of its extension amount to 13,900 ha (Mutangah 1996).
Kakamega District is one of the areas with the highest population density of Kenya, with 369 p/km2 (Ministry of Finance and Planning 1996).
In 1967, northern parts of the forest were transformed into a National Reserve under the management of the Kenya Wildlife Service, while the rest stayed as Nature Reserve under the management of the Forest Department. The forest is surrounded by approximately 70 settlements (KIFCON 1994; Mutangah 1996).
Methodology
To obtain the necessary data, vegetation analytical methods, as well as questionnaires to get data for the socio-economic, respectively anthropogenic, aspects, where used.
Lieberman et al. (1989) formulated an approach to consider a finer scale for categorizing gaps, than the usual approach of gaps and none-gaps. According to this source, a gap should be considered rather as a point on a continuum of different shadiness while variation in canopy composition and foliage provide different shade conditions. Therefore the "dendrocentric" approach seems to be a reasonable paradigm for further research in the field of regeneration (Lieberman et al. 1989).
The frequency-analyzing methods were found to meet the demanded tasks best by slightly changing this method to describe not only the vegetation composition, but also the regeneration mechanisms concerning the dendrocentric approach by arranging it circularly around certain trees in the circular frequency analysis.
Circular Frequency Analysis
Certain tree species were chosen for these observations. *Funtumia africana* and *Polyscias fulva* can be considered as typical pioneer species, while *Croton spec.* and*Olea capensis* are species from the early and mature climax phases. In addition the same survey was conducted on Gaps.
On small square plots of 2 x 2 m all tree seedlings (offspring < 10 cm height) were counted (Figure 1). 52 Plots were arranged around each tree base stand. The Plots were arranged on a line perpendicular to the base stand of the trees towards the 8 compass directions (N, NE, E, SE, S, SW, W, NW). On every line the plots were placed 2 m from each other, beginning 2 m from the tree base stand.

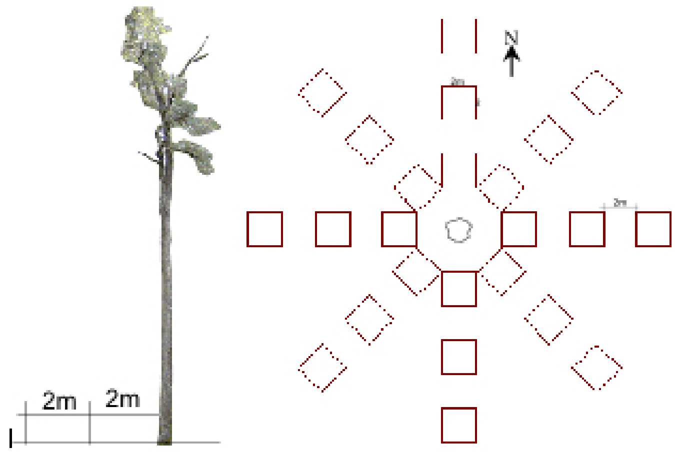

Figure 1. Circular Frequency Analysis, plot design
Figura 1. Analisis de frequencia circular, diseno de las parcelas

Point Quarter Sampling

The Point Quarter Sampling provides a broad variety of useful information about stand structure. Apart from structural parameters diversity indices can be derived. For this study we concentrated on the Relative Frequency (RF) and the Importance Value Index (IVI) of the tree species, in addition to the Shannon Index for diversity.

The Point Quarter Sampling was conducted on 200 m transect lines. The start point of the transect was chosen arbitrarily, by choosing the most homogenous part of the forest. From this point towards the direction of most homogeneity the survey was conducted on sample points with a randomly chosen distance from each other. Randomly chosen distances were collected from random numbers between 1 and 10 multiplied by 2. Multiplication was used to avoid too close sample points. From each point DBH as well as distance from the point for the closest standing trees, in each quadrant of an imaginary circle around the sample point, with DBH >5 cm were measured. Double measured records were marked. The survey ended with the last distance >195 m from the starting point.

Analytical Methods

To describe the regeneration mechanisms, the relative frequencies and densities were calculated from the resulting data. Additionally a diversity index (Shannon-index) was calculated. For a direct comparison of sites the Importance Value Index was calculated. The application of the IVI-calculation for the circular frequency analysis has been changed slightly because the calculation of the basal area and density was not applicable. Therefore the calculation of the Importance Value Index (IVI) for the seedlings was slightly adjusted to the data.

Energy Survey

The probability of getting reliable data drops, when asking people for possibly illegal activities. Therefore this survey was carried out by a local counterpart, in the homes of the people. Moreover the questionnaires used for the survey were written in the mother tongue of the people, so that everybody could read or fill in the questionnaires himself. The Questions were limited to the construction manner of the house and fencing, and the daily, weekly or monthly demand for different energy resources. And information about who is responsible for the procurement of each resource used. For this study, the amount and kind of resource used have been deducted directly from a quantitative analysis of the answers.

Results

Mainly small gaps occur in the sample area, seldomly exceeding an extension of more than 600 m2. Therefore the micro-mosaic approach and the dendrocentric paradigm are a good strategy for a survey of the mentioned area.

Regeneration survey

The results of the circular frequency analysis are shown in (Figure 2). The IVI for 25 most important seedling species depending on the sampled tree is plotted. *Olea capensis ssp. welwitschii* and *Croton megalocarpus* are typical climax species, although *C. megalocarpus* seems to be a transitional species from the secondary to climax phase. *Polyscias fulva* and *Funtumia africana* are considered to be pioneer species, whereas *P. fulva* demands bigger gaps with a higher amount of light than *F. africana*. So far in none of the Gaps a seedling or either sapling of *P. fulva* was recorded. As can be seen in (Figure 3) and (Figure 5).

P. fulva appears to be an important tree in the secondary forest, but in the seedling context it has no importance.

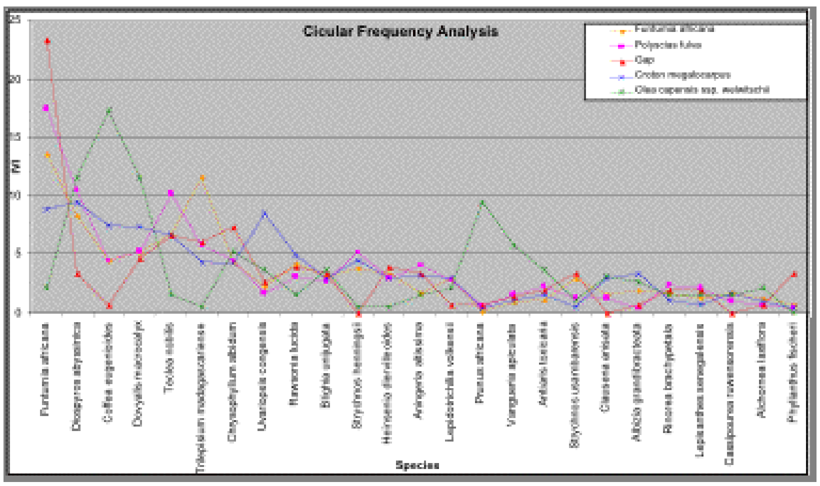

Figure 2. Importance Value Index of 25 most important seedling Species per plot (n=52)
Figura 2. Indice de Valor Importancia de los 25 germinantes mas importantes por parcela (n=52)

Comparing the records from the climax vegetation plots (*C. megalocarpus* and *O. capensis ssp. welwitschii*) with the secondary vegetation plots (*F. africana* and *C. megalocarpus*) the graph shows a clear opposite tendency of the importance of seedling species. *F. africana* seedlings play a major role in the regeneration of open areas and secondary regimes, whereas their role in the climax phases is only minor (the same is valid for *Trilepisum madagascariensis* and *Strychnos heningsii*, but these species belong to the later building phase of the forest). In contrast, seedlings of *Diospyros abyssinica*, *Uvariopsis congensis* and *Prunus africana*. appear in high importance under climax species, and show least importance in secondary regimes and in openings.

(Figure 3) shows the 25 most important species for regeneration, with regard to seedling establishment. Compared to the stand structure only *F. africana*, *T. nobilis* and *D. abyssinica* have a high regeneration success..

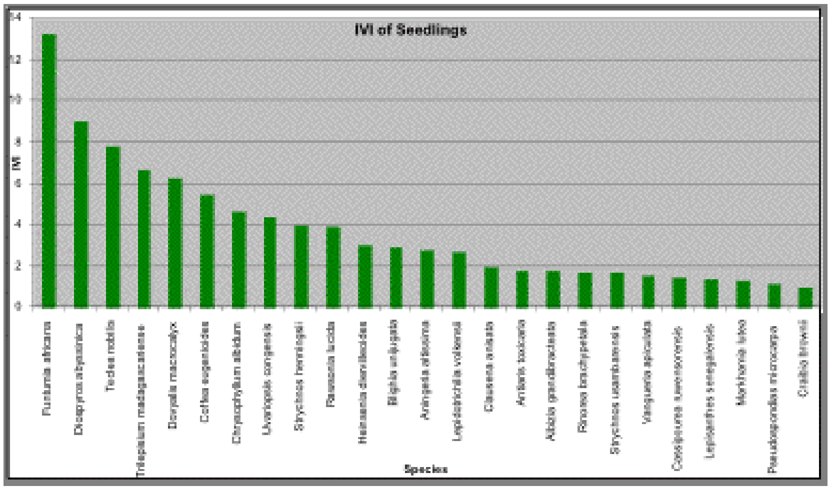

Figure 3. Importance Value Index of 25 most important seedling species from all plots (n=52)
Figura 3. Indice de Valor Importancia de los 25 especies de germinantes mas importantes de todas las parcela (n=52).

Concerning the regeneration structure of the different sampled regimes, (Figure 4) shows, that highest species numbers and therefore highest diversity occurs in the building phase. Openings and climax forest provide a lower diversity.

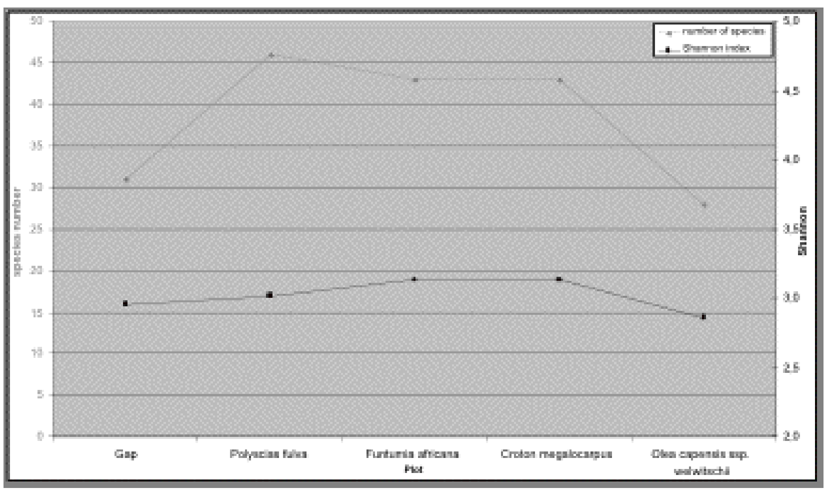

Figure 4. a) max. number of species of sampled plots; b) Shannon index of sampled plots (n=52)
Figura 4. a) numero maximo de especies in las parcelas; b) Indice Shannon por parcelas (n=52)

Vegetation Survey (Figure 5)

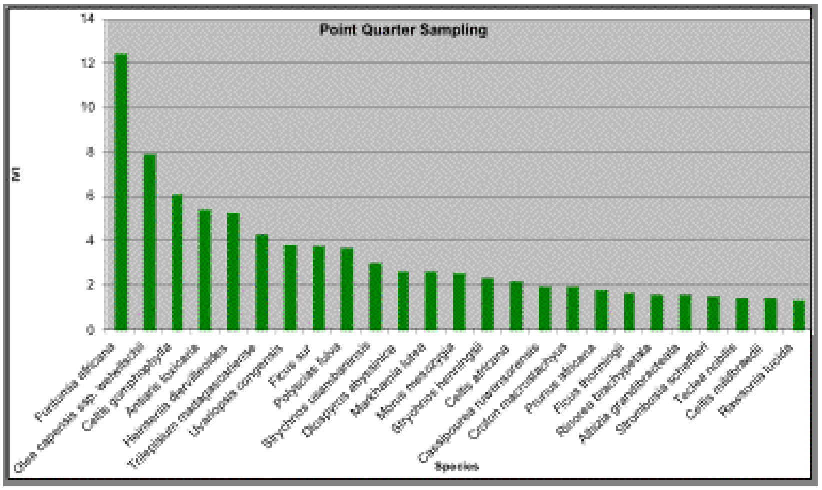

Figure 5. Importance Value Index of 25 most important tree Species of the sample area (n=140)
Figura 5. Indice de Valor Importancia de los 25 especies de arboles mas importantes en el area de estudio (n=107).

The stand structure of the sampled area gives a good picture of the claimed mosaic structure. The highest importance values are shared by pioneer as well as climax species. The highest Frequencies are reached by *F. africana*, followed by three climax species, namely *O. capensis ssp. welwitschii, Celtis gomphophylla, Heinsenia diervilleoides* (the latter a tree from the lower strata), and *Antiaris toxicaria*. Energy Survey (Figure 6)

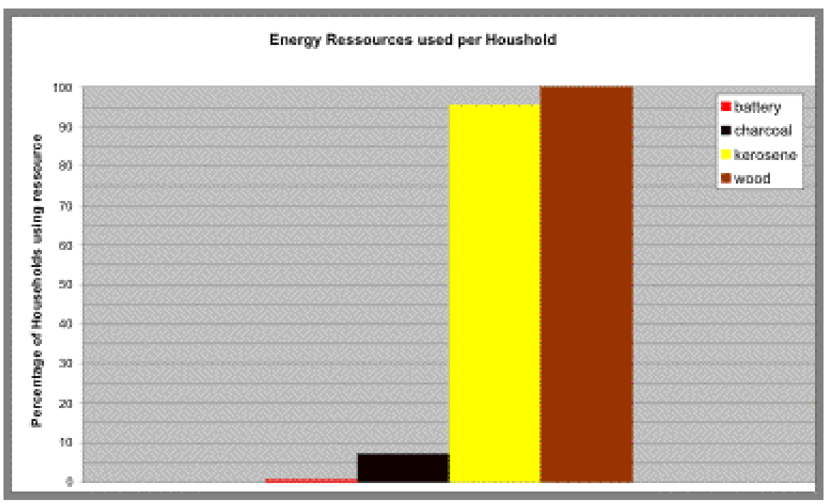

Figure 6. Resources demand
Figura 6. Demanda por recursos

The conducted questionnaire survey shows a very clear picture of the demands of the local people. Wood is used in 100% of the households, mainly for cooking purposes. A similar distribution has kerosene which is used mainly to provide light, but also sometimes for cooking. Charcoal plays a very minor role. Electricity and gas are not used at all, save for one household, which was using a battery.

Discussion

This study shows all known characteristics of the gap phase regeneration paradigm which was established in the mid of the 1980's. It can be concluded, that the sampling area follows these strategies, and moreover, the strategies, which certain species follow, can be indicated. The general mechanism how forest re-growth is initiated and runs can be deducted from the vegetation survey. In early literature there was a common sense, that regeneration follows a cycle of destruction rebuild and maturing (Watt 1947). Based on this, the authors developed the paradigm of the gap phase regeneration in the 1980's (Runkle 1989; Whitmore 1989). They claimed, that gaps are one of the most important factors causing diversity. Whitmore introduced the model of pioneer (or shade-intolerant) and climax (shade tolerant) species. While the climax species can regenerate on a wide range of ecological conditions, and pioneers are restricted to optimal conditions, in this context suitable light conditions. Runkle (1989) claims that the strategy of regeneration is the same on all latitudes, and that there are only differences in characterizing gaps. Lieberman et al. (1989) expanded this when they described their dendrocentric paradigm of a continuum from open to closed canopy, where even leaf shedding contributes to the gap phase regeneration cycle (Lieberman et al. 1989). It is proved, that species, which settled their offspring before or immediately after an opening of the canopy, have the highest regeneration success. The final success is determined, at least for the shade intolerant species, by the width of the opening, and therefore by the availability of light. Sometimes also their germination success depends on a high illumination (Canham 1989). Apart from light as a key factor for regeneration there are other parameters influencing establishment and regeneration success. Microclimate, edaphic and topographic factors, nutrients as well as allelopathic interactions and protecting structures play also a role for a successful upcoming of offspring. Especially gaps (sensu Watt 1980) provide these factors in a wide range and a high variation on the micro scale, e.g. an uprooted tree, high heterogeneity of the vegetation, tree debris, and so on. This provides different microclimatic conditions and protecting structures, with delivery of nutrients at the same time (Heinemann 2000). Taking all these factors into account led eventually to the conclusion of the theory of "Wounds in the Forest" (pers. obs.). Regeneration happens continuously, not only in big openings. The offspring of climax species persists for years in the shadow of the secondary canopy, waiting for suitable conditions, until the canopy degenerates and enables the upcoming plants to close the fissure. These fissures can be broader - the so-called gaps. It can be observed, that gaps behave like wounds, if we abstract the forest to a tissue. Usually the conditions in a forest provide growth of the typical plants of a given vegetation regime. In this way, a scar-less regeneration can happen. If the conditions are drastically changed, by opening the canopy widely, like a wound, there are new conditions. A thin layer, or crust, to cover the sensitive tissue, first covers the wound. The fallow will soon be covered by herbaceous plants, in the case of the sampling area mainly creepers. Where are the similarities? The crust prevents the tissue from drying out, so to say, to establish suitable microclimatic conditions. In the next stage Growth starts laterally where best climatic and nutrition conditions rule. In a small opening the lateral growth will soon establish conditions that allow mainly shade tolerant species to mature. Regeneration succeeds without scar. Bigger openings are different. The crust stage endures longer and a thicker crust develops. The latter is mainly composed from bigger herbs or shrubby vegetation. This provides lighter conditions, and is thus different from the first stage, because there are less ground covering plants. This enables the germination of pioneer species, if they were not already established before. A different vegetation composition can take place and forms as scar, which appears later on as mosaic brick in the canopy coverage. The larger the gap the more persistent the scar the higher the diversity (- as well as -diversity).

The application of these conclusions for the formulated question of this study leads to similarities of the expansion mechanisms and regeneration strategies, and their influence on these sequences. The latter is intrinsic and already mentioned. The anthropogenic influence is the most severe factor affecting nature and forests in particular. If we claim, that on the edges of the forest the same mechanisms as in gaps work, we can consider expansion of forest as closing of the big surrounding gap. Regarding the gap as a wound, the big surrounding gap is also the most sensitive part of regeneration and at the same time the most exposed part of the forest to human activities. Protection of the forest would claim protection of the vulnerable parts of the forest and use of the capable parts.

Because of the long time regeneration takes, and considering the fact, that most of the findings about regeneration come from human excluded observations, we suggest to bring the known facts together with newly collected socio-economic data in a modeling approach, to provide suitable management strategies.

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