BIOTA

Biodiversity Monitoring Transect Analysis in Africa

BIOTA East Africa

Biodiversity in conversion

The influence of fragmentation and disturbance on the biodiversity of East African highland rain forests

An interdisciplinary project of

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BIOTA East Africa
Final Report Phase I

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Synthesis of Phase I

1. Introduction

Changes of the environment happen naturally, but mostly occur faster and are of greater magnitude with human activity. East African rain forests are among the most threatened and least explored ecosystems on earth, largely suffering from over-exploitation by humans. BIOTA East Africa links a set of thematically and geographically strictly co-ordinated analyses of biodiversity conversion in East African highland rainforests. Analyses of biodiversity and its change were carried out mainly at Kakamega forest, Kenya. The research area represents the eastern-most branch of the Guineo-Congolian rainforest block and has protection status as National Forest Reserve. It includes both primary and secondary rain forest, as well as several isolated fragments. It is perfectly suited to conduct comparative analyses of biodiversity within the mentioned habitat types. Principal goal was the establishment of biodiversity observatories for long-term monitoring, mainly of the effects of man-made changes in biodiversity. To achieve this aim, significant interfaces of the trophic network of the tropical rainforest and its replacement communities have been critically selected: diversity of coprophagous beetles, Odonata, and Lepidoptera, decline in anurans, exchange of atmospheric compounds, plant-pollinator systems, forest fragmentation and seed dispersal, and regeneration of tree species. The use of modern remote sensing techniques and the collection of local and historical information on environmental change was used to establish a local information system. As a result, we expected a better understanding of the complex consequences of changes on the different hierarchical levels resulting from degradation and fragmentation, especially at the level of critical trophic and reproductive interfaces.

In summary the goals of BIOTA East Africa were defined as follows:

- Establishing biodiversity observatories for long-term observations of changes in biodiversity
- Establishing a GIS based reference system
- Analysis of climatic and microclimatic changes
- Measuring biodiversity: structural characters and spatial patterns
- Investigation of important ecosystem interfaces: exchange of atmospheric compounds, pollination and seed dispersal, forest regeneration, vegetation/consuments, etc.
- Analysing human impact and changes in biodiversity
- Capacity building at East African counterpart institutions

2. Results

Unless otherwise mentioned, the data presented in the following all result from own research during the first phase of BIOTA East Africa. For a synthesis of the results of the subprojects working in southern Arabia, please refer to the respective section.

2.1 Methodological approach

Establishment of biodiversity observatories along two independent gradients

Since BIOTA East Africa is aimed at the investigation of the influence of forest fragmentation and disturbance on biodiversity, ten biodiversity observatories (BDO's) were established covering the main forest and five forest fragments as well as different disturbance regimes (Colobus, Buyangu, Salazar, Isecheno I, Isecheno II, Yala, Ikuywa, Malava, Kisere and Kaimosi, see Fig. 1). Satellite data were used for quantifying fragmentation patterns and surface parameters. As exact GPS measurements for plot positions within rainforests are rather the exception than the rule, for georeferencing of the observation plots also measurements or readings by tape measure, laser meter as well as by compass were used to set the position and pattern of plots by means of ruler and pencil on a piece of paper before transfering the scetches based on UTM coordinates into GIS datasets. A GIS platform was established for integration of the diverse data sets obtained by the different subprojects. Subproject studies mainly concentrated on plots within the observatories using comparable and standardised methodology.

2.2 Current status of the Kakamega Forest ecosystem

Number and size of fragments

The Kakamega Forest area contains five main forest fragments and a larger main forest area. Some of the fragments may consist of several patches (e.g., Malava). An analysis derived from a visual interpretation and on-screen digitising based on the contrast-enhanced Landsat scene of 05 February 2001 visualised as band combination 5/4/3 revealed the following data for "indigenous forest cover" (a class most similar to but not matching with the class "near natural + old secondary forest" as derived via the supervised multispectral classification of the Landsat time series data, i.e. especially for Malava and Kisere Forest also "secondary forest" is included):

Fragment	*Size*
Kakamega main forest	8,537 ha
Ikuywa	1,370 ha
Yala	1,199 ha
Kisere	420 ha
Malava	190 ha
Kaimosi	132 ha

For comparison, the official forest boundaries gazetted in 1933 for the Kakamega Forest area provide the following sizes: Kakamega Forest – 23,632 ha (at that time including Ikuywa and Yala); Malava Forest – 703 ha; Kisere Forest – 458 ha.

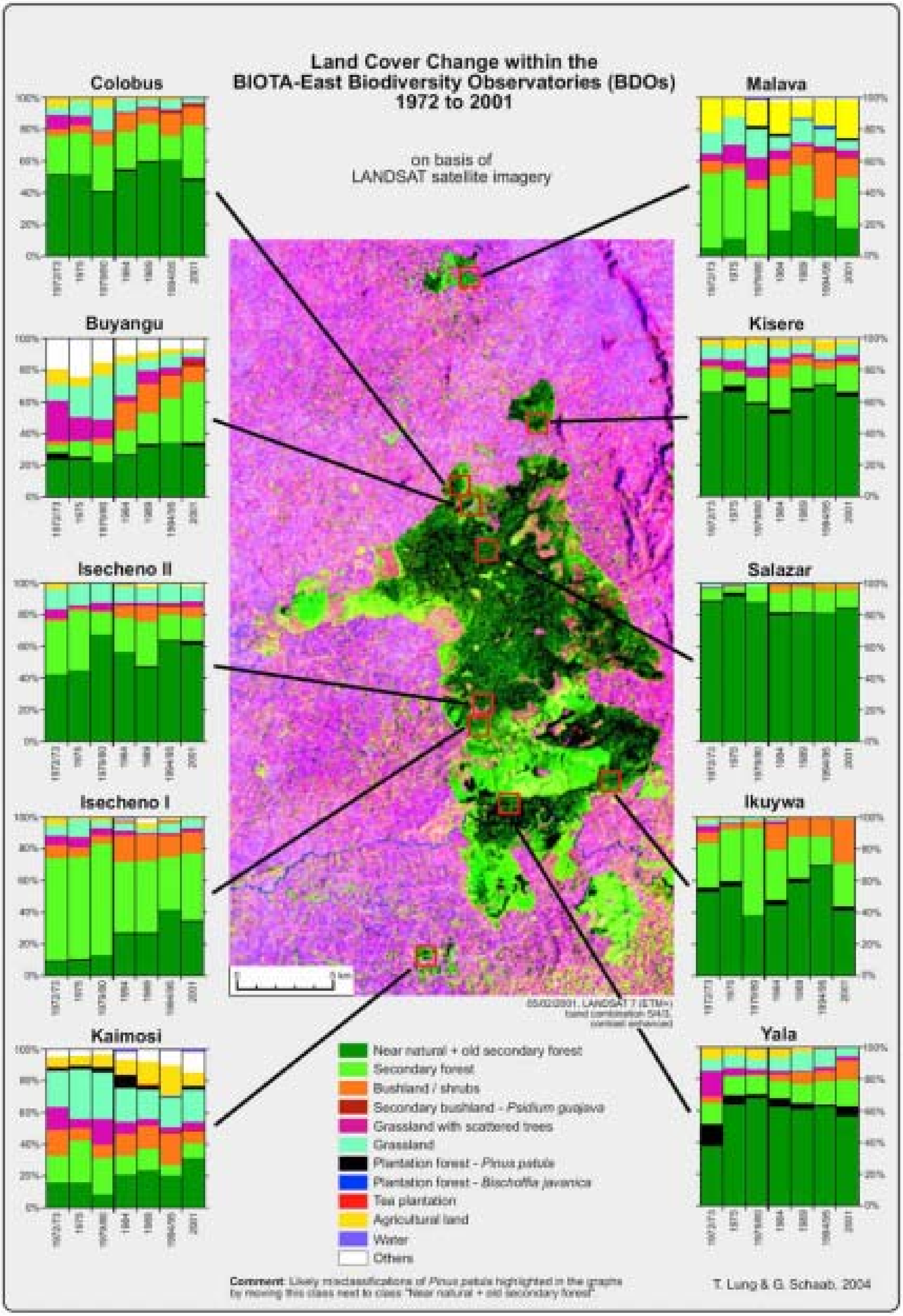

Fig. 1. Land cover change within the BIOTA East Africa biodiversity observatories in seven time steps from 1972 to 2001.

Status of different parts of the forest

From 1933 to 1986, Kakamega Forest was under management by the Forest Department and the number of trees logged more than 20 years ago was equally high at all sites. Since 1986, Kakamega Forest was managed by two different organisations, i.e. Forest Department and Kenya Wildlife Service. The northern National Reserve, including the Kisere Forest and the Buyangu area is managed by the Kenya Wildlife Service (KWS) and is 4,270 ha in size. The southern areas, including Isecheno Nature Reserve and Yala Nature Reserve, are managed by the Forest Department and are 295 ha and 460 ha in size, respectively.

Climate and microclimate

At our meteorological station near the KWS office in the northern part of the Kakamega Forest the mean annual precipitation amounted to 1500 mm/m^2. Single rainfall events showed a half-hourly mean value of up to 25 mm/m^2. Most of the rain events occurred in the months April to July and October/November. Daytime temperatures amounted to 32 °C in February whereas in the night the temperatures may drop to 9 °C. The yearly mean temperature was 20 ∂ 4.8 °C in 2002. The annual mean solar energy input was about 1000 W/m^2 with a photon flux density in photosynthetic active radiation (PPFD) of about 1900 $\mu mol/m^2/s^1$. Land surface temperature calculated from MODIS satellite data revealed that the forested area is about 5 to 10 °C cooler compared to the surrounding area, highlighting the cooling properties of forested areas in this landscape.

Soils

Soils of the Kakamega Forest are deeply weathered, poor to moderate in their nutrient content and partly acidic. According to the Reconnaissance Soil Map of the Lake Basin Development Authority Area, Western Kenya, 1:250'000 (1985) the following soil types are found within the BDOs: rhodic ferralsols at Malava, ferralo-humic acrisols at Kisere, ferralo-orthic acrisols + nitro-rhodic ferralsols at Colobus, Buyangu, Salazar, Isecheno I and II, ferralo-orthic acrisols at Ikuywa, Yala and Kaimosi. The soil carbon and nitrogen stock amounts to 33 g (C)/kg and 3 g (N)/kg, respectively. Plant growth may be restricted due to low calcium content especially in Kaimosi. The leaf litter fraction on the soil is calculated to amount to 8.6 t/ha.

Plant diversity

Kakamega Forest is a unique mixture of Guineo-Congolean and afromontane species with most of the Guineo-Congolian species reaching their easternmost distribution limit. A comparison of the recorded trees, shrubs and lianas shows that about 41 % of all species also occur in the Congo-basin and about 33 % are of afromontane origin. About 26 % of the species could not be assessed (transitional species). In total, 397 species of vascular plants were found in Kakamega Forest. Among them are several new records for the area: 16 tree and shrub species were recorded for the first time from Kakamega Forest, one orchid species is a new record for Kenya, one *Renealmia* is new to science. Fifty species of foliicolous bryophytes and 56 species of foliicolous lichens were recorded from the area. Among them an *Echinoplaca* represents a species new to science. *Dimerella flava*, recently described from New Zealand, is the first record for Africa. About nine species of *Pertusaria* (corticolous lichens) are new to science. About 229 morphospecies of bryophytes could be distinguished, among them 92 mosses and 132 liverworts. The Lejeuneaceae are represented by 57 species. Further species-rich genera are *Plagiochila* and *Frullania*.

In the young forest stages tree species like *Harungana madagascariense* and *Bridelia micrantha* are very abundant and characteristic for this initial phase. The tree height is about 10 to 12 m. In the undergrowth climax species from early stages can be found (e.g. *Funtumia africana*). Shrubs like *Acanthus pubescens* and climbers like *Smilax anceps* or *Dregea abyssinica* are dominant. Middle-aged forest, that has only been selectively logged is the most abundant forest type in Kakamega. The patterns in species composition are due to the different logging history and regeneration period.

Animal diversity

The birdlife of the Kakamega Forest is a unique combination of central African lowland and highland species. With 357 species recorded, richness is very high (U. Savalli, pers. comm.). Furthermore, at least 45 of the species on the Kenya list are to be found only in the Kakamega Forest. It is the last refuge in Kenya of the Grey Parrot (*Psittacus erithacus erithacus*) which is present in very low numbers (probably fewer than 10 individuals) and is close to being extirpated (locally extinct). Two other species, Turner's Eremomela (*Eremomela turneri*) and Chapin's Flycatcher (*Muscicapa lendu*), are globally threatened and a further 15 species are regionally-threatened. Kakamega Forest has the status of an Important Bird Area (IBA).

With respect to amphibians, Kakamega Forest ranges among the most species rich areas in Kenya, with 27 species currently recorded (some of which are only known from the Kakamega Forest and may be local endemics). Four species are expected to represent unnamed taxa (identifiable e.g. through bioacoustics and DNA taxonomy). Most of the species show little specialisation and are terrestrial or arboreal, nocturnal and reproduce seasonally in lentic water with exotrophic larvae.

The insect fauna of the Kakamega Forest is exceptionally rich. Concerning bees (Apidae), an important group of pollinators, more than 190 species were recognised so far during the study, some of which are new to science. Bee species diversity is highest in open farm- and bushland, and lowest in near natural forests.

A slightly different pattern is exhibited by the Lepidoptera. A total of 515 species of butterflies (Papilionoidea and Hesperioidea) were reported for the entire Kakamega Forest, with up to 54 additional butterfly species possibly present in the area. With this remarkably high species count representing almost 60% of the total butterfly fauna of Kenya, the area clearly represents a regional diversity hotspot for Lepidoptera, which also entails special conservation value. Among the butterfly species recorded for Kakamega there are more than five new records for the country, and at least one species new to science. For certain butterfly families, between 20 – 40% of the species recorded are characteristically bound to natural forests. High levels of species diversity could also be demonstrated for six families of moths (Lasiocampidae, Saturniidae, Sphingidae, Lymantriidae, Notodontidae), which yield a count of 342 different species recorded and identified so far. For most moth groups, however, the lack of basic taxonomic and faunistic information is more profound and impedes further data analysis. For just one genus of Tiger Moth (*Asura* Walker, 1854), for example, from 12 species recorded for Kakamega five appear to be new records for Kenya, and at least two new to science.

A pattern equivalent to the Lepidoptera could be demonstrated for dung beetles. Their species richness is highest in near-natural forests or a mosaic of primary and secondary forests formations. However, the dung beetle abundance is much higher in disturbed secondary forest.

A total number of 71 dragonfly species were recorded from the Kakamega Forest, of which 21 species are of regional importance for Kenya. However, compared to more western Guineo-Congolian rainforest areas the dragonfly fauna of the Kakamega Forest is impoverished.

Preliminary inventory work undertaken for two other insect orders yielded records for 33 species of Orthoptera (= about 30% of Kenyan total) and 7 species of Dermaptera including two species new for the country. These still preliminary data also point to insufficient available baseline information for further ecosystem studies, and the need to continue and complete inventory work in the study area.

Surrounding population and landuse

Processing of the 1999 population data set is not yet finished (aggregated for the sublocation level), but see comments on population numbers in last paragraph of “historical change” section.

The land surrounding the forest is now intensively farmed with almost no permanent grassland or forest patches surviving. Human population and subsequent pressure on the land is greatest on the western side where consequently the average size of farm units is now much reduced and the fertility of the soils is readily exhausted. In the surrounding areas, soil properties have changed dramatically. The soil organic carbon and nitrogen was reduced by 30% and 50%, respectively. The litter on cultivated soil dropped one order of magnitude (a factor of 10).

Maize and beans and a variety of vegetables are grown all around the forest as staples of the Luhya people’s diet and steady rainfall throughout most of the year results in two or three vegetable harvests in a single year. Tea plantations have thrived in the southern part of the forest and have been successfully established in a margin adjacent to the forest and between Kakamega and South Nandi Forests. The northern edge of Kakamega Forest is bordered by the sugar cane zone which now represents a considerable cash crop to local landowners.

An extensive field survey on the impact of cultivation on forest soil quality revealed that cultivation of forest soils in the Kakamega area led to a dramatic change in soil properties within 25 to 60 years. As a result maize plants in cultivation have to built up a larger root system in historically converted soils but thus suffer from nutrient and water limitation indicated by low chlorophyll content in the leave. In consequence the productivity of the maize plants is also reduced.

2.3 Land-cover changes in the Kakamega Forest area

Historical change

Historical research has revealed that the area to the west and the south of Kakamega Forest had been forest in former times. The area to the north and east has almost certainly been grassland in recent centuries and there is some evidence to suggest forest expansion in some areas. Both forest and grassland have given way to agriculture with the migration of the Luhya people.

Reduction in forest cover within the forest boundaries was traced through government archives which show sawmills operating in the forest since the 1930s. Selective logging was more commonly practised in the northern half of the forest and contrasts with the often clearfelling methods used in the southern half which is consequently characterised by fragmentation and loss of overall forest cover. The Yala Nature Reserve has, for instance, been rendered a virtual island of indigenous forest. Records of the different sawmills have in some cases enabled a characterisation, by tree species, of the human alteration of the forest at the different BDOs. Although they have been exploited on a local basis for pitsawing, it has been possible to establish Isecheno II, Yala and Kisere BDO as being untouched by large-scale logging. By contrast, the other BDOs have all suffered serious timber cutting at least once since the 1930s. In most cases clear-felled areas were assigned for reforestation with various combinations of exotic softwoods and indigenous hardwoods.

Human population figures are difficult to compare across the years due to differing methods of calculation but 1918 figures suggest an average of 390 people/km^2 for the area now covered by Kakamega District. This compares with 713 people/km^2 as recorded in 1991 for the thirteen sub-locations adjacent to the forest. Great increase in population around the forest is easily detectable in the historical record and is a major cause for pressure on the forest resources.

Time series

We compiled the data for land cover changes within the ten BDOs for seven time steps between 1972 and 2001 (see Fig. 1). A summary of the results reveals the following statements:

Malava Forest consists today of two fragments. Until 1980 a decrease in near-natural forest and secondary forest can be noticed with a total loss of the most northern part. Afterwards, until the middle of the 1980s, first the large agricultural fields disappear. Instead, forest plantations (*Bischoffia*) and bushed areas can be observed. At the same time new forest plantations in that former most northern forest part are made out. This trend reverses for 2001, when forest plantations have disappeared in the most northern part and the 1994/95 bushed area is used for agriculture again.

Kisere Forest: The wedge of secondary forest separating the near-natural forest in a northern and a southern part is generally closing again. Small patches of agricultural land and grassland disappear within this wedge. Along the north-western edge rather large areas of grassland close up via bushland to secondary forest. At the same time the proportion of secondary forest along the southern edge decreases again slightly.

Kakamega Forest – most northern part: Till 1989 generally a slight decrease of near natural and secondary forest is revealed, especially around the glades as well as along the eastern and northern forest edge. During that time span arable land could be found within the glades. Afterwards a reversing trend becomes obvious with a decrease in bushland in favour of increasing secondary forest. Furthermore, hardly any agricultural land is to be found in the glades.

Kakamega Forest – north-eastern forest edge: The high number of forest glades, which is characteristic for this area, is marked by continuous bush encroachment. Agricultural land is hardly seen anymore from 1984 onwards. At the same time a loss of near-natural and secondary forest in favour of bushland could be observed along the edges of the glades and the eastern forest edge. From 1994/95 the trend reverses. The bushland along the glade edges regenerates to secondary forest. Here the successional stages of forest formation are very nicely to be followed.

Ikuywa: Apart from a slight decrease in the classes "Near natural forest" and "Secondary forest" in favour of bushland especially along the southern edge, in general only small changes in forest north of Ikuywa village can be revealed. But for 2001 a stronger share of bushes in the forest along the southern forest edge can be noticed.

Yala: The least changes are observed in the Yala River Nature Reserve as well as in the entire forest area alongside Yala River. Only for 2001 a weak increase in secondary forest and corresponding loss of near-natural forest is revealed. Plantation forest contributes especially in the western forest part stretching towards Kakamega Town (the Kakamega Fuel Area) as well as in the southern half of the forest considerably to forest cover.

Kaimosi: Overall, the heavily fragmented forest area slightly decreases. Since the end of the 1980s an increase in bushland from the south can be noticed while forest area is spreading in the Northeast. In 2001 the southern fragments mostly consist of bushland; the largest assembly of forest is formed in the northwest, although here in the meanwhile the existing forest plantation disappeared again.

General pattern for the area within official forest boundaries (23,632 ha): Decrease in near natural and secondary forest (from around 15,000 to 12,000 ha) accompanied by an increase in bushed area (from around 1000 to 4000 ha, including animal dispersed *Psidium guayava* secondary bushland from 1994/5 onwards).

Influence of KWS and Forest Department management

The number of trees logged illegally in the last 20 years was significantly lower at sites managed by the Kenya Wildlife Service than at sites managed by the Forest Department. Thus, for the BDOs BIOTA East Africa is working on, there are three in main forest and little disturbed (= Colobus, Buyangu, Salazar), two in main forest and heavily disturbed (= Isecheno I, Isecheno II), one in a fragment and little disturbed (= Kisere) and four in fragments and heavily disturbed (= Malava, Yala, Ikuywa, Kaimosi). As a result, it is possible to statistically disentangle the effect of fragmentation and human disturbance.

Fig. 2. Aerial image of the forest fragment Malava in the northern Kakamega Forest area. Malava is one of the smallest fragments investigated by BIOTA East Africa (R. Steinbrecher).

2.4 Influence of fragmentation and fragment size on diversity and ecosystem processes

Plant diversity

Alpha diversity of vascular plants is generally higher in the fragments than in the main forest block. In the northern part of the main forest block (Buyangu, Colobus, Busambuli, Salazar), we observed a mean species number per plot between 40 and 55. In the southern part (Isecheno, Ikuywa, Yala), mean species numbers varied between 50 and 55. Highly disturbed areas of the northern forest block (Isiukhu, Campsite, Buyangu-Secondary) show high mean species numbers (55-70). In the nearly undisturbed fragment Kisere, 45 species were recorded and in the fragments with planted trees the number varied between 40 and 60 species/area. Fragment-size did not show a significant influence on alpha diversity, and the degree of disturbance (number of grassland/pioneer species) seems to be most important. In the fragments with planted trees, different tree species were dominant: Ileho: *Maesopsis eminii*; Malava: *Zanthoxylum gilletii*; Kaimosi: *Trilepisium madagascariense*; Kibiri: *Bischoffia javanica*. In Kisere, the dominant tree species resemble the composition of an old secondary forest from the northern forest block (*Antiaris toxicaria*, *Funtumia africana*, *Diospyros abyssinica*, *Olea capensis*). The forests of the southern parts of the main forest are dominated by *Craibia brownii*, *Croton megalocarpus* and *Celtis mildbraedii*.

Animal diversity

We found significantly fewer species and individuals of frugivorous birds and monkeys in fragments as compared to the main forest. The number of small mammals that act as seed predators did not differ significantly between fragments and main forest sites neither in the dry nor in the rainy season.

With respect to the insect fauna, studies revealed that the abundance of swarm raiding army ants, top predators in the ecosystem, is strongly reduced in forest fragments and clearly correlated to fragment size.

Diversity of pollinating insects seems to be higher in fragments. However, many species, e.g. large carpenter bees (*Xylocopa*), are highly mobile organisms that may easily cover long distances. Our results indeed show that flower visitors almost freely move between the main forest and fragmented habitats.

For Lepidoptera, in particular butterflies, larger fragments of natural forest tend to be more species-rich than smaller, more isolated fragments. For their overall species diversity, however, a mosaic of larger areas of primary forest and smaller patches of secondary or disturbed areas appears to yield and support the highest total number of species. For conservation planning towards sustaining Lepidoptera and probably other insect groups in East African rain forests, the preservation of larger intact areas of primary forest is clearly preferable as opposed to maintaining a series of smaller areas or fragments.

The fraction of Odonata species occurring in Kakamega Forest which are entirely confined to undisturbed rainforest is 35 % (25 species). Of these, 85 % (21 species) are of regional value for Kenya, since they have been recorded from the Kakamega Forest only. All these species are depending on primary rainforest habitats.

Pollination

With the exception of *Dracaena*, in all species studied so far the frequency of pollinator visits to flowers is much higher in fragments than in continuous forest. This is supposedly due to a higher proportion of forest edge effects in fragments. However, in this study, visitation frequency does not seem to influence pollination success in a consistent manner, if at all. For example, fruit set in *Acanthus eminens* is not affected at all, while *Heinsenia* produces much more fruit in fragments. In *Acanthopale* and *Dracaena* fruit set in fragments is strongly reduced. In contrast, seed set remains almost unaffected by fragmentation in *Acanthopale* and *Acanthus*, while in the case of the other species it is elevated in forest fragments. Fragment size appears to control fruit set in *Acanthopale pubescens*. Obviously, it is very difficult to generalise such results. It is rather necessary to take the biology of every species into consideration, especially their habitat requirements, before a general conclusion can be drawn.

Seed dispersal and predation

For *Prunus africana* trees, we found more species and individuals of frugivorous birds and monkeys visiting the trees in fragmented than in main forest sites. This resulted in more seed dispersal of *Prunus africana* in fragmented than in main forest sites. For *Ficus thonningii* trees, we found no significant differences in avian frugivores species and individuals visiting the trees between the continuous forest and forest fragments. Concerning seed predation, for seeds of *Prunus africana* trees we found no significant differences in predation rate between continuous forest and forest fragments.

Forest regeneration

The influence of fragmentation on the regeneration ability of forests cannot be sufficiently answered so far. Our results reveal that forest fragments usually exhibit a higher level of disturbance as compared to the Kakamega main forest block (an exception is the Kisere fragment). Seedling species diversity per m^2 is slightly higher in continuous forest sites as compared to fragment sites. In addition, seedling mortality is slightly higher in fragments, suggesting that fewer tree species may establish in forest fragments and that therefore their regeneration potential - given a constantly high disturbance level of fragments - may be reduced.

2.5 Influence of the disturbance regime on ecosystem processes

Plant diversity

In disturbed forests like in Vihiga or near Isiukhu river, the succession dynamic is higher than in climax stages as pioneer and climax species of different ages share the same habitat. All observed plant communities of Kakamega Forest were influenced by human activities during the last decades. Climax tree species like the “African Mahagony” *Entandophragma angolense* were heavily logged. This species is now very rare and at the edge of extinction. Overall, the mean number of vascular plants is significantly lower in the southern parts as compared to the northern parts of Kakamega Forest. So far, it is not clear if these reduced numbers in the southern part are due to different management (Forest Department versus KWS) or differences in soil conditions. Lowest Ŭ-diversity (Shannon H´) of tree species was found at the most disturbed sites near the camp site, whereas highest alpha diversity was found at Buyangu and Salazar. The fragments Kisere and Malawa showed a lower alpha diversity of tree species.

Concerning the diversity of macrolichens, the most species-rich sites are heavily disturbed plots like the Campsite (68 species), whereas in undisturbed areas like Kisere or Buyangu only 23 species could be recorded. For foliicolous lichens, Isiukhu shows the highest diversity with 85 species, followed by Kisere with 68 species. The lowest diversity was observed in the secondary forest at the Campsite with 27 species. A comparison of all closed-canopy forests with the open secondary forests in Kakamega shows, that disturbed, secondary habitats are much more species-rich than less or undisturbed forests. In the secondary forests, canopy species of macrolichens occur on lower stem close to gaps or in open forest.

Concerning Bryophytes, a comparison of species numbers in primary-like (Kisere) or less disturbed and secondary forests reveals a completely different picture than that of the lichens. While in secondary forests only 78 species could be recorded, the primary forests contained 143 species. Thus a simultaneous inventory of lichens and bryophytes provides a highly sensitive system of bioindicators.

Animal diversity

The factor disturbance did not influence the number of species and individuals of frugivorous birds and monkeys. The number of small mammals that act as seed predators did not differ significantly between less and highly disturbed sites neither in the dry nor in the rainy season.

Concerning amphibians, we assume that some species usually confined to open savanna habitats, e.g. the large African Tiger Frog (*Hoplobatrachus occipitalis*), enters forested areas which have been altered by various disturbance events. *Hoplobatrachus occipitalis* is a large predator and may constitute a local thread for forest species of amphibians.

The distribution of bees was found to be influenced by environmental factors as well as local floral density. While we expected an increase in bee diversity with increasing forest age, the reverse of this trend was observed in the study. The highest species richness and diversity of bees was recorded in the open farmland and in early secondary forests. This patterns is true for the number of both species and individuals and might be attributed to an increase in floral density and diversity in open forests as compared to forests with closed canopies. Apart from site specific differences the Kakamega bee diversity is highly dynamic in time.

Epigaeic army ants were found to be most abundant in secondary forest, whereas their abundance in primary forest is slightly reduced but much higher as compared to open farm land. In hypogaeic army ants highest abundances were found in farmland, while all forest types almost lacked this group of organisms.

Lepidoptera diversity can locally benefit from a mosaic of different degrees of forest disturbance and management regimes, as long as sufficiently large areas of primary forest remain.

Coprophagous beetles were found to be much more abundant in disturbed areas as compared to nearly natural forests. However, species-richness in disturbed areas is much reduced.

Trace gas exchange

Three different land use type were analysed: the northern part of the Kakamega forest (near natural rainforest), the southern part (disturbed rainforest) and cultivated land as reference. The trace gas composition over all land use types show a severe anthropogenic impact as a result of biomass burning as indicated by high acetonitrile and CO values. Methane and N_2O, gases forcing global warming, reach values of 2 ppm and 350 ppb. The reactive gases isoprene and monoterpenes (isoprenoids) contributing together with anthropogenic precursors to ozone and particle formation in the boundary layer amount to about 1.2 pbb and 0.240 ppb, respectively. Isoprene and monoterpene mixing ratios were generally higher over the forested sites compared to the cultivated site where values were 60% and 30% lower, respectively. In general ozone values were about 5 ppb higher over populated land than over the forest.

Fourteen plant species typical of the Kakamega forest were screened with respect to the trace gas exchange potential. All plant species emit isoprenoids and thus are impacting the reactivity of the atmosphere as well as the carbon budget of a rainforest. For example *Croton macrostachys* will loose up to 5% of the photosynthetically fixed carbon via isoprenoid emission. In general, *Croton* and *Maesopsis* species are high isoprenoid emitters compared to other with a factor of 10 to 100 lower emission potential.

Area-averaged fluxes of isoprenoids were highest over the forest sites. No statistically significant difference was observed between the more or less natural forest part in the north of the forest and the managed part in the south. However, over cultivated land isoprene fluxes were significantly lower as compared to the forested sites but monoterpene fluxes were comparable.

Pollination

Disturbance seems to play a bigger role in determination of fruit and seed set than fragmentation, but the outcome depends on the species observed. No general pattern is discernible so far. The degree of disturbance of a certain site seems to positively influence fruit set and negatively influence seed set in *Acanthus eminens*.

Seed dispersal and predation

For *Prunus africana* we found more species and individuals of frugivorous birds and monkeys visiting the trees in highly disturbed sites than in less disturbed sites. This resulted in more seed dispersal of *Prunus africana* in highly compared to less disturbed areas. For the tree *Ficus thonningii*, we found no significant differences in avian frugivores species and individuals visiting the trees between differently disturbed sites. Concerning seed predation, for seeds of *Prunus africana* we found at most a weak effect of increased seed predation in highly disturbed sites.

Forest regeneration

The seedling species diversity per m^2 is significantly higher at less disturbed areas of Kakamega Forest as compared to heavily disturbed sites, suggesting that disturbance significantly reduced the regeneration potential of natural forests.

Based on the Landsat satellite imagery time series a cluster analysis was performed resulting in types of characteristic changes in land cover from 1972 to 2001 (i.e. spatial regions are formed that are alike regarding their specific forest history): While in the north-western part of the Kakamega Forest (stretching towards Kakamega Town) as well as along the western forest edge areas of extensive forest loss are most pronounced, in the north-central and north-eastern part of the Kakamega Forest a regeneration of the forest along the edges of the glades can be noticed. This is not necessarily correlated to forest management but a consequence of lower population numbers along the eastern side of the forest, the steep Nandi Escarpment functioning as a natural border, as well as rather poor road access (i.e. a road not to be used in rainy or muddy conditions).

2.6 Current economic use of forests

Logging, fuelwood collection, cattle browsing, etc.

Illegal timber cutting and charcoal burning represent a persistent and serious problem that threatens biodiversity through selection of species. As surrounding farmland increasingly struggles to feed the expanding human population the forest edges face ever greater pressure. Outside the Nature and National Reserves local collection of dead wood and medicines is allowed in the forest and grazing of cattle in selected glades has also been permitted for an annual fee. An analysis of current logging activities indicate a high level of human impact throughout the forest with illegal logging being most widespread. Furthermore, logging levels appear to reflect management history and effectiveness. Currently, logging is less common within highly protected National and Nature Reserves as compared to frequent logging activities within the less protected Forest Reserves. Data from spot checks showed, that women are mainly observed carrying wood out of the forest, particularly the group of 18 to 40 year old women with 36% of the total observations and an average individual load of 44 kg. Reflecting management effectiveness as well as protection status in Kakamega Forest, logging was demonstrated to be a valuable quantitative indicator for human disturbance and thus an important tool for conservation managers. Several NGOs and CBOs are currently attempting alternative and sustainable income generating projects, for instance bee-keeping, and the cultivation, processing and sale of a forest herb into a medicinal rub.

Nature tourism

Nature Tourism is already being practised with options ranging from campsites to relatively expensive lodges, although few are owned by locals. This brings added income to the forest and to some local inhabitants through employment of staff and guides but so far tourism has only been developed in the north around Buyangu and between Kakamega town and Isecheno in the west.

3. Capacity building

African PhD students trained

PhD thesis: Alex Awiti, WAC, Department of Botany, University of Nairobi, Kenya **–** Linking Soil functional capacity decline to land use and land cover change: A case study of Kakamega forest ecotone.

PhD thesis: Mary W. Gikungu, National Museums of Kenya, University of Bonn – Differences in bee pollination among natural and successional habitat patches at Buyango Forest.

PhD thesis: John Joseph Kisakye, Makerere University, Institute for Environment and Natural Resources, Kampala, Uganda – The diversity and ecology of dragonflies in Bwindi Impenetrable, Mabira and Mt. Elgon Forests.

PhD thesis: Winfred Musila, National Museums of Kenya, Nairobi **–** Soils in Kakamega Forest, properties, spatial distribution and relations to tree species diversity.

PhD thesis: Geoffrey Mwachala, National Museums of Kenya, Herbarium/University of Koblenz **–** Revision of *Dracaena* L. (Ruscaceae) in Central and East Africa.

PhD Thesis: Grace Njery Njoroge, Jomo Kenyatta University, Botany Department, Kenya – Pollination ecology of watermelon and associated ethno botany of the main pollinator.

PhD Thesis: Regina Nyunja, Maseno University, Botany Department, Kenya.

African MSc students trained

MSc thesis: Beryl A. Bwong, National Museums of Kenya, Nairobi - Morphology and bioacoustics of the Ridged Frog species, genus *Ptychadena* (Amphibia: Ranidae), from the Kakamega Forest, Western Kenya.

MSc thesis: Jasper M. Kirika, University of Nairobi - Consequences of forest fragmentation and disturbance for frugivore assemblages in *Ficus thonningii* and implications for regeneration processes.

MSc thesis: Vincent Shitakule Mahiva, ICIPE Nairobi/University of Nairobi – A survey of the dung beetles of Kakamega Forest and the surrounding farmlands: a biodiversity and land use assessment (submitted 2004).

MSc thesis: Flora Njeri Namu, University of Nairobi – Patterns of butterfly diversity in fragments of northern Kakamega Forest, Kenya.

DEA thesis: Paul N'goran, Université Abobo-Adjame, Abidjan – Influence des exploitations agricoles sur les communautés de coléoptères coprophages en zone forestières : cas de l'Université d'Abobo-Adjamé en forêt primaire (Abidjan) et de Bringakro en forêt secondaire (Toumodi) en Côte d'Ivoire (submitted 2004).

DEA thesis: Célestin Kouakou, Université Abobo-Adjame, Abidjan – Influence des perturbations anthropiques sur les coléoptères coprophages : cas du pâturage et de l'urbanisation respectivement en regions de savane (Toumodi) et de forêt (Abidjan) de la Côte d'Ivoire.

Maîtrise: Paul N'goran, Université Abobo-Adjame, Abidjan – Effet de l'anthropisation sur les communautés des coléoptères coprophages (bousiers) en zone urbaine: Commune de Yopougon (Abidjan).

Maîtrise: Célestin Kouakou, Université Abobo-Adjame, Abidjan – Effet de l'anthropisation sur les communautés des coléoptères coprophages en zone urbaine : Cas d'Abidjan-Vridi.

African field assistants and technicians trained

Fred Salano, Evans Savatia, Edward Masheti, Daniel Karanja, Simon Githinji, Lena Sajita, Jared Sajita, Nixon Sajita, Michael Barasa, Caleb Analo, Alfred Yakhuma, Bonny Dumbo, Jackson Mwanje, Benson Chituy, Nelson Musisi, Patrick Inziani, Benjamin Okalo, Fred Munyekenye, Bernard Akwanda, George Eshiamwata, Peter Oweno, Patrick Chalo Mutiso, Simon Gichuky Mathenge, Vincent Muchai, Victor Wasonga, Patrick Malonza.

Maseno Botanical Garden

With the provision of a 15 ha compound from the Maseno University, Maseno, Kenya, in 2000 the foundation of the Garden took place in 2001 after the development of the ground and the construction of a fence. While creating the trails and clearing of the area the establishment of the tree nursery and the creation of experimental fields were conducted. During the project period trees were added to the garden after an initial planting of over 100 tree species from the BIOTA research area in Kakamega. After the research activities started with the establishment of the experimental fields its expansion was induced with the completion of the greenhouse and the office building with the herbarium where the germplasm/seed collection takes place as well. Maseno Botanical Garden is aimed at serving as a local centre of expertise and resource for indigenous plans which are heavily explored in the wild.

Nature tourism

In close cooperation with the Kakamega Environmental Education Programme (KEEP) and the Kenya Wildlife Service (KWS), BIOTA initiated the enhancement of a nature trail at Buyango Hill and designed about 60 signs about specific trees and ecological principles. This nature trail is now visited by schools and ecotourists and demonstrates the necessity of the conservation of the forest. Posters displaying different groups of animals occurring in Kakamega Forest were provided to local KWS authorities.

Education of local community

By several educational events in schools and churches in the Kakamega area, members of the BIOTA project informed the public about the activities and tried to persuade the communities that conservation of the forest, designing of new strategies of usage and maintaining or enlarging the forested area is in their own interest concerning the long term perspectives of survival in that area.

Fig. 3. Women collecting firewood from the southern part of Kakamega Forest, near Ikuywa (T. Bergsdorf).

4. Summary

The present pilot study on biodiversity changes demonstrated that Kakamega Forest is exceptionally species rich for a number of plant and animal groups, particularly birds, bees and Lepidoptera. Furthermore, Kakamega Forest proofed to be a unique forest with a mixture of Guineo-Congolean and Afromontane highland species, containing local endemics and a relatively large number of species globally threatened by extinction. A closer analysis of the effects of forest fragmentation and human disturbance on plant and animal diversity as well as on ecosystem processes revealed that the forest community is differently sensitive to human impact. For a number of animal and plant species, large blocks of undisturbed forest are necessary for the continuous survival of the group. For species richness in a number of other plant and animal groups as well as for pollination, seed dispersal, and seed predation, fragments and heavily disturbed sites in the forest did not differ consistently from the main forest block and less disturbed sites.

On the other hand, Kakamega Forest is highly threatened. Forest cover was reduced by at least 52% since 1933 with the human population surrounding the forest increasing from about 390 people/km^2 in 1918 to about 713 people/km^2 in 1991. As a consequence, Kakamega Forest is no primary forest but has a long history of human utilisation and disturbance. However, the analysis of time series revealed that the process of forest regeneration is still taking place and that regeneration potential is only partly reduced - if at all.

These results demonstrate that Kakamega Forest fulfils all the requirements for understanding and managing biodiversity in Africa. First, Kakamega forest has an exceptionally high value to the conservation of highland rain forests in the whole of East Africa. Second, it has a well-documented history of human disturbance that can provide a baseline to understand how sensitive forest communities respond to human activities. Finally, it is highly threatened and in urgent need of conservation. Thus, Kakamega Forest and its surrounding agricultural area can serve as a model to understand, conserve and manage the biodiversity of tropical forests in rural Africa.

Subproject E01 (coordination)

Biodiversity in conversion: The influence of fragmentation and disturbance on the biodiversity of East African highland rain forests

Subproject leader: Prof. Dr. C. M. Naumann, Dr. J. Köhler, University of Bonn	
Short title: BIOTA E01	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

Subproject E01 is aimed at the coordination of the interdisciplinary biodiversity research project BIOTA East Africa. The coordination included the setting of administrative, logistic and conceptual preconditions for a wide range of disciplines working in Germany, East Africa and southern Arabia.

In summary the basic goals of BIOTA East Africa coordination were defined as follows:

- Conceptual planning and coordination of interdisciplinary research activities
- Establishment of cooperations with East African institutions
- Obtaining all necessary permissions to conduct research in East African countries
- Development of logistics for biodiversity research in East Africa
- Financial planning and accounting
- Coordination and planning of presentations of project activities
- Creating public awareness for biodiversity research and the respective BIOLOG programme in East Africa and Europe

Planning and conduction

Research sites at Kakamega Forest

Analyses of biodiversity and its change were carried out mainly at Kakamega forest, Kenya. The research area represents the eastern-most remnant of the Guineo-Congolian rainforest block and has protected status as a National Reserve. It includes both, near natural and secondary rain forest, as well as several isolated fragments. It is perfectly suited to conduct comparative analyses of biodiversity within the mentioned habitat types. During the first field campaigns all occurring habitat types within the main research area Kakamega Forest, including all forest fragments, were investigated with respect to the scientific questions to be studied. Research sites were chosen according to abiotic and biotic conditions fitting to a maximum number of the subproject's research profiles. According to the focus on the influence of fragmentation on changes in biodiversity and for statistical reasons, almost all present forest fragments (Kisere, Malawa, Ikuywa, Yala, Kaimosi, etc.) were included.

Research within the main forest area of Kakamega was based at the northern Buyangu area and in the south around Isecheno.

Establishment of biodiversity observatories

The first biodiversity observatories for long-term observations were established in northern Kakamega forest where most subprojects already set up their plots. One of the observatories is located at the so-called Colobus trail in forest of predominantly primary character, the other is located south of the Buyangu campsite combining natural and more disturbed secondary forest formations. In the following year, additional observatories including all forest fragments and other areas of the main forest were established - bringing the total number of observatories to ten.

Logistics

The formal preconditions to start the project, including working and research permissions from the Kenyan Ministry of Education and the Kenya Wildlife Service, were all cleared during the first months. In addition we signed Memorandums of Unterstanding (MoU) with most of the counterpart institutions mentioned below, specifying the terms of cooperation.

At the same time, technical equipment was installed at the research site. The two project vehicles were imported tax-free through the kind support of WAC and were available for project members in August 2001.

Important steps were made concerning the improvement of the Buyangu Research Camp at northern Kakamega Forest. At the beginning, the KWS kindly left the existing facilities for BIOTA purposes. Through the financial support of our sponsor *Nature and Culture International, San Diego, USA*, (formally *Fundación Cientifica San Francisco*) and the help of KWS a new station building was erected at Buyangu Campsite. This new building provides the BIOTA team with two working rooms, one storage room for field equipment and a room to dry collected plant specimens. Electricity was initially supplied by a generator and later by solar panels charging a certain amount of batteries. These logistics enabled for the use of computers, microscopes and other current dependent equipment at the research site.

Cooperations with other institutions

African counterparts

The establishment of cooperations with African counterparts and the capacity building at their institutions was one of the main goals of BIOTA and one of the most important preconditions for the implementation of long-term activities. So far, co-operations were established between BIOTA and the following institutions in Africa:

- National Museums of Kenya, Nairobi 4 NMK
- Kenya Wildlife Service, Nairobi 4 KWS
- Forest Department, Nairobi 4 FD
- International Centre for Insect Physiology and Ecology, Nairobi 4 ICIPE
- World Agroforestry Centre, Nairobi 4 WAC
- Kakamega Environmental Education Programme, Kakamega 4 KEEP
- EAFRINET (East African LOOP of BioNET International), Nairobi
- Nature Kenya, Nairobi

- Maseno University, Maseno
- Kenyatta University, Nairobi
- University of Nairobi, Nairobi
- Makerere University, Kampala
- National Forest Authority, Kampala 4 NFA
- Uganda Wildlife Authority, Kampala 4 UWA
- Uganda National Council for Science and Technology, Kampala 4 UNCST
- Budongo Forest Project, Masindi 4 BFP
- African Pollinator Initiative, South Africa 4 API

The National Museums of Kenya (NMK) is the main counterpart of BIOTA East Africa and it takes possession of most of the important and necessary co-ordination of project activities in Kenya. Dr. Helida Oyieke (Director Research and Scientific Affairs) was appointed as the BIOTA contact person at the NMK. The different BIOTA East Africa subprojects were working closely together with the respective NMK departments (i.e. botany, invertebrate zoology, herpetology, ornithology) and training and education of Kenyan students working in the project is carried out jointly.

Another important BIOTA partnership is that with Kenya Wildlife Service (KWS) which is in charge of the management of the Kakamega National Reserve and other protected areas in Kenya. The KWS, as well as the Forest Department of Kenya, were kindly supporting the BIOTA activities not only by unbureaucratically issuing the necessary permits, but also by their continuous help and support concerning logistical matters at the research sites.

Furthermore, the BIOTA project profited remarkably from the co-operation with the Kakamega Environmental Education Programme (KEEP), a local organisation supporting the environmental education of students and the training of field assistants. As a result of KEEP activities, BIOTA was able to employ highly qualified field assistants from the beginning of the project. These field assistants working with BIOTA received further education in using different methods of field research and in identification of organisms. Joint activities concerning the environmental education of the Kakamega local population were conducted.

Cooperation with EAFRINET and API was characterised by more comprehensive goals. Here, the sustainable management of data resulting from the BIOTA project, the joint development of identification tools and rapid assessment procedures, and their later application on a regional level were the main objectives.

During project phase I, the relationships with Ugandan institutions have been strengthened. The Makerere University in Kampala as well as other governmental institutions (UNCST, UWA, NFA) kindly supported the proposal of BIOTA East Africa to expand research activities to Uganda.

For cooperations with various European institutions, please refer to the respective subproject reports.

Fig. 1. Newly constructed BIOTA laboratories at KWS campsite Buyangu, Kakamega Forest, Kenya.

2. Results

2.1 Scientific results

For a summary of scientific results achieved by the interdisciplinary BIOTA East Africa project in phase I, please refer to the *Synthesis*. For more detailed information, please refer to the respective reports of subprojects E02–E16.

2.2 Interdisciplinary components

As is obvious from the synthesis, interdisciplinary relationships between BIOTA East Africa subprojects were multiple. The BIOTA East Africa subproject structure covered all hierarchical levels of biodiversity research. Basic information about the effects of degradation and fragmentation on selected key organisms of the ecosystematic network was obtained at the levels of species and populations, the genetic and community level. The botanical subproject E04 was aimed at providing essential vegetational data for all other subprojects and the basic information needed for the GIS tool (E02). Subprojects E06, E07, E08 and E09 focussed on changes of certain groups of animals at different levels of the trophic network, giving respective input for analyses of ecosystem function and the development of rapid assessment methods. Achieved data were jointly processed for meta-analyses. Research at the level of ecosystem functionality was conducted on nutrient flow and its relation to forest regeneration processes (E03); plant-pollinator interaction in different sized fragments and within a gradient of human disturbance (E10); seed dispersal and the importance of dispersers for forest regeneration (E11) and the potential of the forests for human use (E12). These subprojects were particularly linked closely. Processing of data from all subprojects at local and landscape levels was done by the E02-GIS component. For detailed information on interdisciplinary networking, please refer to the respective subproject reports.

2.3 Likely benefit and applicability of results

By increasing knowledge about biodiversity changes and the respective diversity as well as the means of capacity building, BIOTA East Africa contributes to the comprehensive approach of the CBD aiming at a sustainable global policy to conserve and utilise biodiversity. While pure measures of nature protection still play a role, concepts of sustainable use of biological resources including the participation of local communities increasingly gain importance. The BIOTA East Africa approach pays particular attention to the issues of sustainable use and equitable access to biological resources. By promoting biodiversity research, socio-economic evaluations, the development of management recommendations and capacity building, BIOTA East Africa gives the necessary incentives for respective countries to conserve their biological diversity. The integrated approach, involving local communities, stakeholders, national authorities and policy makers alike, provides the necessary pre-condition to contribute to the aims of the CBD.

As demanded by the CBD, the knowledge generated by BIOTA East Africa will contribute to an information and communication system in the sense of the Clearing-House Mechanism (CHM). By means of the CHM the scientific and technical knowledge is imparted to all relevant national and international levels. BIOTA East Africa will contribute to the development of the CHM by promoting and facilitating technical and scientific co-operation, within and between East African countries, as well as by supporting the necessary human and technological network by capacity building measures. Thus, access to experiences of the implementation of measures for a sustainable use of biological diversity is facilitated and supports decision-making.

The data achieved and the analyses done within phase I serve as the basis for the development of management recommendations on a local, regional and national level. The broad accessibility of these results via the world wide web will provide researchers, conservationists and politicians with a valuable set of information for management planning. Applicability of results and recommendations thus can be tested in other rainforest ecosystems.

2.4 Publications resulting from the project

Kinuthia, W. & J. Köhler (2001): EAFRINET and BIOTA East Africa create a framework for partnership. - BioNET International News No. 9: 6.

Köhler, J. (2002): BIOTA East Africa – Interdisziplinäre Biodiversitätsforschung am Museum Koenig. – ZFMK-Jahresbericht 2001: 3-5.

Köhler, J. (2002): BIOTA Ostafrika – das Museum Koenig im Fokus interdisziplinärer Biodiversitätsforschung. – Zeitschrift der Alexander Koenig Gesellschaft 4: 36-49.

Köhler, J. (2004): Was hat Biodiversitätsforschung mit ‚nachhaltiger Nutzung' zu tun? 4 Tier und Museum 8 (3): 82-91.

Köhler, J. (2004): Lässt sich biologische Vielfalt durch nachhaltige Nutzung erhalten? - Eine Fallstudie in Ostafrika. In: Erdmann, K.-H. & C. Schell (eds.): Zukunftsfaktor Natur - Blickpunkt Naturnutzungen. 4 Bundesamt für Naturschutz, Landwirtschaftsverlag, Münster-Hiltrup: 16-28.

Köhler, J. & C M. Naumann (2003): Towards a sustainable use of East African rain forest systems: analysis of biodiversity function and socio-economic drivers along gradients of degradation. In: Sustainable use and conservation of biological diversity. A challenge for society. – International Symposium Report BMBF, Part A, Berlin: 102-103.

Köhler, J., P. Wagner, S. Visser & W. Böhme (2003): New country records of *Adolfus africanus* (Sauria: Lacertidae) 4 a rainforest lizard with disjunct distribution? – Salamandra 39 (3/4): 241-248.

Naumann, C. M. (2001): Regenwald und Savanne – größte Vielfalt, größte Bedrohung. In: Türkay, M. (ed.): Leben ist Vielfalt. – Kleine Senckenberg-Reihe 41: 31-41.

Naumann, C. M. & J. Köhler (2001): Biodiversity in conversion – the influence of fragmentation and man-made exploitation on the biodiversity of tropical montane forests. – Status Report 2001, BMBF, Bonn: 150-151.

in press

Köhler, J., K. Scheelke, S. Schick, M. Veith & S. Lötters (in press): Contribution to the taxonomy of hyperoliid frogs (Amphibia, Anura, Hyperoliidae): advertisement calls of twelve species from East and Central Africa. – African Zoology

in preparation

Böhme, W., P. Wagner, P. Malonza, S. Lötters & J. Köhler (in prep.): A new species of *Agama* from East Africa, with taxonomic comments on the *Agama lionotus* complex (Reptilia, Sauria, Agamidae).

Wagner, P., J. Köhler & W. Böhme (in prep.): Biogeographic analysis of the reptile fauna of a West Kenyan rain forest remnant.

scientific talks/posters

Köhler, J. (2003): Lassen sich Regenwälder nachhaltig nutzen? Eine Fallstudie in Ostafrika. - Bundesamt für Naturschutz, Ringvorlesung "Zukunftsfaktor Natur - Blickpunkt Naturnutzung", Bonn, 2003 [talk].

Wagner, P., J. Köhler & W. Böhme (2004): Biogeographic analysis of the reptile fauna of a West Kenyan forest remnant. – International Symposium on African Biodiversity – Molecules, Organisms, Ecosystems, Bonn, May 2004. [poster/abstract]

3. Capacity building

3.1 Technical capacity building

The technical support of counterpart institutions during phase I included computers, stereo-microscopes, collection cabinets, office equipment and various field equipment. In addition, scientific staff and students were supported with travel funds to enable visits of training courses and international conferences.

3.2 Students and scientific staff trained

Diploma thesis: Philipp Wagner, University of Bonn: Diversity and biogeography of the reptile fauna of Kakamega Forest, Kenya.

Internship: Guido Velten, University of Bonn: training in project coordination and financial administration.

Internship: Marcell Peters, University of Bonn: training in project coordination and financial administration.

Internship: Francisco Hita Garcia, University of Bonn: training in project coordination and financial administration.

Internship: Carola Schmidt, University of Bonn: training in workshop organisation.

3.3 Workshops

By order of subproject E01 and on request of National Museums of Kenya, BIOTA scientist Prof. Dr. G. Schaab (E02) conducted a workshop in November 2001, introducing GIS methodology to NMK affiliates.

In December 2001, an international workshop on methodology in biodiversity research was organised jointly with BIOTA western and southern Africa and held at the Geographical Institute, University of Bonn.

In April 2002, an international BIOTA workshop was jointly organised and held at BIOTA's main counterpart institution, the National Museums of Kenya (NMK). Participants were East African and German project members as well as external researchers from Kenya, Uganda and Tanzania. The workshop aimed at the presentation of recent scientific results obtained by project members, as well as joint planning of the proposed second phase of BIOTA (2004–2007). In several subsequent local meetings, BIOTA provided information and environmental education for local people and authorities.

In May 2004, German members and East African counterparts of BIOTA had a workshop in Bonn on current research issues at Kakamega Forest. This workshop was part of the "International Symposium on African Biodiversity – Molecules, Organisms, Ecosystems" held at the Zoologisches Forschungsinstitut und Museum Alexander Koenig, Bonn. At this international symposium, several African students presented the results of their BIOTA studies.

Fig. 2. Left: One of the working groups at the international BIOTA East Africa workshop at National Museums of Kenya (NMK), April 2002. Right: Members of BIOTA East and West Africa at the international workshop on methodology in biodiversity research, Bonn, December 2001.

4. Public awareness

During phase I, the interdisciplinary project BIOTA East Africa was portrayed several times in newspapers and TV features. A film team of WDR visited the study sites at Kakamega Forest in May 2003. The most comprehensive report was provided by the ARD channel within the series "W wie Wissen". Other contributions included the channels WDR (e.g., Quarks & Co), 3SAT and HR (Abenteuer Erde).

In addition, the coordinators additionally contributed to the presentation of BIOTA East Africa at conferences (e.g. Leben ist Vielfalt - Aktionswoche Biodiversität, Senckenberg, Frankfurt/M.) and several popular articles (see list of publications).

Subproject E02

Impact of changing biodiversity in tropical agro-forest ecosystems in Africa on the exchange potential of trace gases between ecosystems and atmosphere

Subproject leader: Dr. R. Steinbrecher, Forschungszentrum Karlsruhe GmbH, IMK-IFU	
Short title: BIOTA E02	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

The overall objective of the project was to quantify the impact of land cover change and thus biodiversity change in the landscapes of the Kakamega area on trace gas exchange between the land surface and the atmosphere and its implication for atmospheric trace gas distribution. In order to achieve the objective, sub-objectives were formulated for the following issues:

GIS and RS

(1) Setting-up a geographical information system (GIS) as the common BIOTA-East data base on geo-spatial data for all project partners working in Kenya,

(2) providing information on spatial-temporal patterns of land cover over the past 30 years as well as on intra-annual changes in biophysical parameters, both derived from remotely-sensed imagery, and

(3) capacity building in making use of GIS and remote sensing (RS) techniques for extrapolation and scaling-up of field data, respectively. These activities include the forming of a thorough geodata basis for the envisaged trace gas modelling activities of E02.

Soils

(1) Evaluating the effects of forest conversion and subsequent cultivation on soil functional capacity with special emphasis on carbon and nitrogen depots,

(2) demonstrating the potential of near infrared spectroscopy as an inexpensive and rapid tool for chemical characterization of soil and plant quality,

(3) developing approaches for anticipatory management of soil health.

Trace gases

(1) Developing an adequate measuring system for quantifying the effect of biodiversity change on regional trace gas exchange and regional trace gas distributions in the Kakamega area,

(2) demonstrating the functionality of the airborne sensing platform,

(3) evaluating the effects of different grade of disturbance on the trace gas exchange and trace gas distribution in the atmosphere.

Planning and conduction

For achieving the formulated objectives the following activities were planned and conducted:

GIS and RS

- Conceptual planning of the central GIS (hierarchical structure, coordinate projections, data formats, data description, and internet access).
- Intensive search for available geo-spatial data (contacting UNEP, UNDP, ICIPE, DRSRS, ILRI, KWS, LRP, FU Berlin, Universities of Trier, Bern, and Bonn, OS Internat. Library, Photomap and several scientists).
- Geodata processing: e.g. digitising of analogue maps, geometric and semantic adjustments of digital datasets, georeferencing of observation plots.
- Preparing additional information to be included in the BIOTA-East-GIS online geodata catalogue (meta description, quicklooks, WebGIS applications).
- Ordering or downloading of satellite imagery: a) Landsat time series 1972 to 2001 for the wider Kakamega Forest area, 7 time steps, and b) MODIS value-adding products (LAI/FPAR, T(S)) for Kenya and Uganda, 8-days composites for 2000 to 2003.
- Pre-processing of the Landsat scenes (georeferencing, correction of system errors, radiometric corrections considering atmospheric as well as terrain shading effects).
- Threshold analysis of the Landsat time series distinguishing between “forest” and “no forest”.
- Supervised multispectral classification of the Landsat time series data and analysis of the results.
- Cover search for historical aerial photography and mosaic construction for 1948/52, 1965/67, and 1991.
- MODIS data processing (spatial stratification and interpolation, linear weighted temporal interpolation, harmonic analysis) in order to improve biophysical parameter products.
- Interdisciplinary cooperations with a) the E02 project partners to help analysing aeroplane-based trace gas measurements and b) with other BIOTA-East subprojects (E03, E04, E07, E10, E11, E12) promoting the use of geospatial data in biodiversity research.

Soils

- Selecting and geo-referencing soil plots for a control-impact pair survey and random cluster surveys studying the effect of soil conversion on soil quality.
- Developing a protocol for rapid assessment of soil productivity.
- Plot based field survey on soil physical and chemical parameters.
- Analysing stable carbon isotope ratios to reveal short-and long-term C dynamics in top soils following conversion from forest to cultivation.
- Quantification of soil conversion effects on soil quality.
- Developing a spectral index for rapid screening of soil functional capacity status relative to “undisturbed benchmark” land cover types (forests).

Trace Gases

- Construction and optimising an air sampling system for use on small aircrafts.

- Construction and optimising of a five-hole-probe system for atmospheric turbulence measurements on small aircrafts.
- Hard- and software system integration of the airborne trace gas flux measurement system.
- Wind tunnel calibration of the turbulence probe.
- Optimising sampling procedure and gas chromatographic analysis for quantifying trace gases in ambient air samples of the Kakamega area.
- Field survey on trace gas distribution over areas in the Kakamega region exhibiting different grades of disturbance.
- Trace gas flux measurements over ecosystems with different grades of disturbance
- Quantifying the biogenic VOC emission potential of plant species from the Kakamega forest cultivated at the Maseno Botanical Garden.
- Quantifying the effect of different grades of disturbance of the Kakamega forest on trace gas exchange.

Milestones

after 12 months: BIOTA-East GIS structure and online geodata catalogue set-up, ready-available geodata sets as well as the most urgent ones included, Landsat satellite imagery at hand, preliminary threshold analysis of the Landsat time series distinguishing between „forest“ and „no forest“ in the wider Kakamega Forest area. For the soil investigations the plots selected, geo-referenced. The trace gas sampling system set up, the sampling and analytical parameters for detecting trace gases in ambient air samples of the Kakamega area optimised. The turbulence probe constructed and first tests conducted. First airborne field survey of atmospheric trace gas distributions performed.

after 24 months: BIOTA-East GIS extended focusing on vegetation and soil information, observation plots of several BIOTA-East subproject geo-referenced, Landsat time series data corrected for atmospheric and terrain shading effects, cover search for historical aerial photography launched, preliminary MODIS satellite data processing regarding annual cycles in biophysical parameters. Soil samples taken from the plots and first analytical test performed. Biomass input in plots determined. Ambient air mixing ratios of trace gases quantified and possible effects of increasing disturbance on trace gas distributions analysed. The atmospheric turbulence measurement system calibrated in wind tunnel experiments, field operation tested with a small aircraft.

after 36 months: BIOTA-East GIS continuously updated and extended (now including 76 datasets in total, vector datasets for Kenya geometrically and semantically harmonised), a consistent and complete meta description, WebGIS applications for a better judgement of the data included in the online geo-data catalogue, geo-referenced observation plots for 14 project partners of 8 subprojects, land cover change time series 1972 to 2001 based on Landsat imagery distinguishing between 12 classes (of which 6 belong to forest formations) and their analysis regarding forest change, mosaics of aerial photographs for the time-steps 1948/52, 1965/67, and 1991 for Kakamega Forest, complete cycles of intra-annual variation in the biophysical parameters LAI, FPAR, and T(S) for all of Kenya and Uganda from Oct 2000 to Oct 2003. The effect of soil conversion on soil quality assessed on the basis of soil physical and chemical parameters as well as soil productivity test. Based on the results of the soil survey, the potential application of near infrared spectroscopy as a rapid and inexpensive tool for classifying soils and soil quality demonstrated. The biogenic volatile organic compounds (VOC) emission pattern characterised and quantified of plants from the Kakamega forest, available in the Maseno Botanical garden. Isoprenoid fluxes and ambient air distributions for ecosystems with different grade of disturbance evaluated and statistically analysed. First modelling and scenario studies on trace gas exchange of agro-forest systems performed.

Cooperations with other institutions

- Institutions contacted regarding geodata exchange: UNEP, UNDP, ICIPE, DRSRS, ILRI, KWS, LRP, FU Berlin, Universities of Trier, Bern, and Bonn, OS Internat. Library, Photomap, RAF, Forschungsbibliothek Gotha, and several scientists.
- A close cooperation with WAC (former ICRAF) regarding geodata processing (e.g. digitising of contours and rivers from 1:50’000 scale topographic maps).
- With the BIOTA partners of S01 for guaranteeing a straightforward integration of the diverse geodata processed within BIOTA-Africa later on.
- Helping the BIOTA-East subprojects in georeferencing their observation plots throughout Kakamega Forest and nearby forest fragments.
- Interdisciplinary working together with the BIOTA-East project partners of the subprojects E03, E04, E07, E10, E11 in order to combine field observation findings with geospatial data.
- Selecting dominant plant species of the Kakamega Forest for potential trace gas emission scenarios with BIOTA-East project partners E03 and E04.
- Providing meteorological data to interested parties from the BIOTA-East community from a newly established field station near the KWS office in the Kakamega Forest in close cooperation with WAC.
- The Department of Botany, University of Nairobi, Kenya hosts a PhD student working on soil quality assessment in forested and no-forested sites of the Kakamega area.
- Supporting BIOTA-East subprojects working on soils with additional soil quality measurements.
- The WAC facilities in Nairobi and Kisumu serve as base for BIOTA vehicles to be used by all BIOTA members.

2. Results

2.1 Scientific results

GIS and RS

(1) Setting-up of a central, satellite imagery-based GIS as the common BIOTA-East geodata basis for all subprojects working in Kenya

The BIOTA-East-GIS considers five different levels of detail for monitoring and modelling:

Á The level “Africa” serves as link to the other geodata collections set up within BIOTA-South and BIOTA-West. It comprises datasets necessary to demonstrate the integration of BIOTA-East within BIOTA-Africa.

- For level “Kenya” a large number of geo-spatial datasets has been gathered from varied sources. Before making them available to the BIOTA community, the data layers have been geometrically and semantically harmonised in order to facilitate analysis.
- “Kakamega Forest and associated forest areas” encompasses an area of 60 km by 65 km. Here especially data on changes in land cover/use over time is included for revealing anthropogenic interference and forest fragmentation.
- The level “Kakamega” corresponds with the true extent for most of the observations within the first phase of the project.
- And finally, level “observation plots” allows to zoom to the so-called biodiversity observatories (BDO).

The BIOTA-East-GIS is successively filled with available, collected and/or processed geo-spatial datasets. Access to the geodata is provided via the internet (http://www.biota-africa.org, follow links “East Africa” and “data”). Here a low-cost approach is followed, giving preference to a technically simple but efficient realisation instead of making use of complex database technology that requires expert maintenance. For every single dataset meta information and a quicklook are offered as well as a direct download supported (see Figure 1). While the download requires a password and is thus restricted to the BIOTA community, information on available geodata via meta description and quicklook is open to the public. The online geodata catalogue is further supported by WebGIS applications. These (1) allow for a detailed judgement on the suitability of geodata before starting to download data and (2) they are useful for presentations of project outcomes or results via the internet.

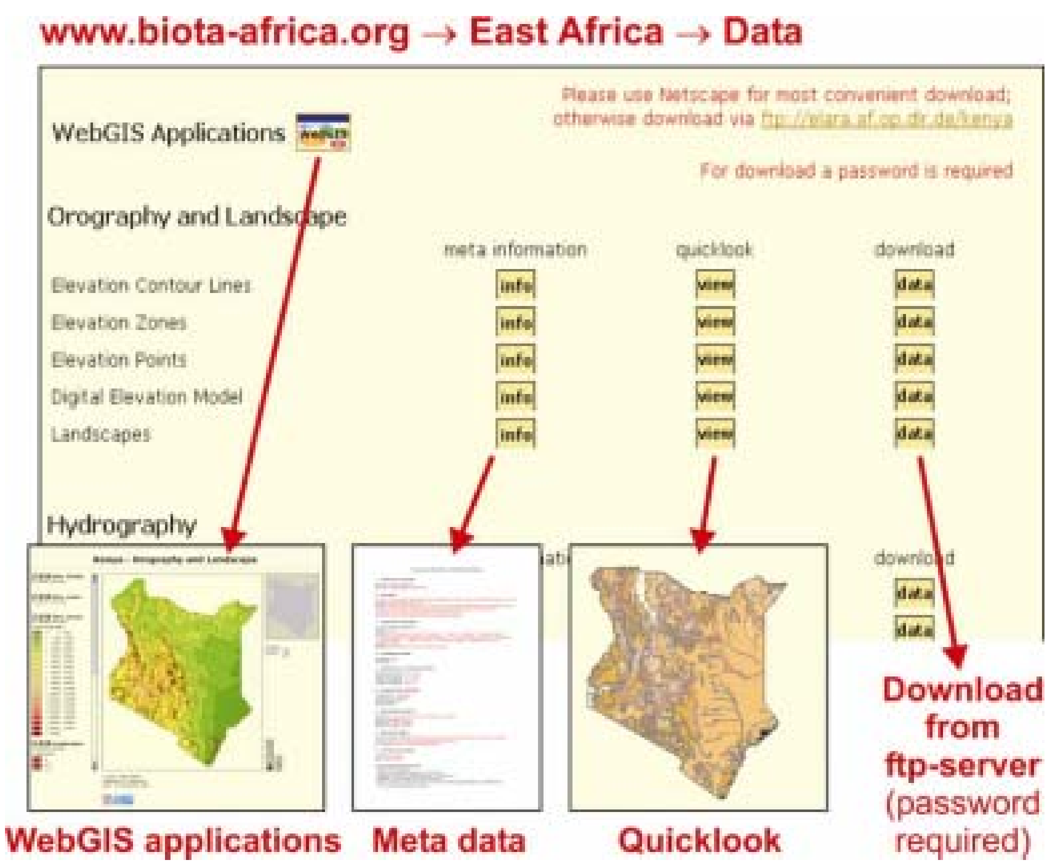

Fig. 1. Components of the BIOTA-East online geodata catalogue, shown for the level “Kenya”.

Not all geodatasets processed so far are included in the online geodata catalogue. The positions of the costly georeferenced observation plots of 14 project partners within 8 BIOTA-East subprojects might be of sensible character. At the level "Kakamega Forest and associated forest areas", with already 25 datasets online, the integration of the classification results of the Landsat satellite time series is still pending. Here a geometrical adjustment of all datasets showing vegetation information would be very ambitious. The level "Kenya" seems to be the most complete with 36 datasets, all geometrically and semantically harmonised in the case of vector-type datasets.

(2) Providing information on spatial-temporal patterns of land cover and vegetation parameters

The analyses for deriving information on changes in land cover and vegetation parameters are based on three different kinds of remotely-sensed data: (1) Landsat data from MSS, TM and ETM+ to look back in time till the early 1970s, (2) historical aerial photography to extend the time series by another 20 years, and (3) MODIS satellite imagery with a high temporal resolution to detect intra-annual variations in e.g. biomass or surface temperature.

a) Land-cover change analysis for Kakamega Forest and associated forest areas

The Landsat data time series consists of seven time steps between 1972 and 2001. A threshold analysis based on the green spectral band allowed to distinguish between "forest" and "non-forest" areas but gave only a crude picture. "Forest" included all kinds of forest formations, even plantation of exotic tree species. Therefore a visual interpretation based on three spectral bands was performed to select near-natural forest only. This resulted in very precise information. But being a very time-consuming task, for analysing the complete time series an automated process was preferred classifying the complete area in a number of different vegetation formations or land cover classes. The methodology of a supervised image classification based on ground truth information from diverse vegetation maps as well as detailed field knowledge by project partners and the maximum likelihood decision rule led to a distinction between twelve land cover classes of which six belong to forest formations (see Fig. 2). A shortcome is that plantation forest of *Maesopsis eminii* (planted mixed in with other indigenous tree species) could not be separated. Nevertheless, the classification results form a solid basis for a consistent and detailed evaluation of forest history between 1972 and 2001. With classifications for seven time steps at hand the results have been intensively analysed either numerically (including a complete transition matrix) or graphically (e.g. animations or a synthesis map of forest development types) thus telling the story of both, severe forest fragmentation and disturbance due to human interference but also of forest regeneration where management actions have begun to show effects. A map presentation showing changes in land cover for the ten BDO's of BIOTA-East spread throughout Kakamega Forest and its fragments allows the project partners to interpret their field findings in relation to structural and compositional changes over the last 30 years. The time series will be extended backwards by another 20 years. As a first step the historical aerial photographs have been georeferenced to produce mosaics for 1991, 1965/67 and 1948/52.

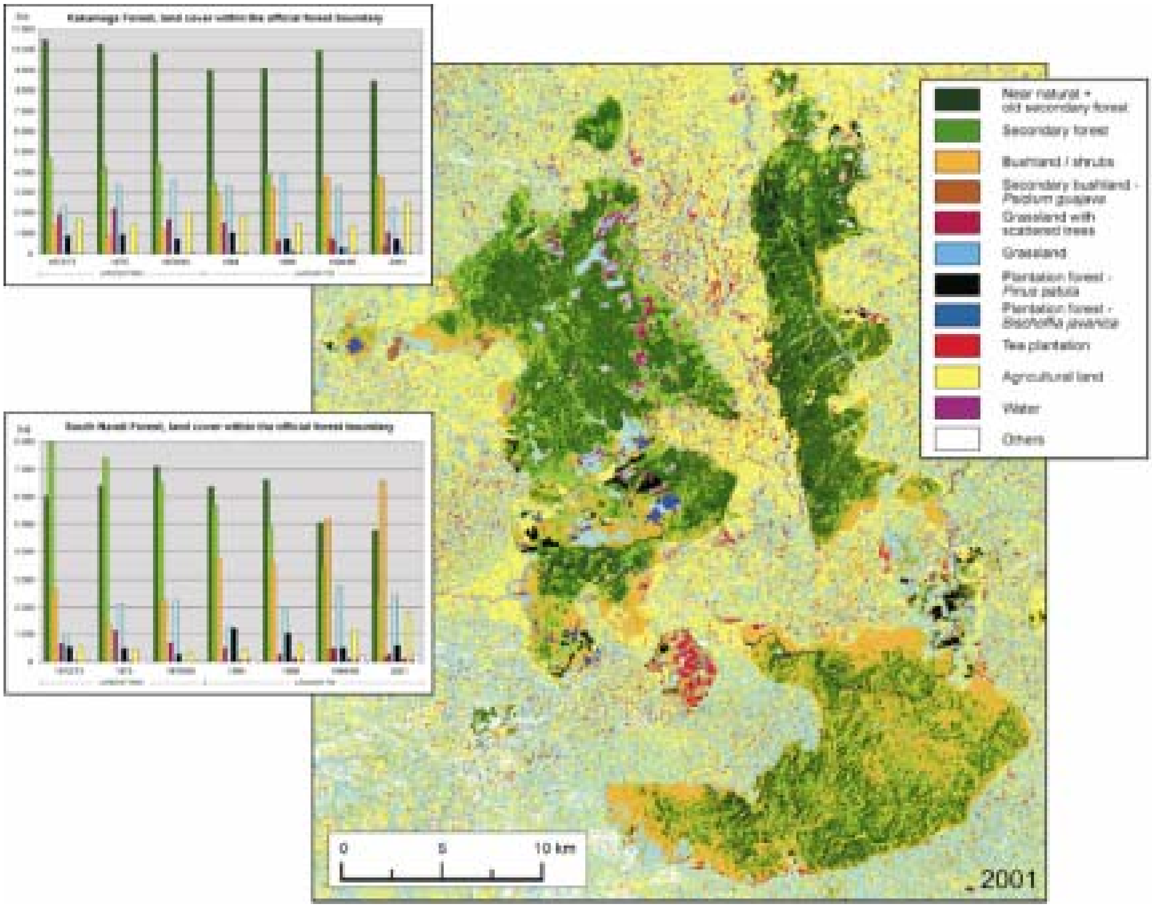

Fig. 2. Land cover classification for Kakamega Forest, the Nandi Forests and surroundings based on Landsat ETM+ scenes from 2001 together with graphs revealing land cover change for seven time steps between 1972 and 2001 for Kakamega Forest and South Nandi Forest as classified also on the basis of Landsat satellite imagery.

b) Deriving intra-annual vegetation parameters for Eastern Africa

Time series of Leaf Area Index (LAI), the Fraction of absorbed Photosynthetically Active Radiation (FPAR) and Land Surface Temperature (T(S)) were derived from MODIS data in order to monitor intra-annual changes for Kenya and Uganda from October 2000 to October 2003. Seasonal variations in these parameters reflect influences of land cover types, precipitation regimes and elevation on biophysical properties of vegetation. In order to improve the MODIS value-adding products (LAI/FPAR and T(S)) the following methodology was developed. The processing chain (see Fig. 3) starts with the detection of data gaps and outliers, the latter found through a spatial stratification approach. Both spatial and linear weighted temporal interpolations are further used to fill the data gaps. Finally harmonic analysis is applied to smooth the LAI, FPAR and T(S) time series and to derive specific output parameters such as amplitude, phase and mean of the included harmonics. On the basis of these parameters the spatio-temporal dataset was classified in an unsupervised clustering approach in order to evaluate characteristic trends of biophysical parameters for certain regions.

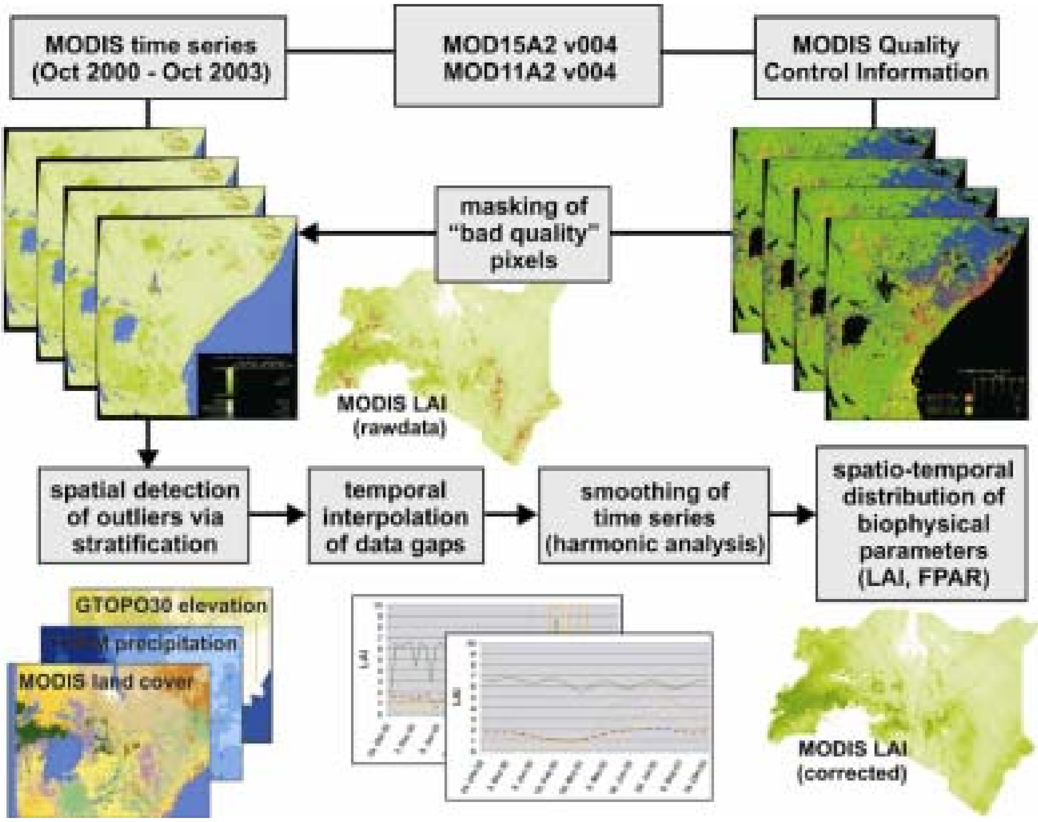

Fig. 3. Flowchart summarizing the MODIS data analysis for deriving intra-annual changes in biophysical parameters for East Africa

Tropical rainforest shows consistent LAI values between 5.9 and 6.8 with maximums of around 7.3 in certain regions of the forest. Differences in forest structure (and therefore in LAI) cannot be easily detected because of the low spatial resolution (1 km). However, a higher seasonality in LAI values at the edges of the forest might indicate (besides mixed pixel effects) higher disturbance levels. Other land cover types clearly follow the precipitation distribution with low LAI values in the dry season and high values after the onset of the rainy season. In addition, grassland and broadleaved crops have a shorter reaction time on rainfall than savannah and shrubland due to their low percentage of woody vegetation cover. Concerning T(S) there is a clear impact of densely vegetated areas. As expected, Kakamega Forest and its associated forest areas show much lower T(S) throughout the year compared to the surrounding agricultural land.

(3) Capacity building

GIS and RS contribute to biodiversity research as they stimulate to extrapolate or scale up from local observations to a wider spatial and temporal extent. They allow for landscape scale conclusions related to global change effects on biodiversity, here in particular to anthropogenic influences. Thus capacity building is followed mainly via direct cooperations with other BIOTA-East subprojects pushing interdisciplinary approaches based on geo-spatial data as well as GIS technology and methods. Typical tasks performed for the project partners include the visualisation of spatial distributions for analysis and/or publications, map overlay and comparison, buffer generation with landscape structure analysis, determination of distances between sample points for tests on spatial autocorrelation, as well as landscape metrics calculations. Capacity building for the Kenyan counterparts included a seminar held in Nairobi.

Soils

(1) Soil physical and chemical properties

Near-infrared reflectance spectroscopy (NIRS) predicts reliably and simultaneously important soil chemical and physical properties for diagnosing soil functional capacity (see Table 1) The results indicate that carbon, nitrogen and particle size were successfully predicted (r^2 >0.80). Overall, the best predictions were achieved for carbon and nitrogen (r^2 >0.90). ECEC, a soil property that does not have a primary response in the near infrared spectral range was accurately predicted by near infrared reflectance (r^2 =0.89). High correlations between ECEC with carbon (r^2 =0.84) may explain this high prediction accuracy.

Table 1. Statistic of near infrared spectroscopy with partial least squares when calibrating signal intensities with soil chemical and physical properties. Shown are the correlation coefficients and the root mean-mean square error (RMSE).

Soil property	r^2	RMSE
% Carbon	0.93	0.111
% Nitrogen	0.92	0.148
Exch. Mg	0.91	0.124
Exch. Ca	0.88	0.166
Exch. K	0.67	0.265
Ext. P	0.54	0.321
pH	0.82	0.03
Exch. CEC	0.89	0.162
Clay	0.82	2.68
Silt	0.88	2.18
Sand	0.91	3.08

(2) Soil quality and Plants

Plant productivity potential of forest-cropland pairs was compared using hybrid maize (grown for 14 days under greenhouse conditions) as an indicator plant. Root to shoot biomass ratio is a suitable parameter for rapid evaluation of plant response to nutrient stress. A generalized linear mixed effects model showed that the probability of observing negative root to shoot ratios for plants grown in Forest and recently converted (RC; <20 yrs) sites was 0.68 while the probability of observing a negative root to shoot ratio in historically converted (HC; 25-60 yrs) sites was 0.31. Positive root to shoot ratios indicate a higher biomass allocation to root tissue in “search” of nutrients. Conversely, a negative root to shoot ratio is indicative for nutrient sufficiency (Fig. 4A). NIRS is suitable for rapid assessment of plant performance. Spectral reflectance of shoot samples drawn from Forest and RC sites were characterised by deeper chlorophyll absorption valleys indicating of high chlorophyll concentration. Conversely, the spectral response of shoot samples from HC sites was characterised by low chlorophyll concentration. Under conditions of nutrient stress, chlorophyll concentrations generally decrease. Low concentrations of chlorophyll can directly limit photosynthetic potential and plant primary productivity (Fig. 4B).

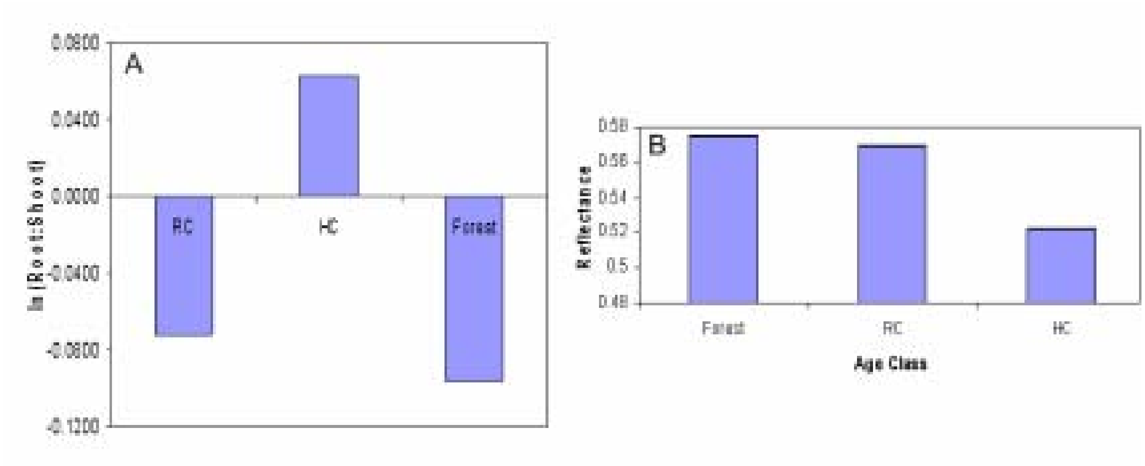

Fig. 4. (A) Root to shoot biomass allocation patterns and **(B)** variations in the normalised difference vegetation index (NDVI) of 14 day old maize seedlings grown in soils of forest, recently converted (RC) and historically converted (HC) sites under greenhouse conditions.

(3) Soil classification

Based on the soil investigations a NIRS spectral index was developed for rapid screening of soil functional capacity status relative to “undisturbed benchmark” land cover types. Three fertility classes (high, medium and low) were defined based on the probability of membership in the modelled “forest class”. We evaluated the sensitivity of the model classes relative to a suite of independently measured soil chemical properties and maize root to shoot ratio measurements. Relationships between Forest Similarity Index (FSI), extractable nutrients, carbon, nitrogen and root to shoot ratios were consistent with changes in soil chemical properties relative to period of cultivation (Table 2).

Table 2. Soil chemical properties and root to shoot ratio of three fertility classes derived from principal components analysis using forest soil near infrared spectra as a benchmark.

	Forest Similarity		
Soil property	***Most Forest like***	***Moderately Forest Like***	***Least Forest Like***
C (g/kg)	32.69	25.99	20.05
N (g/kg)	3.32	2.28	1.89
ExCa (me/100ml soil)	9.89	7.88	7.12
ExMg (me/100ml soil)	1.81	1.25	1.36
ECEC	12.44	9.55	8.90
Pext (mg kg-1)	2.60	2.70	2.74
ExK(cmolc kg-1)	0.28	0.26	0.25
Ln (Root: Shoot)	-0.025	0.16	1.25
PH	6.33	6.02	5.99

(4) Soil organic carbon

Stable carbon isotope analysis revealed medium to long-term changes in soil organic carbon (SOC) input sources associated with deforestation and cultivation. A switch over from dominance in C3 derived carbon to C4 derived carbon in SOC occurs after 37 years of cereal-based cultivation. Mean residence time for C3 source soil organic carbon in converted sites was estimated at 69 years. The lower quartile and upper quartile values were 40 years and 110 years respectively. Under current management practices, cereal residues are mostly grazed or burnt. Average litter into cultivated systems was estimated to be 0.89 ton per ha compared to 8.6 ton per ha in Forest sites. Cultivation systems will only make a modest contribution to SOC in the medium to long term.

Trace Gases

For addressing the impact of disturbance of the Kakamega forest on trace gas exchange between land surface and the boundary layer of the atmosphere three different levels of disturbance were analysed: (1) the northern part of the Kakamega forest (near natural and secondary rain forest), (2) the southern part (highly disturbed rain forest with a large proportion of (exotic) plantation forest) and (3) cultivated land as reference. As an investigation tool an airborne remote sensing platform was developed, calibrated, attached to a Piper Super-Cub and research flights performed.

(1) Trace gas distributions

The investigated trace gas pattern is split into (a) less reactive trace gases and (b) reactive trace gases.

(a) Less reactive trace gases

Over forested areas with different grades of disturbance methane as well as N_2O mixing ratios were comparable with 1.9 ppm methane and 350 ppb N_2O, respectively. Thus, site-specific change in plant diversity is not reflected in the ambient air-mixing ratio of the climate forcing gases methane and N_20. As no significant differences were observed in methane and N_2O mixing ratios between up-wind and down-wind air samples, an airborne determination of fluxes for these compounds was not feasible with the currently available instruments as a result of too less sensitivity.

The trace gas composition over all land use types showed a severe anthropogenic impact mainly as a result of biomass burning as indicated by high acetonitrile (up to 331 ppt) and CO (up to 392 ppb) values as well as visible detection of single fires mainly due to charcoal production going on all over the year.

(b) Reactive trace gases

The reactive gases isoprene and monoterpenes (isoprenoids) contributing together with anthropogenic precursors to ozone and particle formation in the boundary layer amount to about 1.2 pbb and 0.240 ppb, respectively (Fig. 5). Isoprene and monoterpene mixing ratios were generally higher over the forested sites compared to the cultivated site where values were 60% and 30% lower, respectively. The ozone values in this area vary around 50 ppb reflecting also the anthropogenic impact on air quality. In general ozone values were about 5 ppb higher over populated land than over the forest.

(2) Trace gas fluxes

The exchange of isoprenoids was quantified on (a) plant species level and (b) ecosystem level.

(a) Plant species-specific emission

In the Maseno Botanical Garden selected plant species of the Kakamega area are cultivated. 14 typical plant species of the Kakamega forest were screened with respect to the trace gas exchange potential with an open-flow enclosure gas exchange measuring system. All plant species emit isoprenoids and thus are impacting the reactivity of the atmosphere as well as the carbon budget of a rainforest (Table 3). Isoprene emission rates under standard conditions (ca. 25 °C leaf temperature, 1000 µmol m^{-2} s^{-1} photon flux density PPFD for photosynthetically active radiation PAR, ca. 1.5 kPa leaf-to-air water vapour pressure deficit; normalised to projected leaf area) were amounting to 42 nmol m^{-2} s^{-1} for *Croton macrostachys*. Within the monoterpenes emitted 7 different monoterpenes were identified: ζ-pinene, camphene, η-pinene/sabinene $\div^{3}$-carene, limonene, p-cymene and eucalyptol. The monoterpene split emitted is characteristic for the plant species. Most plant species are high limonene emitters with up to 212 pmol m^{-2} s^{-1}. However, *Mahagoni spec.* and *Bridelia microcantha* are high η-pinene/sabiene emitters with an emission rate of up to 318 pmol m^{-2} and s^{-1}. Considering that the carbon of the VOC emitted is mainly resulting from photosynthesis, for example *Croton macrostachys* will loose up to 2% of the photosynthetically fixed carbon via isoprenoid emission. In general, *Croton* and *Maesopsis* species are high isoprenoid emitters compared to other plant species investigated with a factor of 10 to 100 lower emissions potential. It has to be noted that characteristic tree species of the northern part of the Kakamega forest have not been screened yet for their isoprenoid emission potential as corresponding plant material was not available in the Botanical Garden of Maseno.

(b) Ecosystem level exchange

Area-averaged fluxes of isoprenoids were highest over the forested sites with emission rates for isoprene of about 12±6 nmol m^{-2} soil surface area s^{-1} (Fig. 5). Isoprene emission rates for cultivated landscapes were lower with about 4±2 nmol m^{-2} s^{-1}. The sum of monoterpene fluxes amounted to 2±1 nmol m^{-2} s^{-1}. No statistical significant difference was observed between the fluxes of the more or less natural forest part in the north of the forest and the managed part in the south. However, over cultivated land isoprene fluxes were significantly lower compared to the forested sites but monoterpene fluxes were comparable.

(c) Model scenarios

Based on the cuvette studies and MODIS LAI values the ecosystem specific maximum potential of isoprenoid emission was calculated. For a young secondary rainforest with *Harungana* and *Bridelia* species isoprenoid emission may not be larger than 60 nmol m^{-2} s^{-1}. However, in plantations with *Maesopsis*, isoprenoid emission may be as large as 132 nmol m^{-2} s^{-1}. Using *Bischoffia* as plantation tree isoprenoid emission is reduced by a factor of 42 to about 3 nmol m^{-2} s^{-1}. The carbon uptake via photosynthesis is comparable for both plant species with about 60 µmol m^{-2} s^{-1} on ecosystem level. In conclusion, *Bischoffia* has an about 1% higher carbon gain compared to *Maesopsis*. Thus, a *Bischoffia* plantation of 1 km^2 size is able to take up an additional 451 tons CO_2 per year compared to a *Maesopis* plantation of the same size. The amount of 451 tons CO_2 additionally fixed by a non VOC emitting forest plantation is equivalent to the CO_2 output of the live time (100 000 km) of 2 to 3 passenger cars.

Table 3. Isoprenoid emission rates for selected plant species from the Kakamega Forest area. Emission rates are given in pmol m^{-2} projected leaf area s^{-1} for monoterpenes and nmol m^{-2} projected leaf area s^{-1} for isoprene. The range shown represents the span of the emission rates of 9 investigated leaves on three individuals per plant species. Nd: not detectable.

	Monoterpenes							**Isoprene**
Plant Species	***ζ-Pinene***	***Cam-phene***	***η-Pinene /Sabinene***	***÷^{3}-Carene***	***Limo-nene***	***p-Cymene***	***Eucalyptol***	
Mahagoni spec.	29	nd	219	17	152	28	nd	Nd
Mondia whitei	8-30	nd	35-69	4-5	28-41	2-8	nd	0.35-0.69
Prunus africanus	nd-4	nd	4-68	nd	1-33	nd-3	nd	nd-0.40
Markhamia lutea	1-3	4-44	39-61	nd-5	33-99	3-17	nd	0.60-0.62
Tabernae-montana stapfiana	3	4	nd	nd	64	44	3	0.08
Vitex keniensis	14-21	nd	40-176	4-5	79-190	7-61	nd-1	0.50-1.46
Bischoffia javanica	nd-19	5-8	nd-92	nd-7	8-180	9-28	4-5	0.07-0.16
Croton macrostachys	2-5	nd-14	nd-33	nd-4	71-110	11-78	44-111	20.71-41.76
Maesopsis eminii	2-6	nd-6	nd	nd	36-158	5-9	48-149	15.17-21.38
Harungana spec.	nd-4	nd-15	nd-183	nd-4	29-53	3-14	nd-3	0.97-9.48
Croton megalocarpus	nd-28	nd-4	2-44-	2-11	12-212	2-26	nd-7	4.25-10.94
Olea welwitschii	4-9	nd-19	nd-70	1-4	30-87	6-55	nd-10	0.08-0.43
Spathodea campanulata	nd-30	nd-3	18-72	7-25	5-94	3-9	nd-5	0.03-0.28
Bridelia microcantha	nd-5	nd	23-318	1-13	nd-21	Nd-20	nd-4	0.08-0.19

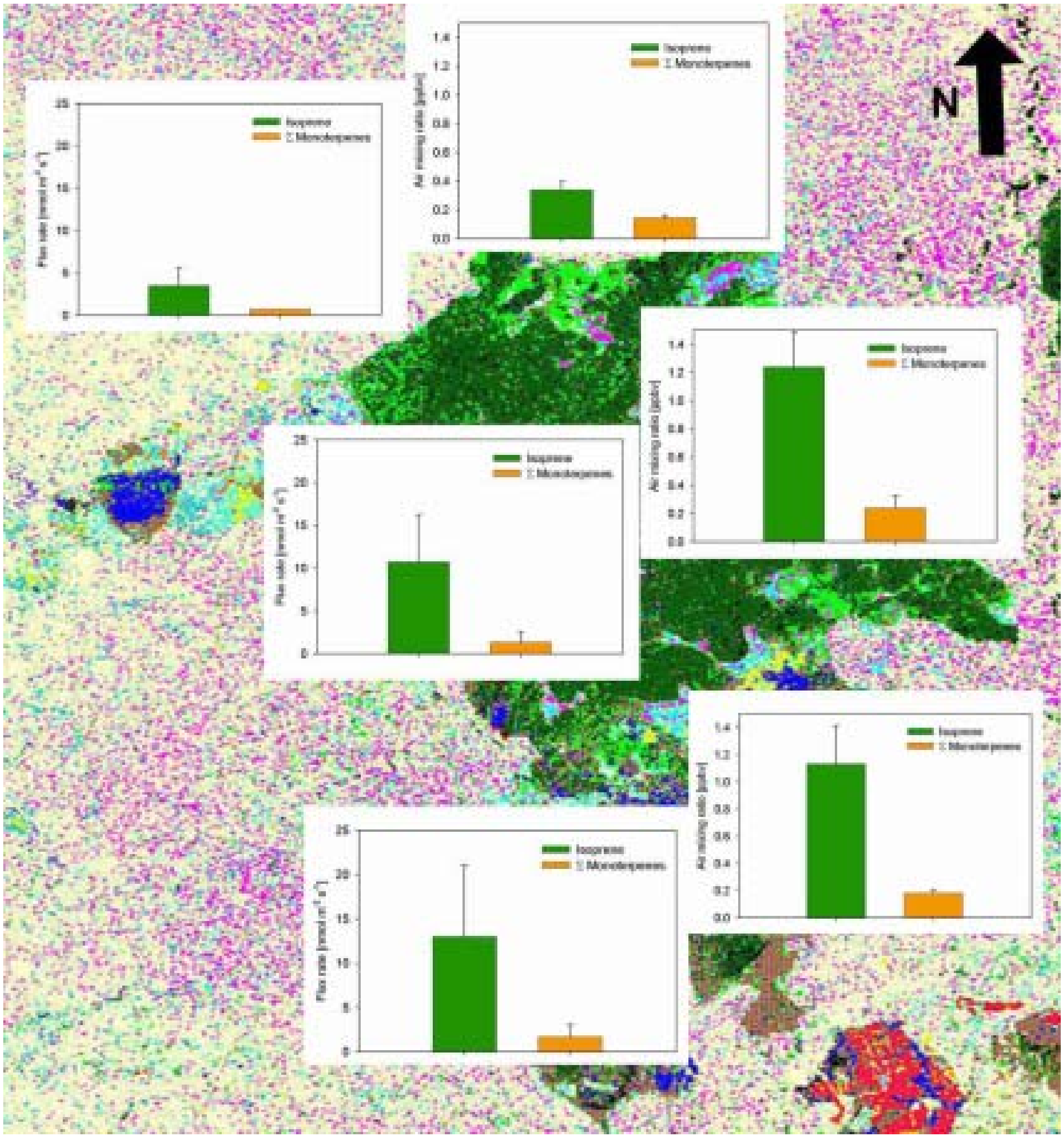

Fig. 5. Mixing ratios of isoprenoids and ecosystem fluxes over ecosystems in the Kakamega area with different grade of disturbance: (A) cultivated land as reference (B) the northern part of the Kakamega forest (near natural and secondary rain forest), (C) the southern part (highly disturbed rain forest with a large proportion of (exotic) plantation forest). Shown are means and the corresponding standard deviation from daily flight missions in the period 06/09 to 06/16/2004. Measurements were performed around noon.

(3) Meteorological parameters

At the meteorological station near the KWS office in the northern part of the Kakamega forest key meteorological parameters were recorded (Fig. 6). The sum of annual precipitation amounted to 1500 mm m^{-2}. Single rainfall events showed a half-hourly mean value of up to 25 mm m^{-2}. Most of the rain events occurred in the months April to July and October/November. Daytime temperatures amounted to 32 °C in February whereas in the night the temperatures may drop to 9 °C. The yearly mean temperature was 20$\pm$4.8 °C in 2002. The annual mean solar energy input was about 1000 W m^{-2} with a photon flux density in photosynthetically active radiation (PPFD) of about 1900 µmol $m^{-2}s^{-1}$. Land surface temperature calculated from MODIS satellite data revealed that the forests are in about 5 to 10 °C cooler compared to the surrounding area, highlighting the cooling properties of forested areas in this landscape.

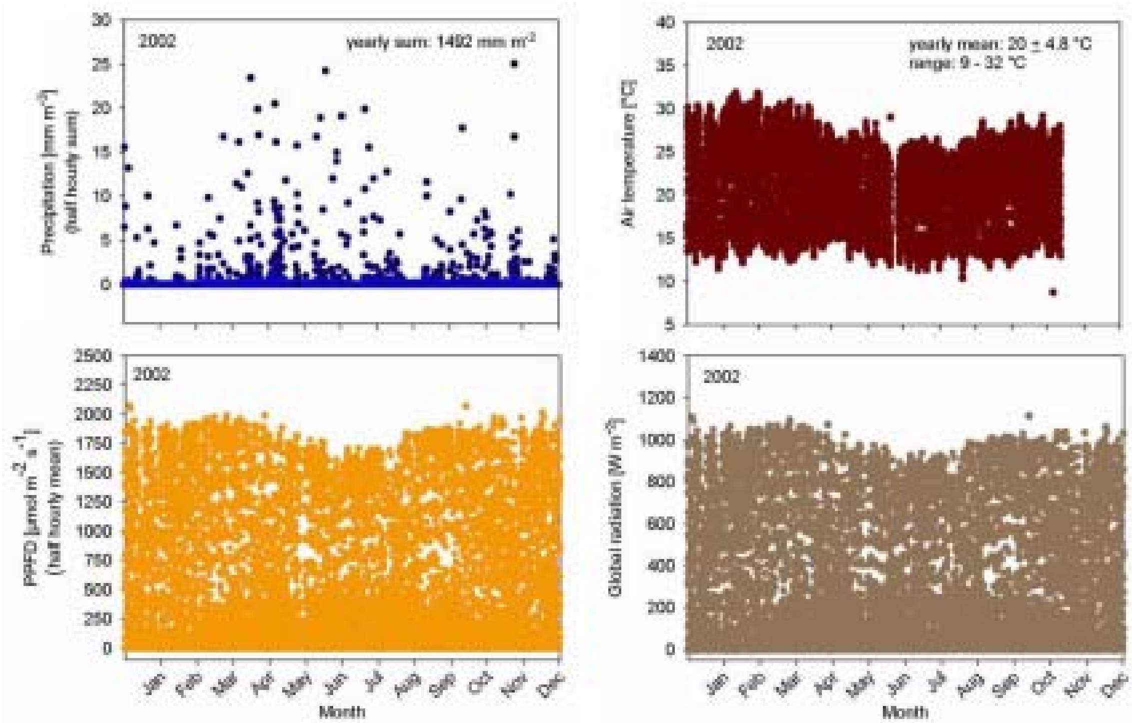

Fig. 6. Meteorological parameters measured in the northern part of the Kakamega Forest for the year 2002.

2.2 Interdisciplinary components

Cooperations within BIOTA

A close cooperation within the BIOTA-East research community allows for diverse benefits related to the BIOTA-East-GIS. It not only serves as data source for the project partners but part of the spatial data sets included have been processed by project partners themselves e.g. by WAC and E12, the latter contributing GIS layers for Maseno University botanical garden.

In E02 there has been a close cooperation between the subproject's working groups from the start. Here, the geodata basis for the modelling of land cover change effects on trace gas composition will be the land cover change time series as well as intra-annual cycles of biophysical parameters like LAI and surface temperature. For E03 GIS helped to georeference the soil pit data and thus enabled overlay and comparison with a reconnaissance map in 1:250'000 scale. For E04 the Landsat image classification of 2001 is of great interest as these project partners plan to come up with a vegetation map showing plant communities for Kakamega Forest. Therefore, the classification scheme was decided on in discussions with E04. As E07 is working on a larger scale or extent, the investigation areas related to dragonfly diversity have been mapped as a start in the direction of distribution maps. In E10 the question aroused if there is a relation between landscape structure and abundance of bees or army ants. This was answered by calculating forest proportions within defined buffers around the observation plots and transects, respectively, by means of GIS. In order to account for spatial autocorrelation effects in the data of E11, every single observation point (39 per plot in 9 BDO's) was located in the GIS and distances calculated between all possible point pairs. And finally, to the joined work on forest disturbance levels of E11, E10 and E03, we contributed indigenous forest patch sizes as delineated via visual interpretation of the most recent Landsat image as well as some maps for the publication of the results. In the Maseno Botanical Garden the gas exchange of latest cultivated plant species from the Kakamega forest was investigated with support of Prof. Onyango from the Maseno University. The research airplane was used for taking aerial photographs of the Kakamega area that were made available for BIOTA-East partners. The meteorological data of the field station near the KWS office of the Kakamega forest are used by interested BIOTA-East partners and are accessible via FTP.

Cooperations outside BIOTA

Thomas Brooks (Conservation International, Washington D.C.) helped with historical aerial photography. Russ Krushka from ILRI (Nairobi) kindly supplied numerous GIS datasets. Both of them will receive their datasets back, including any improvements added in the meanwhile. To Marina Cords and co-workers (Columbia University, New York) we are grateful for copies of rare maps. In reaction we helped with up-to-date information. And Kambona Oscar Ouma (University of Salzburg) is participating in outcomes of the land cover change analysis for Kakamega Forest he wishes to correlate with his eco-tourism data. These data have been promised to BIOTA-East. The PhD thesis of A. Awiti is hosted by the Institute of Botany, University of Nairobi. The airborne sensing platform for atmospheric parameters has been developed with information of the Institute for Flight Control, University of Braunschweig and input from Prof. Dr. Jörg Hacker (Airborne Research Australia, Flinders University, Adelaide, Australia). Flight missions were performed with the ever available and uncomplicated support of Christian Strebel and his Yellow Wings team, Nairobi.

2.3 Likely benefit and applicability of results

GIS and RS

Biodiversity research is in need of geo-spatial data, especially when working at the landscape level and including global change aspects. Therefore, geo-spatial data need not only to describe the recent environment but also changes that have occurred in the past or even those that are likely to happen in the future.

The BIOTA-East-GIS forms the basis for a) the extrapolation and scaling-up of individual observations to the landscape scale, b) conclusions related to global change effects on biodiversity, here in particular to anthropogenic influences, and c) the interdisciplinary integration of findings by the different research projects. The structure of the GIS is flexible. Thus further levels can be easily included, e.g. for the geodatasets on Maseno University botanical garden (provided by E12), the data on biophysical parameters with a wider East African extent as well as the new Ugandan study sides of the 2nd BIOTA-East project phase. If required, the BIOTA-East geodata could be also integrated in a common pool with the geodata of BIOTA-South and -West.

The remote sensing time series analyses (land cover as well as biophysical parameters) are important input parameters for modelling changes in trace gas composition of the tropical atmosphere due to human interferences. But the results will also help to answer other ecological and socio-economic research questions of BIOTA-East, thus contributing more directly to biodiversity research. The improved time series of intra-annual variations in LAI, FPAR and T(S) can be used to quantify the effect of biotic and abiotic factors on biodiversity change. Time series of land cover change document not only changes in area but will be also assessed regarding biodiversity-related indicators as valuable tools for biodiversity management. They will be further made use of when developing a model of land use/cover change based on natural as well as socio-economic driving factors. Such a model enables to look at possible future scenarios.

Elaborating capacity building via an even more close cooperation with the other BIOTA-East subprojects as well as the Kenyan counterparts will ease an interdisciplinary and integrative assessment of biodiversity change at the landscape scale and will finally help in drawing recommendations and statements for conservation planning of East-African rainforests.

Soils

Near-infrared reflectance spectra are sufficiently sensitive to subtle variations in soil chemical properties and plant response associated with land use and land management. Development of strategic spectral libraries at watershed level for ‘undisturbed’ benchmark sites and sites at various stages post disturbance offer a great potential for monitoring soil quality change. Once a suite of diagnostic indicators of soil health are identified, the spectral library approach can be used to develop a Benchmark Similarity Index (BSI) to routinely monitor management or disturbance induced changes in soil quality and plant performance. BSI can then be used to establish allowable ranges for optimal soil functioning as well as clarify the limits to ecologically sustainable management interventions. The BSI provides a reliable platform evolving a strategy for anticipatory management of soil quality.

Trace Gases

The airborne platform for sensing atmospheric parameters is now a tool that can be used by European small environmental research aircraft fleet for detecting atmospheric composition change in the boundary layer as contribution to the IGBP-program. Emission factors of VOC of plant species characteristic for East-African forest communities will improve biogenic VOC emission inventories for example needed for quantifying the natural impact on air quality in East-African landscapes. The highly plant specific emission of VOC significantly reduces the carbon sink in the vegetation and is not yet considered in the carbon budget of the ecosystems. The presented results will aid decision makers looking for most productive trees with most environmental as well as economical benefit for future reforestation programs. For example, selecting the plantation tree with the best carbon gain will directly and positively impact the CO_2 trading business in the frame of the Kyoto protocol.

2.4 Publications resulting from the project

Papers

Althof, A., G. Schaab & E. Fischer (in prep.): Mapping vegetation in the Buyangu National Reserve (Kakamega, Kenya) by means of remotely-sensed imagery.

Awiti, A.O. & M.G. Walsh (in prep): Nutrient stress detection of Maize plants: Early detection and discrimination using near infrared reflectance spectra (NIRS).

Awiti, A.O., M.G. Walsh & K.D. Shepherd (in prep.): Spectral discrimination of changes in soil properties associated with tropical forest conversion.

Awiti, A.O., M.G. Walsh & K.D Shepherd (2004): Spectral discrimination of changes in soil properties associated with tropical forest conversion. In Woomer, P.L. and Lynam, J.K. (Eds.). Enhanced Soil Productivity in East and Southern Africa: Program, Participants and Abstracts. Rockefeller Foundation Grantees Workshop, 20 to 23 September 2004, Safari Park Hotel, Nairobi, Kenya, 70pp.

Bleher, B., N. Saijita, K. Böhning-Gaese & G. Schaab (in prep): Seedling diversity in peril? The effect of fragmentation and disturbance in Kakamega Forest, Kenya.

Junkermann, W., R. Steinbrecher, F. Homburg & J. Burger (in prep.): Atmospheric turbulence measurements with a new highly integrated 5-hole-probe system for small environmental research aircrafts.

Kraus, T. & G. Schaab (2003): Biodiversitätsforschung in Westkenia - Mit GIS und Fernerkundung von lokalen Beobachtungen zu Aussagen in Zeit und Raum. In: Strobl, J., T. Blaschke & G. Griesebner (Hrsg.), Angewandte Geographische Informationsverarbeitung XV, Beiträge zum AGIT-Symposium Salzburg 2003, Heidelberg, 244-249.

Lung, T. & G. Schaab (2004): Change-detection in Western Kenya – The documentation of fragmentation and disturbance for Kakamega Forest and associated forest areas by means of remotely-sensed imagery. In: ISPRS Archives, Vol. XXXV, Part B (CD-ROM), Proceedings of the ISPRS XXth Congress, 12.-23. Juli 2004, Istanbul.

Müller, U., C. Conrad & T. Kraus (2004): Analyse der raum-zeitlichen Vegetationsdynamik in Ostafrika unter Verwendung von MODIS-Daten. In: Strobl, J., T. Blaschke & G. Griesebner (Hrsg.), Angewandte Geoinformatik 2004, Beiträge zum 16. AGIT-Symposium Salzburg, Heidelberg, 484-489.

Peters, M., G. Schaab & M. Kraemer (in prep.): Impact of habitat fragmentation on swarm-raiding army ants.

Schaab, G. (2001): Comparative analyses of biodiversity in the Kakamega Forest (Western Kenya) - The use of GIS within the BIOTA-East project. In: Proceedings of the AfricaGIS Conference, 5.-9. November 2001, Nairobi.

Schaab, G. (2004): Aus der Ferne in und für Kenia aktiv. In: Magazin der Fachhochschule Karlsruhe – Hochschule für Technik und des Vereins der Freunde und seiner Freundeskreise, 25. Jg. / Nr. 50, 45-46.

Schaab, G. (2004): Biodiversitätsforschung in Ostafrika – nur ein Abenteuer für Kartographen? In: H. F. Kern (ed.), 50 Jahre Sektion Karlsruhe der Deutschen Gesellschaft für Kartographie e.V. Festschrift. Karlsruher Geowissenschaftliche Schriften, Rh. A, Bd. 16., 222-229.

Schaab, G., B. Hörsch & G. Strunz (2002): GIS und Fernerkundung für die Biodiversitätsforschung im Rahmen des BIOTA-Projektes. In: CD-ROM mit den Tagungsbeiträgen zum 19. DFD-Nutzerseminar, 15.-16. Oktober 2002, Oberpfaffenhofen.

Schaab, G., T. Kraus & G. Strunz (in press): GIS and Remote Sensing Activities as an Integrating Link within the BIOTA-East Africa Project. In: Proceedings of International Symposium on Sustainable Use and Conservation of Biological Diversity, 1.-4. Dezember 2003, Berlin.

Schaab, G. & R. Steinbrecher (2002): GIS-Unterstützung bei der Abschätzung des Stoffaustauschs zwischen tropischen Waldökosystemen und der Atmosphäre. In: IFU-Jahresbericht 2001, 80-84.

Schaab, G., R. Steinbrecher, T. Lung, T. Kraus, G. Strunz, D. Steigner & T. Winters (in prep): Effects of rainforest degradation on biogenic VOC emission: A case study for the Kakamega Forest and neighbouring forested areas in western Kenya.

Steinbrecher, R., W. Junkermann, F. Homburg & D. Steigner (in prep.): Airborne REA-flux measurements for isoprenoids: System development and application.

Steinbrecher, R., W. Junkermann, F. Homburg, D. Steigner, R. Zuurbier, G. Schaab, T. Kraus, G. Strunz, A. Awiti & M.G. Walsh (2003): Impact of changing biodiversity in tropical agro-forest ecosystems in Africa on the exchange potential of trace gases between ecosystems and atmosphere: BIOTA-East E02, Poster, International Symposium „Sustainable use and conservation of biological diversity, Berlin, 01.12- 04.12.2003, Tagungsband, Projektträger DLR, Bonn, ISBN 3-00-012577-9, pp 104-105.

Steinbrecher, R., R. Zuurbier, W. Junkermann, F. Homburg & D. Steigner (2003): Airborne turbulent flux measurements of trace gases: problems and solutions. In: Proceedings of ILEAPS: Intergrated Land Ecosystem - Atmosphere Process Study, Arneth A. (ed), Report Series in Aerosol Science; 62B, Vol.2, ISBN 952-5027-41-4, 394-98.

Walter, M. & G. Schaab (in press): WebGIS zur Unterstützung von Online-Geodatenkatalogen – Realisierung für das BIOTA-Ostafrika-Projekt. In: Kartographische Nachrichten. Fachzeitschrift für Geoinformation und Visualisierung.

Abstracts

Awiti, A.O. & M.G. Walsh (submitted): Spectral detection of changes in soil and plant quality following deforestation and cultivation. Soil and Water Conservation Society 2005 Annual conference July 30-August 4. Hyatt Regency and Riverside Convention Centre, Rochester, NY.

Awiti, A.O., MG. Walsh & K.D .Shepherd (2003): Locating the frontiers of deforestation: Evidence from multi-date satellite imagery and tree-structured classifiers.

Bleher, B., K. Böhning-Gaese & G. Schaab (2003): Human impact on seedling establishment of animal-dispersed trees. Poster contribution to the 17. Jahrestagung der Gesellschaft für Tropenökologie, Biodiversität und Dynamik in tropischen Ökosystemen, 18-20 February 2004, Bayreuth (Abstract: Program and Abstracts of the 17th Annual Meeting of the Society for Tropical Ecology (gtö), Biodiversity and dynamics in tropical ecosystems, 96).

Bleher, B., K. Böhning-Gaese & G. Schaab (2003): Human Impact on seedling establishment of animal-dispersed trees. Oral presentation at the ATB meeting 2003, Biotic Interactions in the Tropics (A special symposium of the British Ecological Society and the Association for Tropical Biology and Conservation), 7-10 July 2003, Aberdeen (Program and Abstracts of the ATB meeting 2003, 37).

Bleher, B., G. Schaab & K. Böhning-Gaese (2003): Man, Birds and Berries – Human Impact of Forests and Plant-Animal-Interactions. 16. Jahrestagung der Gesellschaft für Tropenökologie, 19.-22. Februar 2003, Rostock (Abstract: Tagungsband 16. Jahrestagung der Gesellschaft für Tropenökologie, Tropische Biodiversität im globalen Wandel, 29).

Schaab, G., A. Awiti, R. Forkel, W. Junkermann, G. Strunz, M. Walsh, R. Zuurbier & R. Steinbrecher (2002): Die Abschätzung des Stoffaustauschs zwischen tropischen Waldökosystemen und der Atmosphäre – ein Beitrag zum Forschungsschwerpunkt Biodiversität und Globaler Wandel. Poster contribution to the BMBF-Tagung "Bedeutung der Wechselwirkungen Biosphäre - Atmosphäre für die nachhaltige Nutzung der Biosphäre und den Klimaschutz", 16-17 September 2002, Bonn (Abstract-

Band, Themenbereich: Landnutzungsänderungen und ihre Rolle für den Spurengashaushalt der Erde, 35).

Schaab, G., T. Kraus & G. Strunz (2004): GIS and remote sensing activities within BIOTA-East Africa. Poster contribution to the 17. Jahrestagung der Gesellschaft für Tropenökologie, Biodiversität und Dynamik in tropischen Ökosystemen, 18-20 February 2004, Bayreuth (Abstract: Program and Abstracts of the 17th Annual Meeting of the Society for Tropical Ecology (gtö), Biodiversity and dynamics in tropical ecosystems, 99).

Schaab, G. & R. Steinbrecher (2001): Land Cover changes and its impact on biogenic VOC emission. Poster contribution to the Global Change Open Science Conference, 10-13 July 2001, Amsterdam (Abstract: Challenges of a Changing Earth, IGBP Stockholm, 2001, P.6.0.015, 311).

Steinbrecher R., W. Junkermann, R. Zuurbier, D. Steigner, B. Rappenglück, J. Burger & G. Schaab (2003): Biodiversity of the Kakamega forest in Kenya and the impact of increasing pressure through population: A new technique for assessing area averaged change in trace gas exchange between ecosystems and the atmosphere. Tropische Biodiversität im globalen Wandel : 16.Jahrestagung der Gesellschaft für Tropenökologie, Universität Rostock, 19.-22. Februar 2003, Tagungsband S.70.

Steinbrecher, R., R. Zuurbier, W. Junkerman, F. Homburg & D. Steigner (2003): A new technology for studying trace gas exchange between biosphere and atmosphere on human impacted biodiversity change in rainforests, AGU Chapman Conf. on Ecosystem Interactions with Land Use Change, Santa Fe, N.M., June 14-18, 2003, Book of Abstracts S.60.

Theses

Herz, O. (2004): Georeferenzierung und Mosaikierung von historischen Luftbildern für den Kakamega Forest und assoziierte Waldgebiete (Westkenia) sowie erste visuelle Auswertung bzgl. Landbedeckungsänderungen. Unpublished Bachelor thesis, Karlsruhe University of Applied Sciences, Department of Geoinformation.

Lung, T. (in print): Landbedeckungsänderungen im Gebiet „Kakamega Forest und assoziierte Waldgebiete“ (Westkenia) - Multispektrale Klassifikation von Landsat-Satellitenbilddaten und Auswertung mittels Methoden im Raster-GIS. In: Karlsruher Geowissenschaftliche Schriften, Rh. A, Bd. 15, ed. by G. Schaab.

Müller, U. (2004): Raum-zeitliche Analyse der Vegetationsdynamik in Ostafrika anhand von MODIS-Daten. Unpublished Diploma thesis, University of Würzburg, Chair for Remote Sensing.

Walter, M. (2003): WebGIS-Einsatz zur Unterstützung von Online-Geodatenkatalogen - Applikationen im Rahmen des BIOTA-Ostafrika-Projekts. Unpublished Diploma thesis, Karlsruhe University of Applied Sciences, Department of Geoinformation.

3. Capacity building

3.1 Technical capacity building

The WAC-staff was trained to operate the meteorological station at the KWS office in the Kakamega Forest.

3.2 Students and scientific staff trained

PhD thesis: Alex Awiti, WAC, Department of Botany, University of Nairobi, Kenya - Linking Soil functional capacity decline to land use and land cover change: A case study of Kakamega forest ecotone.

Diploma thesis: Meike Walter, Karlsruhe University of Applied Sciences - WebGIS-Einsatz zur Unterstützung von Online-Geodatenkatalogen - Applikationen im Rahmen des BIOTA-Ostafrika-Projekts.

Diploma thesis: Tobias Lung, Karlsruhe University of Applied Sciences - Landbedeckungsänderungen im Gebiet „Kakamega Forest und assoziierte Waldgebiete“ (Westkenia) - Multispektrale Klassifikation von Landsat-Satellitenbilddaten und Auswertung mittels Methoden im Raster-GIS.

Bachelor thesis: Oliver Herz, Karlsruhe University of Applied Sciences - Georeferenzierung und Mosaikierung von historischen Luftbildern für den Kakamega Forest und assoziierte Waldgebiete (Westkenia) sowie erste visuelle Auswertung bzgl. Landbedeckungsänderungen.

Diploma thesis: Ulrike Müller, University of Würzburg – Raum-zeitliche Analyse der Vegetationsdynamik in Ostafrika anhand von MODIS-Daten.

Seminar: Gertrud Schaab, DFD-DLR / IMK-IFU – GIS in Biological Sciences. At the National Museums of Kenya (NMK), Centre for Biodiversity, Nairobi, 12 November 2001.

Subproject E03

Regeneration of tropical-montane tree species – Spatio-temporal dynamics of positive feedback processes

Subproject leader: Dr. H. Dalitz, University of Bielefeld	
Short title: BIOTA E03	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

Within this project we wanted to investigate the role of tree species diversity and dispersion on ecological processes like canopy throughfall, changes of soil conditions and regeneration. Main hypothesis was that the spatial differentiation of the canopy caused by the different species within a plot is one of the main reasons for spatial heterogeneity of ecological processes. The resulting spatial differentiation of water and nutrient input and the light conditions will cause different conditions for the establishment of tree species seedlings. Therefore we expected a positive feedback process for the regeneration of tree species where the driving forces are spatial heterogeneity of abiotic processes and disturbance by humans.

Planning and conduction

According to this hypothesis we conducted detailed research plans before the project started. The plans were based on a hypothesis, which proposes a feedback process between structural and functional components on the process of tree species regeneration (Dalitz et al. 2000; Dalitz et al. 2004).

The study is plot-based within the biodiversity observation plots of the BIOTA-East project. The study is individual-based also, which means that each tree or seedling is individually marked and growth is recorded monthly. Within the plots collectors for canopy throughfall and litter fall were installed. Water and nutrient pathways were recorded for two years on a weekly or daily basis. Soils were investigated grid-based within the plots with a high number of samples and, additionally with soil pits in each of the biodiversity observation plots.

First step was the installation of the plots, marking and determining the trees with all attached data (position, tree height, tree diameter). In this step regeneration observation plots were marked to avoid their further disturbance. Second step was the installation of dendrometers for the recording of the incremental growth of each tree within the plots with more than 10 cm DBH. Thirdly the collectors for canopy throughfall and litter fall were installed together with the soil sampling. Each step gave preliminary results and a high number of samples for further analysis. This analysis was done both in Kenya and Germany. The sampling was started within the proposed time. The soil samples, which were collected within this step were partly analysed in Kenya in the soil lab of ICRAF in Maseno (especially for grain sizes). Nutrient analyses and the sample preparation for this were proceeded in Bielefeld, Germany. Additionally a joint cooperation between the BIOTA-subprojects was established for a detailed analysis of soils in all biodiversity observatories. This investigation was proceeded by E03 (Musila et al., in press).

In each site of the BIOTA-East framework three plots were installed as replicates for this site. The numbers of investigated plots differ for the different work packages. In the second workpackage 30 plots were investigated according the tree species composition, and diversity, tree species growth and seedling establishment. For the detailed soil analysis 12 plots were chosen from the northern part of Kakamega Forest, excluding the fragments. For the first workpackage only nine plots could be installed for the water and nutrient flux studies. This was decided due to the high number of resulting samples and the costs of chemical analysis and the time consumption.

In general the proposed work plan was successfully finished according to most of the milestones and expected results. Exceptions are the following topics: Workpackage 1: Due to the comments of the reviewers we reduced the number of replicates per site from 5 to 3. Workpackage 2: First, the determination of the minimum area for seedling plots was found to be time consuming; therefore we decided to use a common plot size of 4 m^2. Secondly, we decided that in the first phase not to conduct experiments on seedling establishment, but to record the fate of individual seedlings in 30 plots in a monthly interval. This very detailed work is still in progress to be evaluated and will later be compared with surveys of E11. Workpackage 3: The anatomical studies of the leaves which were investigated concerning their nutrient loss is still in progress. All other plans were successfully finished. Additionally the soil studies were done much more intensive than planned, and the results will be published soon.

Cooperations with other institutions

Cooperations were established successfully with the following institutions:

National Museums of Kenya, Herbarium Department (NMK), Nairobi: For the determination of species the herbarium could be used and the knowledge of the herbarium was offered for the determinations. One member of the NMK, Mrs. Winfred Musila was trained in theoretical and practical aspects of soil analyses. Mrs. Musila spent a lot of time in the German lab in Bielefeld to be successfully trained in the techniques of element analyses using the Atomic Absorption Spectrometry (AAS). This includes sample preparation, procedures of standardization, techniques of decontamination and data analysis.

ICRAF, Nairobi: The cooperation with this international institute is of great importance for the whole BIOTA framework concerning the maintenance of the project cars, the possibility to import scientific items to Kenya. For our project the cooperation was quite close in the fields of soil investigations, joint publications (Dr. Alain Albrecht in Musila et al. in press) and a joint investigation on spectrometric data of soils from different origins of the Kakamega Forest (Dr. Keith Shephard). The water purification system was built up in the lab of the ICRAF in Kisumu and used by E03 and the ICRAF staff.

Kakamega Environmental Education Program (KEEP): In a joint project a nature trail was built at Buyangu Hill together with members of the KEEP, which is now used by local people, school classes and tourists as well.

DFG-Research group 402 (working in Ecuador): With this group there are close connections on two fields: a) development of ‘Visual Plants’ as a database for the visual determination of plants; b) scientific cooperation on spatial heterogeneity of canopy throughfall, light conditions and tree growth, dispersion and diversity. Two of the projects in this research group use the same methodology like E03 did in Kakamega.

University of Costa Rica, San Ramon: With the department of botany there are close cooperations on the development of the database 'Visual Plants' and on the ecological processes in an undisturbed tropical rain forest. This allows interesting comparisons concerning the influence of disturbance on the development of diversity.

University of Luxembourg, Dr. Martin Schlather: With this institute we had substantial discussion about the analysis of the data concerning the usability of geostatistical methods. This cooperation will lead to a more detailed analysis of our data.

University of Duisburg-Essen, Department of Molecule- and Polymerspectroscopy, Prof. Siesler: In this cooperation NIR spectroscopy was performed with the soil samples from 12 plots, to get information about the organic matter in the soil profiles.

2. Results

2.1 Scientific results

Within this subproject results for different components of our hypothesis (see Fig. 1) were gained. Results for the different workpackages will be presented in the separate chapters. In general, E03 has gained information about tree species diversity in 30 investigation plots, in which all trees were marked individually and incremental growth was recorded for all trees with more than 10 cm breast height diameter. The 30 investigation plots were installed in the BIOTA biodiversity observation plots and cover all 10 sites of the Kakamega Forest, including the fragments (Fig. 2).

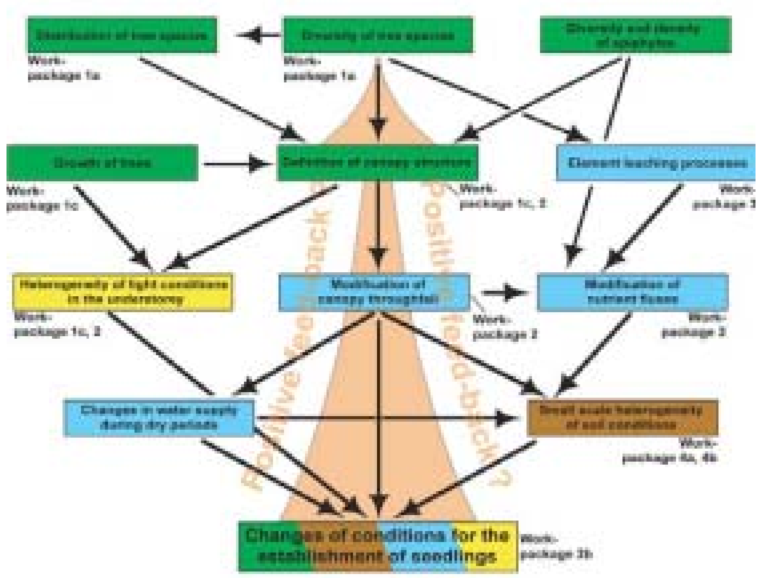

Fig. 1. General structure of the project and the underlying hypothesis

In and around all plots investigations on disturbance were conducted together with the subprojects E10 and E11. In all 30 plots results were gained about seedling recruitment and seedling survival, based on individually marked seedlings. In three sites in the northern part of the Kakamega Forest (Buyangu Hill, Colobus and Salazar) nine plots (three per site) were installed for a detailed investigation on canopy throughfall and water nutrient transport from canopy to soil. For a one-year period litter fall was recorded on a weekly basis, to get information about this pathway of nutrient input to the soil. Mineralization rates of single leaves were measured using litterbags and a photographic method for recording the destruction of single tree leaves of different plant families.

Photosynthetic radiation (PAR) was measured directly using the SunScan system and was calculated from hemispherical photographs in all plots. Canopy structure was estimated from hemispherical photographs.

Leaching experiments were conducted from single tree leaves (with different ages and from different families) and gave information about the different amount of nutrient losses out of the leaves.

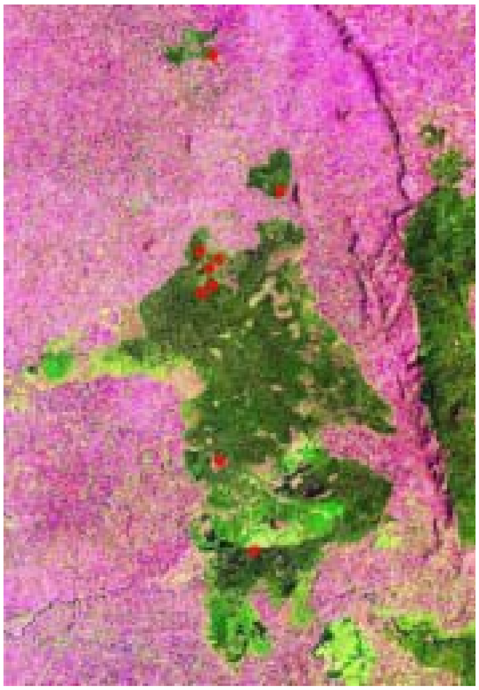

Fig. 2. Location of the investigation plots of the subproject E03 (red dots).

Soil investigations were preceded in 12 plots very intensively using soil cores and additionally in all 10 sites by analysing soil properties in soil pits. Spectroscopic measurements were conducted from the soil samples to get information about the organic matter in the soil profile. Results from this part are not available yet, because the data are being analysed. First preliminary results indicate that in the soils there is no clear development of horizons and organic matter is transported throughout the profile gradually.

This small summary shows that more or less all parts of the proposed hypothesis are under investigation by the subproject. All results show a high spatial heterogeneity, but at the same time a high temporal variability. This is especially true for the canopy throughfall. The spatial heterogeneity of canopy structure, of canopy throughfall, of light conditions, of leaching processes (along the diversity of the trees from which nutrients are leached out) and the soil conditions support the proposed hypothesis. But within E03 (and the DFG-project in southern Ecuador) this spatial heterogeneity is investigated at the first time in that intensity of a high number of parameters at the same sites.

Workpackage 1

Workpackage 1 contained the investigations of canopy throughfall as a function of water and nutrient fluxes from canopy to soil. As a first result a high temporal variability was found (see Fig. 3). This indicates that the rain intensity at the different days is one important factor for the spatial distribution of canopy throughfall. But at the left upper corner there is one part of the plot, which gets more canopy throughfall than others parts, which clearly indicates that the canopy structure is important for this result.

As a second example, Table 1 shows the spatial heterogeneity of canopy throughfall in all investigated plots. The minimum and maximum values differ significantly from the mean. A high regional variance can be seen between the three different sites, where ‘Colobus’-plots get much more canopy throughfall than the two other sites.

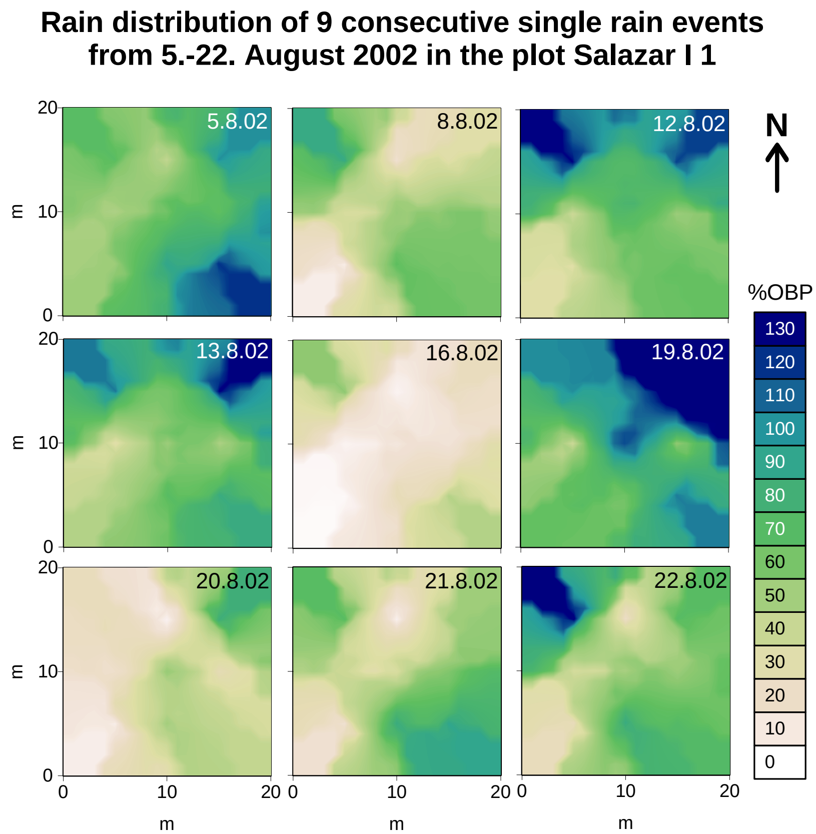

Fig. 3. For 9 consecutive rain events from 5.-22. August 2002 the distribution of canopy throughfall is shown as percentage of open beds precipitation.

Table 1. Mean values of canopy throughfall during a period from 13.5. to 22.8.2002. Additionally from the nine collectors the minimum and maximum value is shown.

Plot name	Mean	Minimum collector	Maximum collector
Buyangu Hill 1	68,31	28,10	87,13
Buyangu Hill 2	69,06	30,36	96,38
Buyangu Hill 3	64,47	49,55	88,53
Colobus Trail 1	81,14	66,22	92,02
Colobus Trail 2	79,58	56,29	99,77
Colobus Trail 3	71,35	63,38	79,26
Salazar I 1	67,99	35,58	118,27
Salazar I 2	72,29	42,52	95,02
Salazar I 3	69,59	34,08	97,43

There is conspicuous differentiation according to the rain event intensity as it is shown in Figure 4. Minimum and maximum rain intensity shows different spatial pattern in the canopy throughfall, which may then affect the conditions under which seedlings have to survive.

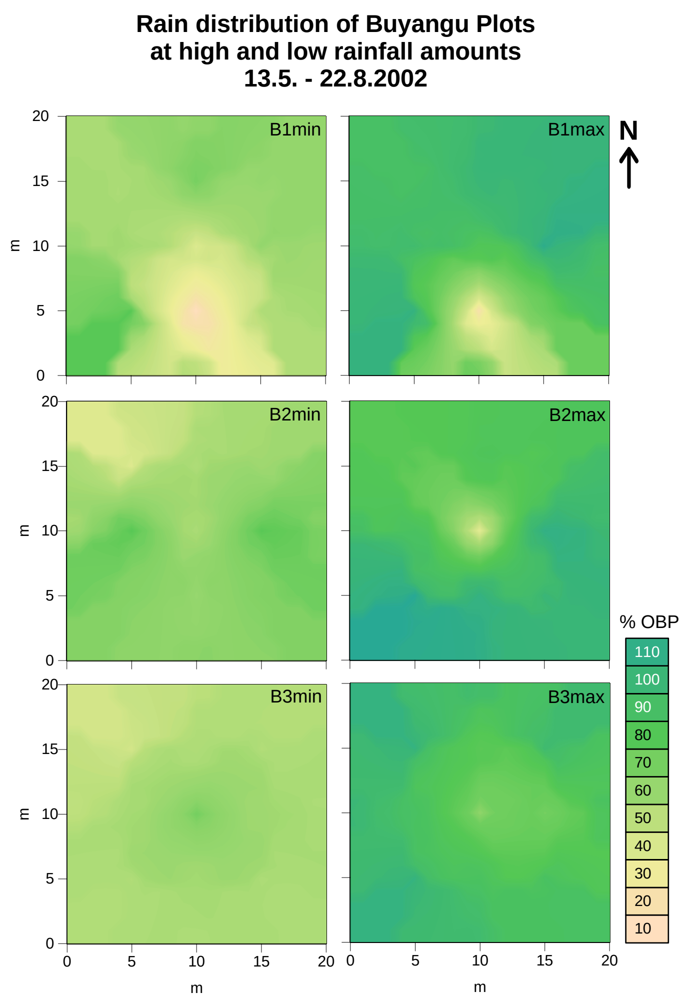

Fig. 4. For three plots from Buyangu Hill the graph shows the distribution of canopy throughfall as percentage of open beds precipitation differentiated into rain events with more than 150% of the mean (max) and less than 50% of the mean value for the rainfall.

With the rainfall not only nutrient elements were imported into the exosystem but also heavy metals. Based on six rain events in October/November 2001 we calculated the annual input of heavy metals as shown in Table 2. These are preliminary results, which should not be used for further decisions. But, collected samples fro a one year period are under investigation to clarify whether the indicated heavy metal input is consistent over the whole year or not. But, for a first analysis the data show that for all heavy metals an enrichment factor was found indicating that the pathway of input for heavy metals is not only the rainfall but also the dry deposition of ions on leave surfaces, except of nickel. The high input of nickel can be traced as an input from geogenic nickel sources. These are nickel-containing layers in East Africa where high nickel concentration in minerals can be found on the surface. In case of lead and zinc the high input values may be anthropogenic caused by traffic and industrial sources.

Table 2. Preliminary results of the annual input of heavy metals into the Kakamega Forest ecosystem based on the six rain events in 2001 (October to November). In all cases an enrichment factor was found from rainfall to canopy throughfall.

	Al 27	**Mn 55**	**Ni 60**	**Rb 85**	**Sr 88**	**B**	**Ba**	**Pb**	**Zn**	**Sum**
	$g*ha^{-1}a^{-1}$	$g*ha^{-1}a^{-1}$	$g*ha^{-1}a^{-1}$	$g*ha^{-1}a^{-1}$	$g*ha^{-1}a^{-1}$	$g*ha^{-1}a^{-1}$	$g*ha^{-1}a^{-1}$	$g*ha^{-1}a^{-1}$	$g*ha^{-1}a^{-1}$	$g*ha^{-1}a^{-1}$
Rainfall	32,42	30,38	108,25	23,20	33,58	55,31	73,41	76,97	67,36	500,88
Canopy throughfall	86,64	94,66	112,31	269,21	372,99	446,43	115,16	187,79	160,94	1846,13
Factor	2,67	3,12	1,04	11,61	11,11	8,07	1,57	2,44	2,39	

Workpackage 2

In workpackage 2 structural characteristics of the stands were to be investigated followed by investigations on seedling establishment. During the project period it became clearer that the assumption that the northern part of Kakamega Forest might be a more or less untouched forest is not true. A study initiated by E03, E10 and E11 (Bleher et al. 2004; Mitchell 2004) shows that the Kakamega Forest has a long tradition in different amounts of disturbance. Due to this report we analysed the similarity of tree species composition between the plots using the NESS-index followed by a NMDS (Fig. 5).

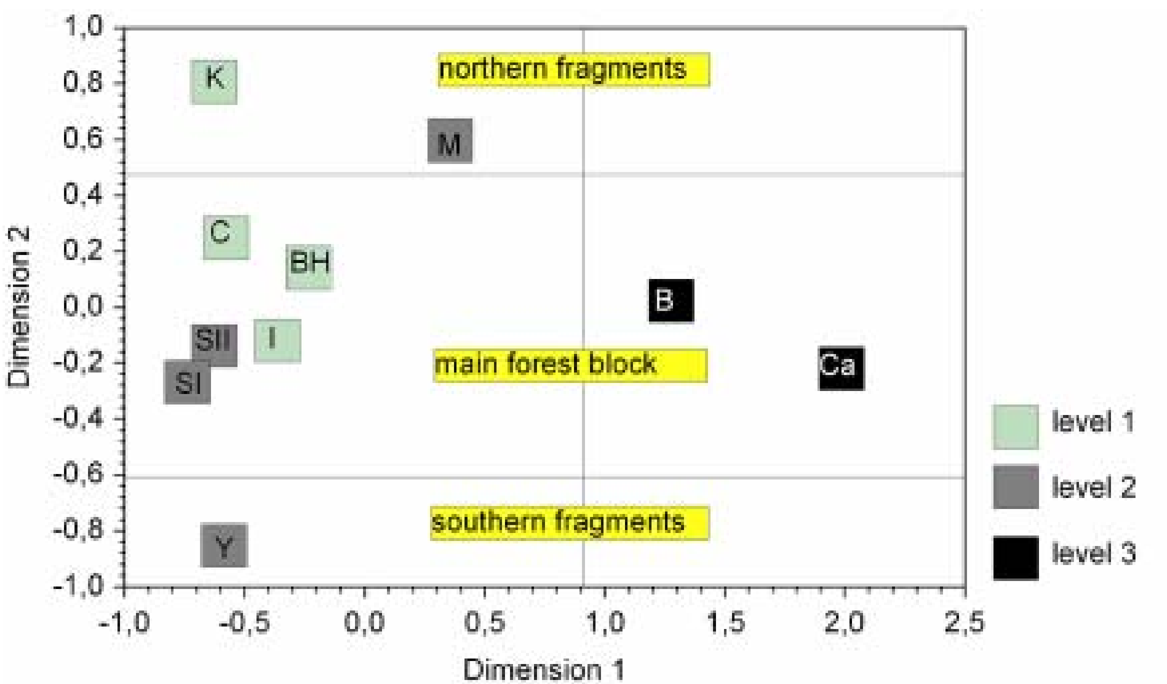

Fig. 5. Multi-dimensional scaling of dissimilarities between the investigated plots. Abbreviations: K-Kisere; M-Malava; C-Colobus; BH-Buyangu Hill; SI and SII-Salazar; Y-Yala; B-Buyangu (near to camp site); Ca-camp site; I-Isecheno.

With this we got the information that there seems to be a gradient from north to south (dimension 2), which could be explained as a soil or precipitation gradient. Dimension 1 indicates very clearly a disturbance gradient, because the plots Ca and B are located around the campsite.

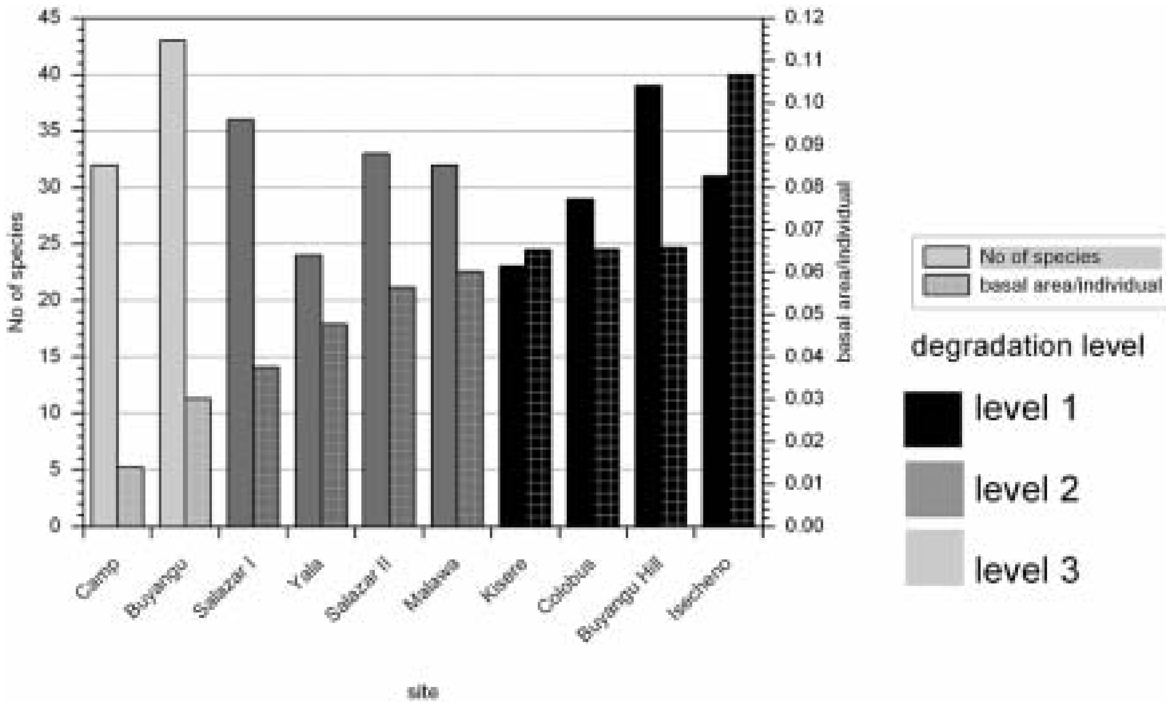

Fig. 5a. Number of species and basal area per individual tree for the investigated plots. The plots were grouped along a disturbance level, which was gained from analysis of tree stumps.

Figure 5a indicates that we found the highest values for the basal area per tree individual in the degradation level 1, which has the least tree stumps, whereas degradation level 3 with the highest number of tree stumps shows the lowest values for the basal area per individual. But tree species number can be as high as in level 1.

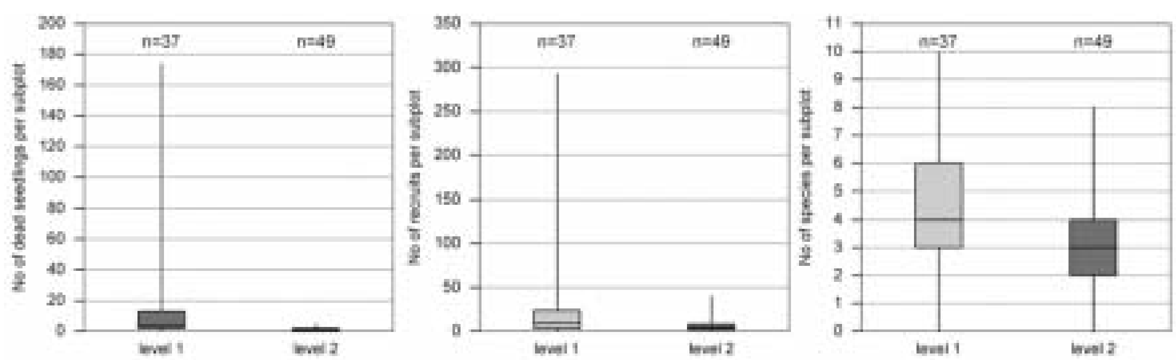

Fig. 6. In these three graphs the number of dead seedlings (left), the number of recruits (middle) and the total number of species (right) per subplot under two different levels of degradation (1=low, 2=high degradation).

The seedling surveys show for the degradation levels 1 and 2 clear differences concerning the number of species, the number of recruits and the number of dead seedlings per subplot (Fig. 6). The less the degradation is the more species and recruits can be found. But also the number of dead seedlings is higher than in degradation level 2.

Reasons for that results may be the ecological conditions, indicated by the photosynthetic active radiation (PAR) and the leaf area index (LAI) (see Fig. 7). The highest values for LAI were found in the least degraded plots and the highest values for the PAR were found in the more open forest stands of the degradation level 3.

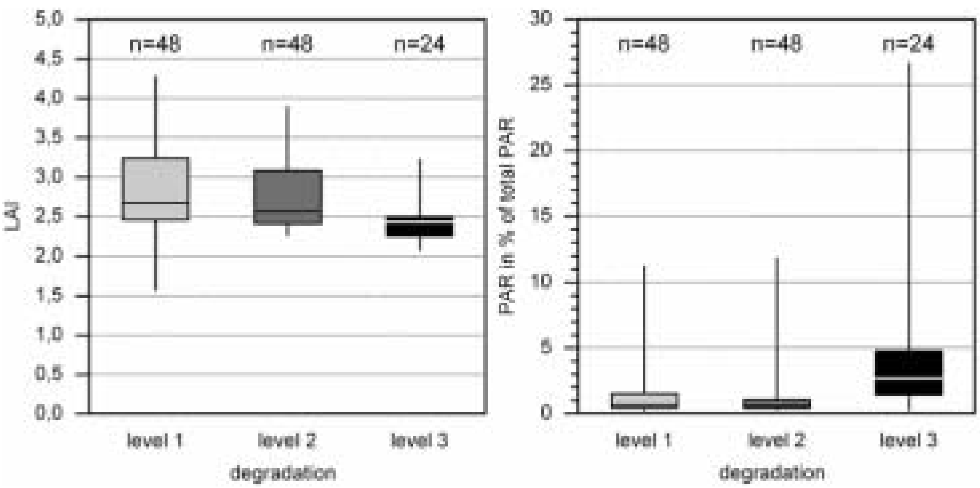

Fig. 7. Values for leaf area index (LAI) and photosynthetic active radiation (PAR) in the seedling subplots. Values were derived from the analysis of hemispherical photographs.

Workpackage 3

To summarize the results of workpackage 3 a comparison of leaching rates of different species and three nutrient elements (Table 3) can be used.

Table 3. Annual leaching rates for potassium, calcium and magnesium from different sites. All these data were gained within our group (Costa Rica and BIOTA-East, Kenya).

Autor	Area/Species		untersuchte Komponente	Ca	Mg	K
				[kg*ha^{-1}*yr^{-1}]		
WOLTER (2002)	RBAMB, Costa Rica		Rainfall	6,19	2,43	6,37
			Canopy throughfall	13,94	5,48	25,23
GUTT (2002)	RBAMB, Costa Rica	*Billia columbiana*	Leaching	10,8	2,4	37,2
		Calatola costaricensis	Leaching	8,6	2,9	25,1
		Elaeagia auriculata	Leaching	5,9	2,7	57,5
		Neea pittieri	Leaching	4,9	1,9	26,7
KRETSCHMER (2003)	RBAMB, Costa Rica	*Heliocarpus appendiculatus*	Leaching	46	8	63
		Plinia salticola	Leaching	6	1	91
		Hampea appendiculata	Leaching	10	3	39
RASCHE (2003)	Kakamega-Forest, Kenya	*Funtumia africana*	Leaching	8,89	1,62	13,35
		Heinsenia diervilleoides	Leaching	19,89	2,65	30,89
		Prunus africana	Leaching	17,63	2,18	14,24
Klippel (2004)	Kakamega-Forest, Kenya	*Markhamia lutea*	Leaching	7,02	0,68	14,54
		Rawsonia lucida	Leaching	14,53	1,79	21,86

Two thesis (Rasche 2003; Klippel 2004) investigated 5 species from the Kakamega Forest. The results show a comparable leaching rate. For each species the potassium values were the highest and magnesium the lowest. The data show a significant contribution of leaching processes for the element flux from canopy to soil, especially for potassium.

Workpackage 4

Additionally to the proposed three workpackages we realized a detailed soil analysis in the BIOTA-framework, which was proceeded by Mrs. Winfred Musila (Kenyan PhD student). As one example for the results Figure 8 shows a spatial heterogeneity of soil properties between three adjusted sites, grassland, shrubland and forest for Colobus, Isecheno and Salazar. Results were gained from soil pits. There is a clear effect of the forest stand to buffer low pH values during the passage of rainwater through the canopy.

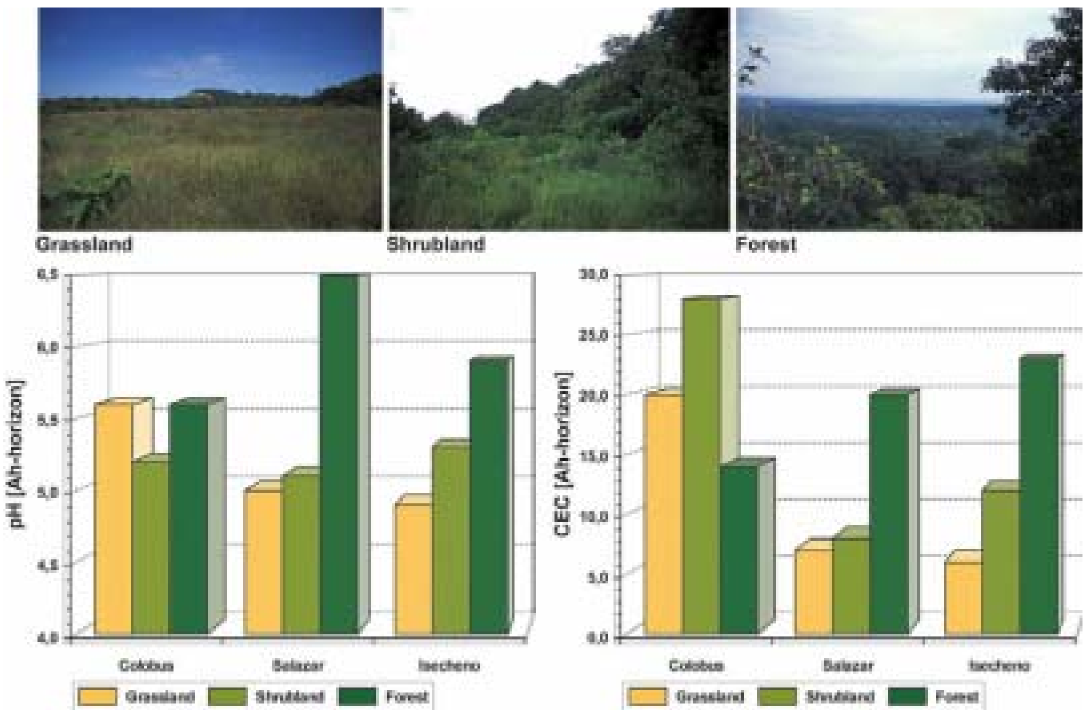

Fig. 8. Spatial heterogeneity of pH and CEC in three different vegetation types: forest, shrubland and grassland. Soil parameter values were gained from samples of the Ah-horizon out of soil pits. The three vegetation types are close together in the sites Colobus, Isecheno and Salazar (Subproject BIOTA-East E03). CEC values are given in cmol • kg-1.

2.2 Interdisciplinary components

During the project phase an additional workpackage was installed called the soil project. Intensive investigations of soil properties were possible through the joint efforts of E04, E06, E11 and E12 together with E03. The results were handed over as a draft at the beginning of 2004, the final report will be presented at the end of 2004 (Musila et al 2004).

A joint effort of the subprojects E03, E10 and E11 allows it to analyse the disturbance in the different sites using a counting method of tree stumps. These results are in print (Bleher et al.).

The cooperation with E02 concerning the measuring of rainfall with different methods, and the data sharing between E02 and all other subprojects made it possible for E02 to develop maps of the Kakamega Forest and to establish a GIS system.

2.3 Likely benefit an applicability of results

Some of these results may be useful for further planning of restoration strategies. This is especially true for the effects of spatial heterogeneity created by tree species diversity. If the assumption is true, and our results indicate this, that high tree species diversity in a stand is responsible for a high spatial heterogeneity of water and nutrient fluxes, which creates small-scale differences in the environmental conditions, restoration strategies should use this result. For the restoration of forest stands therefore a high number of different tree species with different growth rates and different demands should be used to create the basis for the development highly diverse forest stands with a high diversity in the understorey.

2.4 Publications resulting from the project

Bleher, B., Uster, D. & Bergsdorf, T. (in press): Assessment of threat status and management effectiveness in Kakamega Forest, Kenya. Biodiversity and Conservation.

Dalitz, H., Dalitz, C. & Breckle, S.W. (2000): Aspects of potassium cycling in a tropical montane rainforest in Costa Rica. In: Breckle, S.W., Schweizer, B. & Arndt, U. (eds.): Results of worldwide ecological studies. Proceedings of the 1st Symposium of the A.F.W. Schimper-Foundation est. by H. and E. Walter, Hohenheim, Germany, October 1998. Günter Heimbach, Stuttgart. 195-207.

Dalitz, H. (2002): Visual Plants - Bildbasierte Datenbank für die vegetationskundliche oder ökologische Forschung in den Tropen. Berichte der Reinhold-Tüxen-Gesellschaft, Band 14, 119-129.

Dalitz, H. (2002): Spatial heterogeneity in tropical montane rain forests: Diversity and dispersion of tree species and their influence on spatial heterogeneity of canopy throughfall. In: Proceedings of the 15th annual meeting of the German Tropical Society (Meeting abstract). p 36.

Dalitz, H. (2003): Kleinräumige Heterogenität - ein Diversitäts-generierender Faktor?. In: Proceedings of the 16th annual meeting of the German Tropical Society (Meeting abstract), p. 33.

Dalitz, H. (2004): Spatial heterogeneity of parameters likely influencing tree speices diversity and regeneration. In: Results of worldwide ecological studies. Proceedings of the 2nd Symposium of the A.F.W. Schimper Foundation. Breckle, S.W., Schweiter, B. & Fangmeier, A. (eds). Günther Heimbach, Stuttgart, 387-388.

Dalitz, H. & Homeier, J. (2004): Visual Plants - Image based tool for plant diversity research . Lyonia 6 (1), pp 13.

Dalitz, H., Homeier, J., Salazar, H.R. Salazar & Wolters, A. (2004): Spatial heterogeneity generating plant diversity?. In: Results of worldwide ecological studies. Proceedings of the 2nd Symposium of the A.F.W. Schimper Foundation. Breckle, S.W., Schweiter, B. & Fangmeier, A. (eds). Günther Heimbach, Stuttgart, 199-213.

Gliniars, R. (2004): Nutrient fluxes from the tree canopy to the soil in an East African rainforest in Kakamega, Kenya. Diploma thesis, University of Bielefeld, pp 120.

Homeier, J., Dalitz, H. & Breckle, S.-W. (2004): Visual Plants - a database as a tool for the determination of tropical plants. In: Results of worldwide ecological studies. Proceedings of the 2nd Symposium of the A.F.W. Schimper Foundation. Breckle, S.W., Schweiter, B. & Fangmeier, A. (eds). Günther Heimbach, Stuttgart, 371-374.

Klippel, G. (2004): Morphologisch-anatomischer Bau und Nährstoffauswaschung aus Blättern von Baumarten des tropischen Hochlandregenwaldes Kakamega-Wald in Kenia. Diploma thesis, University of Bielefeld, pp 188.

Mitchell, N. (2004): The exploitation and disturbance history of Kakamega Forest, western Kenya. In: Bleher, B. & Dalitz, H. (eds): Bielefeld Ökologische Beiträge, Bd. 20, 78 p.

Musila, W., Straßl, L., Uster, D. & Dalitz, H. (2002): Spatial pattern of soil pH and electrical conductivity in the Kakamega forest, Kenya. In: Proceedings of the 15th annual meeting of the German Tropical Society (Meeting abstract). p 153.

Musila, M., Kamoni, P.T., Albrecht, A., Todt, H., Uster, D. & Dalitz, H. (in press): Soil characteristics of Kakamega Forest, Kenya. In: Dalitz, H. (ed): Bielefelder Ökologische Beiträge, Bd, 21.

Musila, W., Todt, H., Uster, D. & Dalitz, H. (in press): Is geodiversity correlated to biodiversity? A case study of the relationship between spatial heterogeneity of soil resources and tree diversity in a western kenyan rainforest. Proceedings of the 5th International Symposium of Tropical Biology, Bonn 2004.

Musila, W., Todt, H., Uster, D., Gliniars, R. & Dalitz, H. (in prep): Horizontal and vertical patterns of nutrient fractions in forest soils of Kakamega Forest.

Rasche, G. (2003): Untersuchungen zu Elementverlusten aus Blättern (leaching) verschiedener Baumarten eines montanen afrikanischen Regenwaldes. Examensarbeit, University of Bielefeld.

Straßl, L., Musila, W., Uster, D. & Dalitz, H. (2002): Investigations on heterogeneity of canopy throughfall in a tropical montane rain forest in East Africa. In: Proceedings of the 15th annual meeting of the German Tropical Society (Meeting abstract), p 188.

Todt, H., Dalitz, H. & Breckle, S.-W. (2003): Kleinräumige Verteilung von Bestandesniederschlag im guineo-kongolesischen Regenwald Kakamega, Kenia. In: Proceedings of the 16th annual meeting of the German Tropical Society (Meeting abstract), p.192.

Todt, H., Uster, D., Musila, W. & Dalitz, H. (2004): Chemical properties and heterogeneity of precipitation in three different parts of the Kakamega Forest (Kenya). In: conference Proceedings of the 17th annual meeting of the German Society for Tropical Ecology "Biodiversity, and dynamics in tropical ecosystems", Bayreuth 2004, p. 57.

Uster, D., Musila, W., Straßl, L. & Dalitz, H. (2002): Tree species diversity, spatial pattern and age distribution in an indigenous rain forest remnant in Kenya. In: Proceedings of the 15th annual meeting of the German Tropical Society (Meeting abstract). p 192.

Uster, D. & Dalitz, H. (2003): Tree diversity and dispersion in a guineo-congolian forest remnant, Kakamega forest, Kenya. In: Proceedings of the 16th annual meeting of the German Tropical Society (Meeting abstract), p. 195.

Uster, D., Todt, H., Musila, W. & Dalitz, H. (2004): What consequences has the degradation of a tropical rain forest for stand structure and related processes?. In: conference Proceedings of the 17th annual meeting of the German Society for Tropical Ecology "Biodiversity, and dynamics in tropical ecosystems", Bayreuth 2004, p. 41 (Oral presentation).

Uster, D., Musila, W., Strassl, L. & Dalitz, H. (2004): Tree species diversity, spatial pattern and age distribution in an indigenous rain forest remnant in Kenya. In: Results of worldwide ecological studies. Proceedings of the 2nd Symposium of the A.F.W. Schimper Foundation. Breckle, S.W., Schweiter, B. & Fangmeier, A. (eds). Günther Heimbach, Stuttgart, 389-390.

Uster, D & Dalitz, H. (in prep.): Growth patterns investigated from monthly girth recordings using dendrometers in a tropical montane forest in Kenya.

Uster, D & Dalitz, H., Todt, H. & Todt, L. (in prep): Canopy structure influencing regeneration processes.

Uster, D & Dalitz, H. (in prep): The human impact on Kakamega forest and its consequences for forest texture and structure.

3. Capacity building

3.1 Technical capacity building

(1) Installation of a water purification system (Millipore) at the lab of ICRAF in Kisumu. Training of staff in using and maintaining it. (2) Improving of soil sampling equipment at the lab of ICRAF in Maseno (Eijkelkamp-equipment). (3) Installation of a nature trail in Buyangu Hill. This trail was designed and realized in close cooperation with KEEP and KWS. Its now intensively used by school classes, KWS, KEEP and tourists.

3.2 Students and scientific staff trained

Students involved in the project

PhD thesis: Musila, Winfred, NMK, Soils in Kakamega Forest, properties, spatial distribution and relations to tree species diversity

Doctoral thesis: Todt, Henning, University of Hohenheim – Atmospheric input of elements and spatial heterogeneity of canopy throughfall and its implications for tree species regeneration.

Doctoral thesis: Uster, Dana, University of Bielefeld – Tree species diversity and dispersion along gradients of disturbance and of soils.

Diploma thesis: Klippel, Gunther, University of Bielefeld, Morphologisch-anatomischer Bau und Nährstoffauswaschung aus Blättern von Baumarten des tropischen Hochlandregenwaldes Kakamega-Wald in Kenia.

Diploma thesis: Rasche, Gesa, University of Bielefeld, Untersuchungen zu Elementverlusten aus Blättern (leaching) verschiedener Baumarten eines montanen afrikanischen Regenwaldes.

Diploma thesis: Gliniars, Robert, University of Bielefeld, Nutrient fluxes from the tree canopy to the soil in an East African rainforest in Kakamega, Kenya.

Kenyan technicians and field assistants trained

Lena Sajita, Jared Sajita, Nixon Sajita, Michael Barasa, Caleb Analo, Alfred Yakhuma, Bonny Dumbo, Jackson Mwanje, Benson Citui, Nelson Musisi, Patrick Inziani

Subproject E04

Influence of anthropogenic and natural fragmentation on diversity of flora and vegetation in montane rainforests in East Africa

Subproject leader: Prof. Dr. E. Fischer, University of Koblenz-Landau	
Short title: BIOTA E04	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

In two isolated montane rainforests, the Kakamega Forest and the forests of Mt. Kenya, the diversity of flora and vegetation in primary and secondary forests was investigated along an altitudinal gradient. One of the main aims of the project was to study how Ŭ-diversity changes in different forest fragments caused by anthropogenic and natural disturbance. Furthermore, the differences between forests of different structure, fragmentation and distance to each other are investigated (ɓ-diversity). A further aim was to identify groups that are suitable indicators for biodiversity assessment of Central and East African forests.

Planning and conduction

As described in the application, at least one or two field campaigns per year were conducted in 2001, 2002 and 2003. In 2001, first field investigations took place in the Northern part of Kakamega Forest (Kisere, Buyangu Hill, Colobus-Trail, Udos Bandas, Busambuli, Salazar and Isiukhu) as well as on the Eastern slope of Mt. Kenya (Chogoria Trail). First inventories of vascular plants, bryophytes and lichens were made and different plot sizes were tested for phytosociological investigations. In 2002 we focused on the altitudinal transect of Mt. Kenya and further plots of the Central and Southern part of Kakamega Forest (Isecheno, Yala, Ikuywa and Kaimosi). In 2003, additional data were obtained from all plots of Kakamega Forest with special reference to bryophytes and lichens from Isecheno, Yala and Ikuywa. In 2002 and 2003 different herbaria for identification of plants were contacted (Brussels, Canberra, Graz, Kew, Liège, Nairobi, Oslo, Paris, Tromsø, Uppsala). In 2004 additional fieldwork was performed by one of the field assistants. The main goal was, however, the analysis of obtained data.

Cooperations with other institutions

In our subproject we had intensive cooperation with the following institutions in Kenya and Germany:

1. Kenya Wildlife Service, Nairobi: the cooperation focused on questions of conservation management (Northern part of Kakamega Forest)

2. National Museum of Kenya, Nairobi: a very close cooperation exists between our research group and the herbarium staff. Beside numerous joint field trips the main focus concerned

exchange and determination of herbarium material. We provided additional specimens of vascular plants, bryophytes and lichens from Kakamega Forest and Mt. Kenya.

3. Additionally, we cooperated intensively with the following subprojects of BIOTA East Africa: E02 (Steinbrecher), E03 (Dalitz), E06 (Häuser), E07 (Miehe), E08 (Veith), E9 (Naumann/Krell), E10 (Naumann/Kraemer), E11 (Boehning-Gaese), E12 (Bussmann).

2. Results

2.1 Scientific results

Workpackage 1: Diversity of vascular plants and communities in Kakamega Forest

Introduction and methods

In four field sessions three main methods were conducted: 1. the relevé method after Mueller-Dombois & Ellenberg (1974) to analyse the plant communities and the vertical structure of the forest in the different vegetation types; 2. line-transects to investigate the stand structure and the horizontal structure of the different forest sites; 3. the variable-area transect method (see Krebs 1999) to make predictions of the logging activities of single tree species in the past and present. Altogether 200 phytosociological relevés (10 x 10 m), eight line-transects (every 50 m a 5 m x 5 m plot, length between 800 and 1150 m) and 20 variable-area transects (between 700 and 1500 m with transects width between 5 and 14 m) were established in 19 different forest sites (Malava, Kisere, Udos Campsite, Buyangu, Buyangu-top, Colobus, Buyangu-Secondary forest, Isiukhu, Busambuli, Salazar, Shiamololi, Vihiga, Isecheno, Ikuywa, Yala, Ghostisland, Ileho, Kibiri, Kaimosi).

Results

A total of about 397 taxa of 93 families were found in Kakamega Forest. Grassland and pathway vegetation species were underrepresented, because the main focus of the investigation was on the forest vegetation. Kakamega Forest is a unique mixture of guineo-congolian and afromontane species with most of the guineo-congolian species reaching their easternmost distribution limit. A comparison of the recorded trees, shrubs and lianas shows that about 41% of all species also occur in the Congo-basin and about 33% are of afromontane origin. About 26% of the species could not be assessed (transitional species). Altogether 16 woody species were recorded as new for Kakamega Forest, e.g. *Suregada procera*, *Dregea abyssinica*, and *Meyna tetraphylla*, but only a *Rothmannia* (Rubiaceae) is probably a new species for science. *Vernonia conferta* is a new record for Kenya. Numerous herbs are new records for Kakamega, some of them probably new to science, e.g. a *Renealmia* and two *Aframomum* species. *Oecoclades ugandensis* (Orchidaceae) is new for Kenya.

The number of species per relevé varies between 29 (in the Buyangu area) and 97 near Isiukhu-river. The highest amount of species occurs in the disturbed areas with secondary forest (Udos camp-site, Buyangu Hill). The more undisturbed forests in Southern Kakamega (Yala) are more species-rich than comparable areas in the Northern part (Kisere fragment and the protected area of the Colobus forest).

Ǔ-diversity is calculated and compared for all 19 study sites (Fig. 1). The less disturbed places in the Northern and Central parts of the forest show a lower species number than the highly disturbed parts. In disturbed forests like in Vihiga or near Isiukhu river, the succession dynamic is higher than in climax stages as pioneer and climax species of different ages share the same habitat.

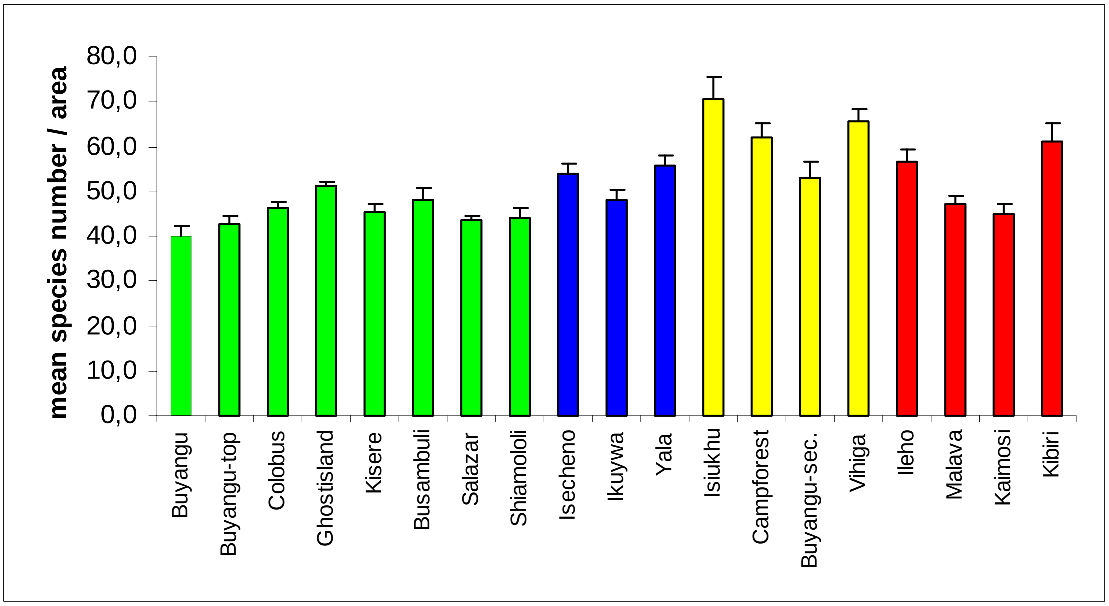

Fig. 1. Average vascular plant species number per area – green columns: study areas of the Northern and Central parts of the forest, blue columns: areas of the Southern part, yellow columns: highly disturbed study areas, red columns: areas with planted trees and plantations.

Figure 2 shows the correlation between the grade of human disturbance and the diversity of the studied area. With higher grade of anthropogenic influence like selective logging we observe a higher diversity.

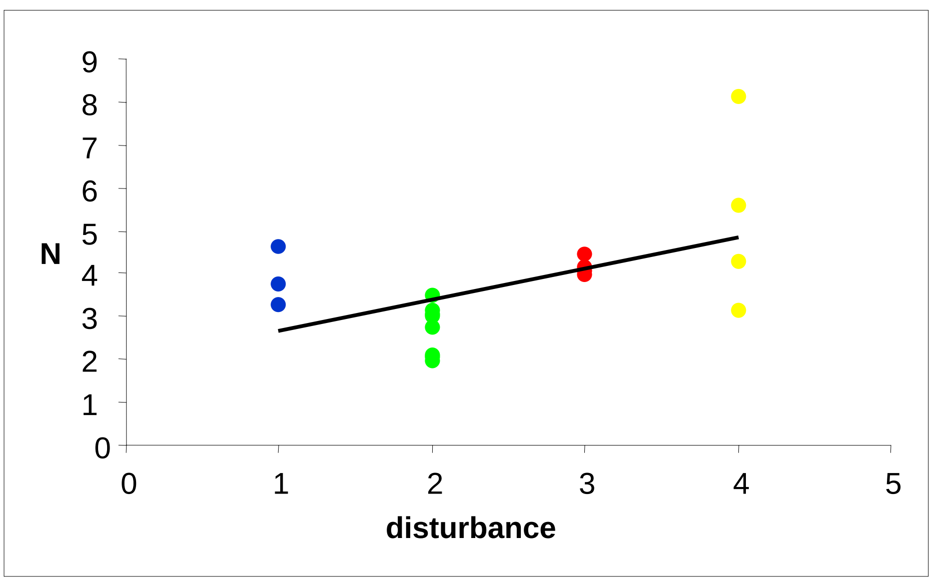

Fig. 2. Shannon-Wiener diversity in the 19 study areas (for colours see Fig. 1).

Calculations of ϐ-diversity show considerable differences between the study sites (see Table 1). A higher similarity only exists between adjacent forests or those with a similar succession stage. A strong diversity gradient can be observed between the study areas of Northern and

Southern Kakamega Forest (see e.g. Buyangu and Ikuywa). This is probably due to differences in soil types (see report of subproject E 03).

Table 1. Sørensen-index for studied areas.

Sørensen	Buyangu	Buyangu-top	Colobus	Ghostisland	Kisere	Busambuli	Salazar	Shiamololi	Isecheno	Ikuywa	Yala	Isiukhu	Campforest	Buyangu-sec.	Vihiga	Ileho	Malava	Kaimosi	Kibiri
Buyangu	**0**																		
Buyangu-top	0,64	**0**																	
Colobus	0,70	0,73	**0**																
Ghostisland	0,59	0,70	0,71	**0**															
Kisere	0,59	0,68	0,72	0,72	**0**														
Busambuli	0,56	0,61	0,62	0,64	0,65	**0**													
Salazar	0,63	0,63	0,68	0,73	0,65	0,69	**0**												
Shiamololi	0,56	0,70	0,70	0,67	0,63	0,61	0,62	**0**											
Isecheno	0,59	0,65	0,68	0,68	0,71	0,68	0,64	0,66	**0**										
Ikuywa	0,63	0,66	0,69	0,68	0,69	0,71	0,64	0,64	0,82	**0**									
Yala	0,56	0,66	0,65	0,64	0,66	0,66	0,63	0,63	0,81	0,74	**0**								
Isiukhu	0,58	0,57	0,64	0,60	0,62	0,63	0,62	0,55	0,63	0,62	0,63	**0**							
Campforest	0,50	0,50	0,58	0,53	0,58	0,53	0,52	0,49	0,57	0,58	0,55	0,75	**0**						
Buyangu-sec.	0,44	0,51	0,54	0,52	0,56	0,51	0,48	0,49	0,53	0,53	0,49	0,68	0,69	**0**					
Vihiga	0,47	0,50	0,56	0,56	0,56	0,48	0,48	0,56	0,54	0,53	0,50	0,64	0,66	0,77	**0**				
Ileho	0,51	0,62	0,63	0,63	0,61	0,56	0,56	0,63	0,64	0,62	0,59	0,58	0,56	0,59	0,64	**0**			
Malava	0,65	0,67	0,72	0,66	0,69	0,63	0,74	0,64	0,72	0,67	0,68	0,55	0,60	0,56	0,54	0,63	**0**		
Kaimosi	0,50	0,57	0,62	0,60	0,60	0,62	0,55	0,58	0,72	0,68	0,65	0,60	0,56	0,52	0,55	0,62	0,64	**0**	
Kibiri	0,52	0,63	0,62	0,58	0,62	0,60	0,54	0,66	0,68	0,66	0,64	0,60	0,56	0,63	0,64	0,70	0,61	0,66	**0**

All observed plant communities of Kakamega Forest are influenced by human activities in the last decades. Climax tree species like the “African Mahagony” *Entandophragma angolense* were heavily logged. This species is now very rare and at the edge of extinction. Actual anthropogenic disturbances are e.g. collecting firewood, cattle grazing, tree barking, charcoal burning and selective logging. The forest parts protected by KWS and p.p. also by the Forest Department (FD) show a good regeneration concerning number of seedlings and saplings.

An overview of the plant communities and succession stages is presented in Figure 3. In the young stages tree species like *Harungana madagascariense* and *Bridelia micrantha* are very abundant and characteristic for this initial phase. The tree height is about 10 to 12 m. In the undergrowth climax species from early stages can be found (e.g. *Funtumia africana*). Shrubs like *Acanthus pubescens* and climbers like *Smilax anceps* or *Dregea abyssinica* are dominant. Four different study sites can be classified as young secondary forest. Middle-aged forest, which has only been selectively logged, is the most abundant type in Kakamega. Their differences in species composition are due to the different logging history and regeneration period. Also the influence of the management is reflected in the floristic inventory of the different forest parts.

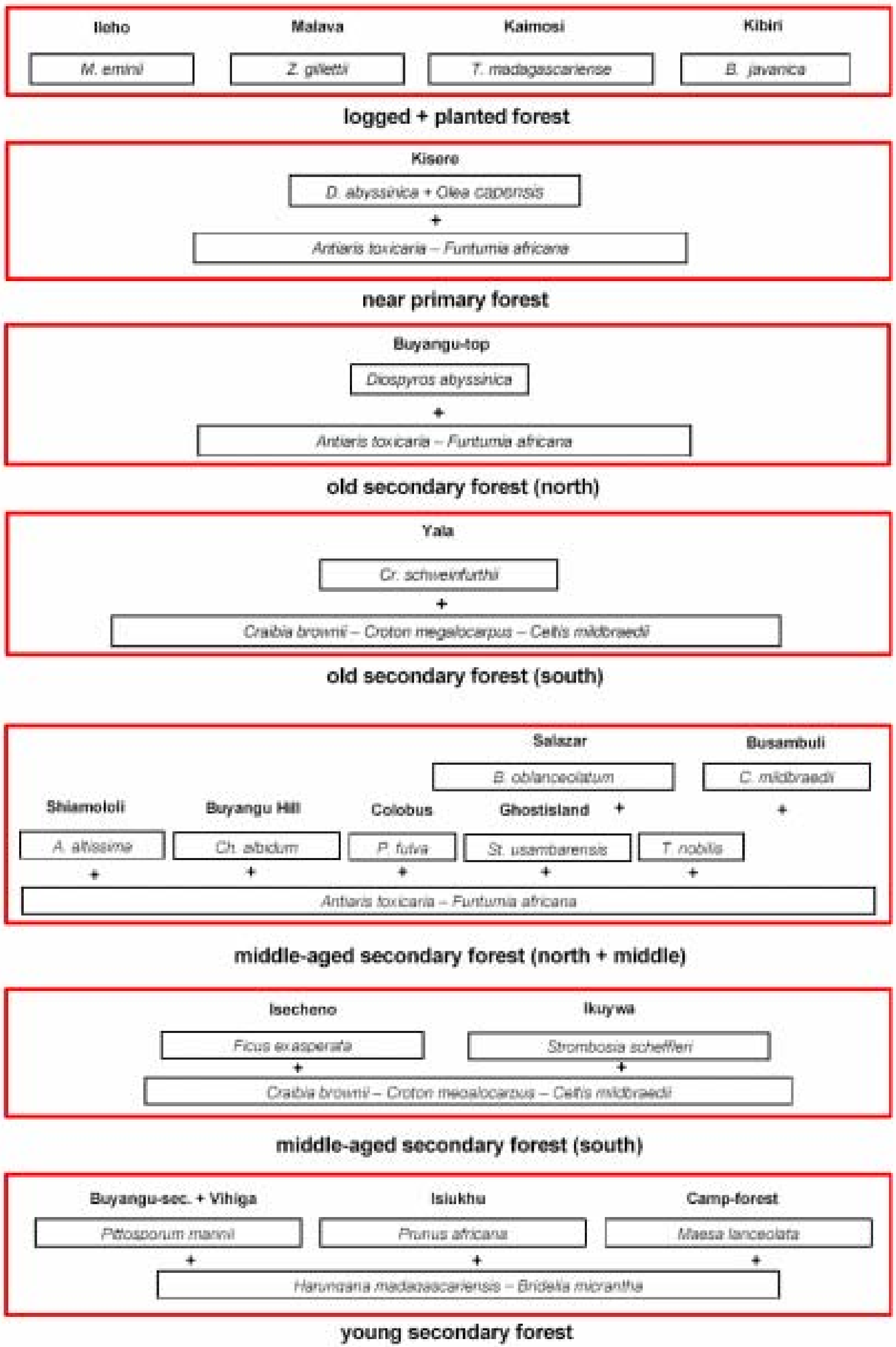

Fig. 3. Different succession stages and plant communities of Kakamega Forest.

A correspondence analysis diagram of all studied relevés with their floristic information shows four different groups (Fig. 4). Axis 1 can be interpreted as disturbance gradient. On the left side more or less undisturbed relevés are situated whereas disturbed plots are on the right side. Axis 2 is a gradient from the north to south. Relevés at the bottom of the diagram are located in the Northern part of Kakamega, and vice versa.

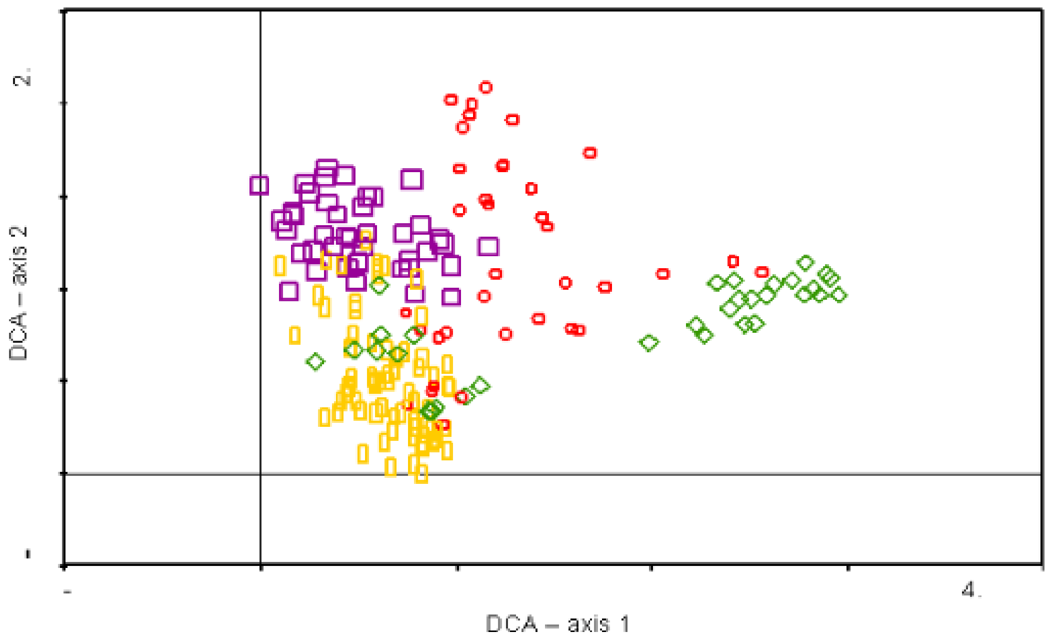

Fig. 4. DCA-ordination diagram of the 200 relevés – yellow coloured samples: relevés from the Northern and Central part of the forest; lilac samples: southern relevés; green samples: disturbed forest parts everywhere in Kakamega Forest; red samples: relevés with planted tree species.

Fig. 5. Diagrams of the eight line transect with a map of their distribution over the forest. On the y-axis the height of vegetation is presented. Every column represents a measured plot.

A further method comprised the line transects. In eight parts of the forest investigation of the horizontal structure was done to make predictions about stand structure. Along these line transects the proportion of closed and open crown cover could be measured. These data provide an indicator for the degree of disturbance and the species turnover from closed canopy forest to forest gaps. The main results are shown in Figure 5. Everywhere in the forest a high amount of gaps as result of selective logging and other human activities was observed. Given the amount of closed canopy as an indicator for more or less undisturbed forest, then Colobus showed the best results. In Salazar and Kisere we also encountered closed canopy, but on nearly half of the transects gaps occurred.

The Variable-Area transect method was applied for 7 study sites. In an easy and rapid way the density of single tree species could be examined. The population structure of three different ecological tree types was investigated (Table 2). *Antiaris toxicaria* is a species, which is abundant in climax stages, *Funtumia africana* is a tree that occurs in a high number of individuals in younger stages, but cannot be classified as a pioneer species, and *Croton megalocarpus* is occurring in different succession stages.

Table 2. Number of tree individuals/ha.

Individuals/ha	Malava	Kisere	Isiukhu	Bukhaywa	Shiamololi	Ikuywa	Yala
Funtumia africana	304	640	432	408	670	46	587
Antiaris toxicaria	307	282	149	289	141	497	119
Croton megalocarpus	0	95	153	102	112	437	153

A high amount of small tree individuals shows that the stand represents a regeneration stage where large older trees are missing (indicator for high disturbances in the past). Also a close distance of tree individuals is an indicator for a closed canopy forest without gaps (Fig. 6). Height and age of trees enables to interpret the population structure and to compare the different study sites.

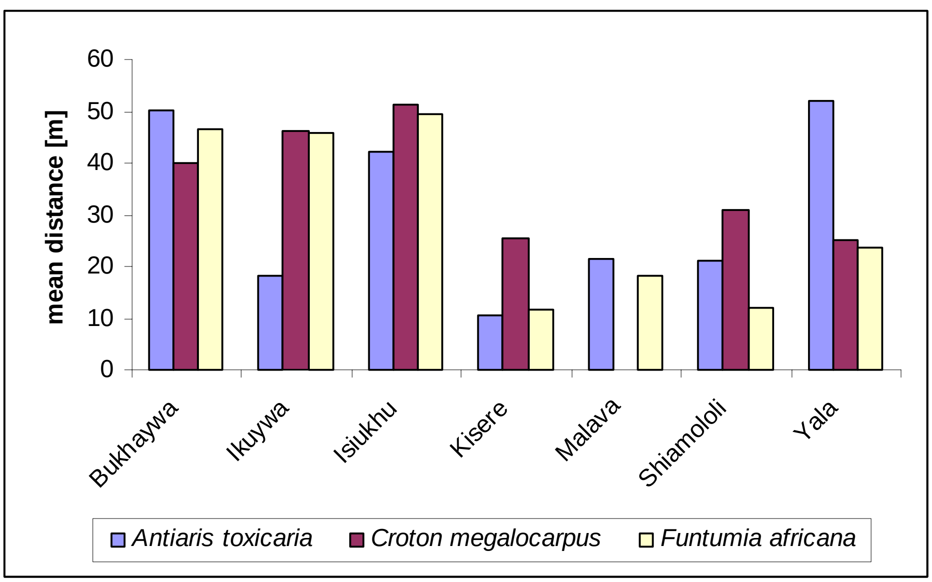

Fig. 6: Average distances between the tree individuals of three species in every studied area.

Workpackage 2: Diversity of epiphytic and foliicolous lichens and bryophytes in Kakamega and on Mt. Kenya

Introduction and methods

In Kakamega, 167 phytosociological plots of epiphytic bryophytes and lichens in the lower stem parts have been studied on 141 phorophyte trees. Due to the different phorophyte species and the recorded epiphytes, no standard plot size could be used. Within Graphidaceae-communities dominated by small crustose species, the plot size was 100 cm², while in case of large fruticose lichens and pendulous mosses, 1500 cm² have been established. The phytosociological relevé was recorded using the method of Braun-Blanquet (estimation of abundance and coverage, modified after Kürschner 1995). On Mt. Kenya, 132 phytosociological plots of epiphytic bryophytes and lichens have been studied on 111 phorophyte trees along an altitudinal transect from 1700 to 3000 m a.s.l.

Results

Lichens

In Kakamega Forest and on Mt. Kenya, a total number of 100 epiphytic and 50 foliicolous lichens have been identified up to now. Additionally, nine species of *Pertusaria* (corticolous lichens) are probably new to science and will be described in a forthcoming paper. 11 species are new records for Kenya and about 20 species are new records for Kakamega Forest.

The diversity of macrolichens in Kakamega Forest has been analysed by using morphospecies. The most species-rich sites are heavily disturbed plots like Udos Campsite (68 species), whereas in undisturbed areas like Kisere or Buyangu only 23 species could be recorded.

Foliicolous lichens have been studied in nine areas in Kakamega Forest (Isiukhu, Buyangu, Colobus, Salazar, Kisere, Udos Campsite, Isecheno, Yala, Ikuywa) and along an altitudinal transect on Mt. Kenya. Up to now, 50 species could be identified (see Table 3). Among them an *Echinoplaca* represents a species new to science. *Dimerella flava*, recently described from New Zealand, is the first record for Africa. For comparison of diversity, morphospecies have been analysed. Isiukhu shows the highest diversity with 85 species, followed by Kisere with 68 species. The lowest diversity was observed in the secondary forest at Udos Campsite with 27 species.

Table 3. Foliicolous lichens of Kakamega Forest.

Actinoplaca vulgaris	*Dimerella flava*	*Porina epiphylla*
Arthonia spec.	*Dimerella lutea*	*Porina nitidula*
Aspidothelium fugiens	*Dimerella* spec.	*Porina rubentior*
Aspidothelium geminiparum	*Echinoplaca* spec. nov.	*Porina* spec.
Asterothyrium spec.	*Fellhanera farinosa*	*Porina vezdae*
Aulaxina spec.	*Fellhanera paradoxa*	*Sporopodium phyllocharis*
Bacidina pallidoarnea	*Fellhanera* spec.	*Sporopodium* spec.
Byssolecania deplanata	*Fellhanera* spec.	*Strigula complanata*
Byssoloma chlorinum	*Fellhanera viridis*	*Strigula nemathora*
Calenia depressa	*Graphis* spec.	*Strigula phyllogena*
Calenia solorinoides	*Gyalectidium fuscum*	*Strigula smaragdula*
Calopadia fusca	*Gyalectidium filicinum*	*Strigula subtilissima*
Calopadia perpallida	*Lasioloma arachnoideum*	*Strigula elegans*
Calopadia puiggarii	*Mazosia rotula*	*Tricharia* spec. (white)
Calopadia spec.	*Opegrapha* cf. *phylloporinae*	*Tricharia* spec. (black)
Chroodiscus spec.	*Phylloporis phyllogena*	*Trichothelium* spec.
Dimerella epiphylla	*Phylloporis viridis*	

A comparison of all closed-canopy forests with the open secondary forests in Kakamega showed, that disturbed, secondary habitats are much more species-rich than less or undisturbed forests. In the secondary forests, canopy species of macrolichens occur on lower stem close to gaps or in open forest. Foliicolous lichens show a contrary pattern and have a low diversity in disturbed areas. At Isiukhu, only close-canopy plots are highly diverse. Thus epiphytic and foliicolous lichens provide suitable indicators for disturbance of ecosystems.

Bryophytes

In the Kakamega-Forest, 229 morphospecies of bryophytes could be distinguished, among them 92 mosses and 132 liverworts. The Lejeuneaceae are represented by 57 species. Further species-rich genera are *Plagiochila* and *Frullania*. A comparison of species numbers in primary-like (Kisere) or less disturbed and secondary forests reveals a completely different picture than that of the lichens. While in secondary forests only 78 species could be recorded, the primary forests contained 143 species. Thus a simultaneous inventory of lichens and bryophytes provides a highly sensitive system of bioindicators.

Table 3. Diversity of foliicolous bryophytes in 6 different areas of Kakamega Forest.

Species	Colobus	Kisere	Isiukhu	Isecheno	Yala	Ikuywa
Bazzania decrescens		X				
Bryaceae spec.		X		X	X	X
Cheilolejeunea cf. *usambarensis*			X			
Cheilolejeunea spec. A			X		X	
Cheilolejeunea spec. B					X	
Cololejeunea appressa			X		X	
Cololejeunea bolombensis	X				X	X
Cololejeunea cardiocarpa					X	X
Cololejeunea cf. *nigerica*						X
Cololejeunea distalopapillata	X	X	X		X	X
Cololejeunea himalayensis					X	
Cololejeunea minutissima					X	X
Cololejeunea mosambiquensis					X	X
Cololejeunea nigerica	X	X			X	
Cololejeunea obtusifolia	X	X	X	X	X	X
Cololejeunea pusilla					X	
Cololejeunea spec. A					X	
Cololejeunea spec. B						X
Cololejeunea spec. C						X
Cololejeunea zenkeri					X	
Diplasiolejeunea cornuta						X
Diplasiolejeunea spec.					X	
Drepanolejeunea spec.					X	

Species	Colobus	Kisere	Isiukhu	Isecheno	Yala	Ikuywa
Fabronia spec.					X	X
Frullania spec.					X	
Hypnaceae spec.		X				
Lejeunea cf. *caespitosa*		X	X	X	X	X
Lejeunea setacea					X	X
Lejeunea spec. A		X			X	X
Lophocolea cf. *concreta*					X	
Metzgeria cf. *consanguinea*					X	
Metzgeria spec.	X		X		X	X
Microlejeunea africana			X	X	X	X
Microlejeunea kamerunensis		X	X	X	X	X
Musci spec.			X			
Neckeraceae spec.	X					
Neckeraceae spec.		X			X	
Odontolejeunea lunulata			X		X	X
Pilotrichella ampullacea					X	
Plagiochila fusifera	X	X	X			
Plagiochila spec. A					X	
Plagiochila spec. B						X
Plagiochila terebrans		X				
Porella hoehneliana					X	
Ptychanthus striatus		X	X		X	
Radula cf. *flaccida*						X
Radula flaccida					X	X
Radula holstiana					X	
Radula spec.					X	X
	7	13	13	5	36	23

The study on foliicolous bryophytes in Kakamega (Table 3) confirmed their important role as bioindicators. It revealed that areas with low disturbance as Yala and Ikuywa bear a high species number whereas disturbed plots like Isecheno are species poor. Also, a northern-southern gradient of diversity could be confirmed.

2.2 Interdisciplinary components

In cooperation with subproject E02 a classification of a time series of satellite images from Kakamega Forest was conducted. The distribution of the different forest types and succession stages could be shown as well as changes over the last years. For more details and for the illustration see the report of E02.

In cooperation with subproject E03 publications on the correlation between vegetation and soil are in preparation. Data about vegetation of all study sites are made available for all other subprojects. A close cooperation between E 04 and E 10 resulted in exchange of data on diversity of plants selected for different pollinators. Together with E11 data on seed-dispersal of selected trees (e.g. *Ficus thonningii*) were obtained. In cooperation with E12 data on succession in gaps and anthropogenic use of selected species could be exchanged. Thus the influence of vegetation on pollination network and seed dispersal birds can be analysed.

2.3 Likely benefit an applicability of results

The following results provide a base for analysis of data obtained by the other subprojects and for long-term monitoring of diversity.

- The first description of plant communities in Kakamega Forest with information on all vegetation layers including spectra of life forms is provided.
- The distribution of the different succession stages could be analysed in cooperation with subproject E02 with a first satellite-image based classification of vegetation.
- A complete floristic inventory is now available. Trees, shrubs and climbers could be assessed to different ecological and chorological classes.
- The influence of habitat fragmentation on flora and vegetation can be explained.
- In cooperation with subproject E03 the correlation between vegetation and soil has been studied.
- The importance of epiphytic and foliicolous lichens and bryophytes as bioindicators for disturbance has been shown.

2.4 Publications resulting from the project

Althof, A., Dalitz, H., Fischer, E. & Uster, D. (in prep.): Effects of different plot sizes and sample numbers on tree diversity analyses in East African upland rain forest.

Althof, A. & Fischer, E. (2003): The vegetation of Kakamega Forest – a result of human impact? Posterabstract GTÖ 2003 – 16. Jahrestagung in Rostock: 87.

Althof, A. & Fischer, E. (in prep.): Vegetation of Kakamega Forest/Kenya. Phytocoenologia.

Althof, A., Killmann, D., Solga, A. & Fischer, E. (2001): Influence of natural and anthropogenic fragmentation on the vegetation in montane rainforests of Kakamega and Mt. Kenya. BIOLOG-Status report 2001.

Archer, W., Sérusiaux, E., Killmann, D. & Fischer, E. (in press): The genus *Pertusaria* in Central and East Africa (Congo-Kinshasa, Rwanda, Burundi, Kenya). Lichenologist.

Fischer, E., Killmann, D. & Solga, A. (2003): Diversity of epiphytic lichens and bryophytes on Mount Kenya – Comparison of natural and anthropogenic habitat fragmentation along an altitudinal rainforest transect. Posterabstract GTÖ 2003 – 16. Jahrestagung in Rostock: 107.

Fischer, E., Killmann, D., Lichtenthäler, T. & Thiel, C. (in prep.): Diversity of foliicolous bryophytes in Kakamega Forest/Kenya. Nova Hedwigia.

Fischer, E., Solga, A. & Killmann, D. (in prep.): Diversity patterns of epiphytic bryophytes in a highly fragmented rainforest (Kakamega, Kenya). Nova Hedwigia.

Killmann, D. & Fischer, E. (in prep.): Diversity of macrolichens along an altitudinal gradient on Mt. Kenya. Cryptogamie.

Killmann, D. & Fischer, E. (in prep.): New records of lichens for Kenya. Cryptogamie.

Killmann, D., Fischer, E. & Sérusiaux, E. (in prep.): Diversity of foliicolous lichens in Kakamega Forest/Kenya. Nova Hedwigia.

Killmann, D., Fischer, E. & Sérusiaux, E. (in press): *Dimerella flava* Malcolm & Vezda – a foliicolous lichen new to Africa. Cryptogamie.

Musila, W. & Althof, A. (in prep.): Influence of soil properties on the vegetation in Kakamega Forest.

Mwachala, G., Fischer, E. & Muasya, M. (2004): Morphological Analysis of *Dracaena* L. (Ruscaceae) in Central and East Africa. Posterabstract. Afrika-Symposium Museum Alexander Koenig, Mai 2004.

Mwachala, G., Fischer, E. & Muasya, M. (in prep.): Ecology of *Dracaena* in montane forests of Kenya. Flora.

3. Capacity building

3.1 Students and scientific staff trained

Doctoral thesis: Arnhild Althof, University of Koblenz, The influence of anthropogenic and natural fragmentation on diversity of flora and vegetation of Kakamega Forest.

Doctoral thesis: Geoffrey Mwachala, National Museums of Kenya, Herbarium/University of Koblenz, Revision of *Dracaena* L. (Ruscaceae) in Central and East Africa.

BSc thesis: Timo Lichtenthäler, University of Koblenz, Diversity of foliicolous bryophytes in Northern Kakamega Forest and on Mt. Kenya.

BSc thesis: Andrea Schüller, University of Koblenz, Diversity of foliicolous lichens in fragmented rainforests (Kakamega, Kenya).

BSc thesis: Nicole Lemaire, University of Koblenz, Diversity of foliicolous lichens along an altitudinal gradient on Mt. Kenya.

BSc thesis: Carolin Thiel, University of Koblenz, Diversity of foliicolous bryophytes in different forest fragments of Central and Southern Kakamega.

Field assistant: Bonny Dumbo.

Field assistant: Caleb Analo.

Subproject E06

Lepidoptera as indicators for human impact on tropical rain forest systems in East Africa

Subproject leader: Dr. C. Häuser, Staatliches Museum für Naturkunde Stuttgart	
Short title: BIOTA E06	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

Within the project cluster BIOTA East which focuses on the effects of fragmentation and human utilisation of tropical rainforest ecosystems in East Africa, the challenge for this project (BIOTA E06) was to investigate the impact of different degrees of habitat disturbance and different land use practises on species-rich groups of insects, specifically Lepidoptera. Based on comprehensive species inventories and surveys of selected families of Lepidoptera, the final aim of this project was to identify suitable indicator species in order to assess the effects of changing land use and habitat structure for the sustainability of their natural biodiversity in African forest ecosystems.

As part of the three-year pilot phase of BIOTA East, the following specific questions were to be addressed in this project:

- What are the differences regarding species composition, population dynamics, and frequencies of the Lepidoptera families under investigation between different study areas (BIOTA observatories)?
- Which relationships exist between soil parameters, vegetation, and the groups of Lepidoptera under investigation in the study areas?
- Which habitat disturbance factors (in particular type and intensity of land use, isolation/fragmentation of forest area) affect the alpha-diversity in Lepidoptera?
- Which are suitable, i.e., easily recordable and identifiable Lepidoptera indicator species to assess and evaluate East African forests for their state of biodiversity?
- To what extent is the impact of different types of land use on Lepidoptera communities representative for other insect groups?

Planning and implementation of the project

The research carried out in this project formed part of an extensive programme within BIOTA East directed towards the ecological and sociological investigation of one of the last larger, continuous rainforest areas in western Kenya. Situated in Kenya's Western Province some 50 km north of Kisumu, Kakamega Forest has been declared a „National Reserve“ under the administration of the Kenya Wildlife Service (KWS) since 1986, and covers a surface area of about 240 km² at elevations between 1500 and 1700 m. It currently consists of a mosaic of differently disturbed forest areas varying from heavily degraded to almost undisturbed, primary rainforest (Mitchell 2004). For further details on the common study area, we refer to the report of the BIOTA East umbrella project (E01), and the references cited there.

Our research and fieldwork in Kenya benefited greatly from the logistical support and set up provided for the entire BIOTA East cluster. This included the use of the KWS camp at Kakamega Forest near Buyangu, access to BIOTA study sites around Mt. Kenya, the availability of BIOTA East project vehicles, possibilities of transport, and storing equipment in Nairobi. Further details of the project logistics and arrangements for field work can be obtained from the BIOTA East umbrella project report.

The project was conducted throughout the official funding period for the BIOTA East pilot phase (March 2001 - May 2004), and data analysis is still ongoing. In April 2001, a first exploratory trip to Nairobi and the Kakamega Forest was undertaken jointly with the BIOTA East co-ordinator Prof. C.M. Naumann, and basic administrative and logistic arrangements were made for conducting field work. Following the official BIOTA-East "kick-off" trip in June 2001, field work and data recording commenced at Kakamega Forest for this project during September - October 2001, and was subsequently continued by Kenyan field assistants and students throughout 2002. Additional field work by German members of the project team was carried out during March - April 2002, September - October 2002, November - December 2002, and finally in January - February 2004. The Kenyan M.Sc. student supported by this project conducted field work on butterflies for her thesis proposal from September 2003 until May 2004.

Apart from several working periods spent in the entomological collections of the National Museums of Kenya, Nairobi, the collections at the Natural History Museum, London and the Royal Museum for Central Africa, Tervuren (Belgium) were also visited for verification of identifications of collected specimens and for obtaining additional faunistic records. The main preparation of materials and identification work, however, took place in museum collections in Germany; apart from the institution of the project leader (State Museum of Natural History, Stuttgart), notably in Berlin (Museum of Natural History of the Humboldt University), Munich (Zoological Collections of the State of Bavaria), and Bonn (Research Institution and Zoological Museum Alexander Koenig).

In early 2002, the soil studies initially planned to be conducted within this project were transferred to the BIOTA East project E03 ("Regeneration of tropical-montane tree species: dynamics of feedback processes in time and space and their modelling"; project leader: Helmut Dalitz, University of Bielefeld). This project took over responsibility for all soil research within BIOTA East, especially for the projects E04, E10, E11, and E12 (see their separate reports).

According to the original project proposal, a preliminary Lepidoptera survey using the same methodological approach should be undertaken during the third year in direct co-operation with partners from BIOTA West in the Ivory Coast for comparative purposes. Because of the developing political and economic instabilities in Ivory Coast during 2002 and 2003, this initial plan had to be abandoned. Instead, preliminary Lepidoptera surveys were undertaken along an altitudinal transect on Mt. Kenya established by other BIOTA East projects, and the recording schemes for this project at Kakamega Forest were extended to the orders Orthoptera and Dermaptera.

Cooperations with other institutions

Apart from multiple interactions and intense collaboration with other BIOTA East projects and the entire BIOTA network, work for the present project benefited from co-operation with the following institutions:

a) in Kenya:

- The African Butterfly Research Institute (ABRI), Nairobi
- International Centre for Research in Agroforestry (ICRAF), Nairobi
- Kenyan Wildlife Service (KWS), Nairobi
- Department of Invertebrate Zoology, National Museums of Kenya (NMK), Nairobi
- University of Nairobi, Nairobi

b) in Germany:

- Abteilung Terrestrische Zoologie (Entomologie II), Forschungsinstitut und Naturmuseum Senckenberg (FIS), Frankfurt am Main
- Institut für Zoologie, Museum für Naturkunde der Humboldt-Universität (MNHU), Berlin
- Zoologisches Forschungsinstitut und Museum Alexander Koenig (ZFMK), Bonn
- Zoologische Staatssammlung (ZSM), München

c) abroad:

- Department of Entomology, The Natural History Museum, London, U.K.
- Department for African Zoology, Royal Museum for Central Africa, Tervuren, Belgium.

2. Results

2.1 Scientific results

Selection of study sites

According to the proposed BIOTA project outline, a number of forest sites experiencing different degrees of human disturbance within the common study area at Kakamega Forest should be compared with regard to their species composition to assess the possible effects of different land use practices and forest management regimes on biodiversity. Based on available maps, aerial photographs, and other information sources a number of possible study plots representing primary forest, secondary forest, and heavily disturbed forest were examined during a first short field trip in 2001. In consultation with the other BIOTA-East partners, twelve plots were initially selected for the present project within three of the designated biodiversity observatories (Colobus, Buyangu, Salazar) at the northern part of Kakamega Forest, and one observatory (Yala River) at the southern part. Out of those twelve sites, seven plots (three for primary forest, two for secondary forest, and two for heavily disturbed areas) were sampled regularly for at least two years, supplemented by irregular recording at the other five plots, and occasional visits to two other BIOTA-East observatories at Kakamega (Kisere, Isecheno 1).

In addition to the field work at Kakamega Forest, pilot studies to establish an altitudinal transect of recording sites on Mt Kenya comprising four stations (at 1700 m, 1850 m, 2300 m, and 3050 m) were undertaken during short visits in 2001, 2002, and again in early 2004. Preliminary analysis of the obtained data, however, showed profound differences in species composition especially at higher elevations when compared to the main study area at Kakamega Forest, and regular recording at those sites were not continued.

Tests and evaluation of recording and monitoring techniques

For the inventorying, recording and monitoring of insect diversity, in particular Lepidoptera, four commonly used methods were tested, standardised, and partly modified under field conditions during the project:

1. Recording diurnal Lepidoptera (and other insects) along transect routes

Diurnal Lepidoptera were recorded by walking along selected transect routes within each plot for fixed time periods during the day. All butterflies seen within an estimated radius of 5 m around of the recorder were counted, and species difficult to identify on the wing were netted.

This technique requires the recorder to be familiar with most of the butterfly species locally present, and can only be successfully employed by workers with special knowledge or good training. Results are much dependant on individual capacities and attitudes, and thus data collected by different individuals are usually difficult to compare. Standardisation is best achieved by fixed recording times (rather than absolute length of transect routes), and by collecting vouchers for all species difficult to identify. Despite these problems, the technique is still the only procedure for a standardised recording of the majority of butterfly species, especially those which are not attracted by traps (see below).

2. Recording butterflies with bait traps

Common butterfly traps were hung in the vegetation at heights from 2 to 5 meters in every sample plot, and usually checked twice daily. Traps were baited with fermented fruits, usually bananas, but sometimes faeces, fish and other organic matter was used as bait. Traps had to be frequently repositioned or replaced, due to invasion by ants or destruction by mammals (monkeys and/or arboreal rodents) or birds.

As has been well documented in previous studies, fruit-baited traps are highly selective for members of the butterfly family Nymphalidae, and will only collect good numbers of specific groups from that family, e.g., Apaturinae, Charaxinae, and some Nymphalinae and Satyrinae. In addition to trap design and bait used, the exact placement of the trap (height above ground, surrounding vegetation structure, shade or canopy cover, exposure to wind, etc.) appears to be a most influential factor for the effectiveness of a trap, and thus results obtained from different locations are difficult to standardise or compare. On the other hand, traps have the advantage that they can easily be applied in larger numbers and can be run by unspecialised workers or field assistants with comparatively little training. For the present study, traps proved very useful for obtaining records from several nymphalid taxa, particularly *Charaxes* spp., which probably otherwise would not have been recorded.

3. Recording nocturnal insects by automatic light traps

Self-operating light traps equipped with a battery powered, single 15 Watt superactinic UV-light tube were installed on selected sites within each plot, and usually run for an entire night. Lepidoptera and other insects attracted to the light hit vertical plastic sheets and are funnelled through a opening with a diameter of 6 cm into a bucket, where they are tranquillised by chloroform contained inside the bucket in a small container with an open lid. During recording periods, traps were operated simultaneously on different plots three times a week, and a nightly sample would yield 250 Lepidoptera specimens on average per trap.

The selectivity of these traps appears not to be very high with regard to most nocturnal Lepidoptera, but there are clear indications that certain groups (e.g., Sphingidae, Geometridae, and many smaller taxa) are significantly underrepresented in the samples obtained. For the present study, this method proved to be most cost efficient for obtaining larger samples of nocturnal Lepidoptera simultaneously from several sites. Constraints for the wider application of this technique, however, quickly become apparent for the processing and recording of the samples, which still require considerable time and effort. Even if no determination or documentation of individual specimens is attempted on site, the mere handling and preservation of all specimens obtained sets a maximum number of 8-10 traps which can be processed by a two-person team per night and the following day. A further disadvantage of self-operating traps is the high number of often severely damaged specimens obtained, which in the case of medium to smaller-sized moths can delay or even prevent their exact identification. Although the human factor is less likely to influence the comparability of different samples than with any other technique, the exact placement of the trap within the site appears again as a major influence for its effectiveness, which however could not be tested systematically in the present study but nevertheless should be taken into consideration for data analysis.

Fig. 1. Examples of traps used during Lepidoptera monitoring: butterfly trap with fruit bait exposed at forest trail (left), automatic light trap (right).

4. Recording nocturnal insects by direct observation at light

Cylindrical “light towers” of 1,60 m in height and 0.60 m in diameter fully covered by fine netting were used as a standard light trap set up, which were equipped with a 125 Watt mercury vapour lamp inside. Light towers were placed at the same locations used for self operated traps, and the light was run for three hours starting at dusk. All species of the targeted Lepidoptera families settling on or circling the tower in close proximity were recorded quantitatively, either by manual collecting or removing specimens into bags or boxes. With the same set up, two superactinic tubes (2 x 15 Watt) were also tested as an alternative light source.

Manual operation of light traps is labour intensive and for efficient recording requires highly trained personnel with specialist knowledge, which delimits a wider application of this technique to numerous sites. Compared to automatic traps, however, the quality of the data and the specimens obtained is much higher, as virtually all species attracted to the light irrespective of their individual behaviour can be recorded. For the present study, this technique yielded numerous records of otherwise unseen species or taxa, and it seems indispensable for general inventory purposes of nocturnal Lepidoptera.

As indicated, each of the tested methods proved successful. However, the comparison of sampling methods demonstrated that in order to investigate the fauna of a given study area and to draw up a comprehensive faunal inventory a combination of all available sampling and observing techniques should be employed. No single method can completely cover the entire group of Lepidoptera or even parts of the diurnal or nocturnal Lepidoptera. A long-term monitoring of selected target species of butterflies can be effective by employing single methods (bait traps: Nymphalidae: Charaxinae; transect routes: Pieridae; observation at puddles and wet soil sites: Papilionidae: Papilionini, Lycaenidae: Polyommatini, males) but if larger species groups are to be monitored several methods have to be used simultaneously. Differences in species composition were also observed in nocturnal moths using different light-trapping devices (fully automatic traps vs. manual operation, use of different types of light sources). The successful use of standardised methods requires concentrated efforts by trained and competent observers, who need to be stationed in the study area, also with regard to the handling and preserving of sampled materials.

Species inventories and biodiversity assessment

In addition to the Lepidoptera target taxa listed in the original project proposal, the present study could be extended to two additional insect orders, Orthoptera, particularly Ensifera, and Dermaptera, because the planned comparative survey of Lepidoptera in the Ivory Coast in Western Africa had to be cancelled due to the increasingly unstable situation in that country. Whereas Lepidoptera could be surveyed extensively at the Kakamega Forest, the inventory data for Orthoptera and Dermaptera are still quite preliminary as are presented below.

Lepidoptera (Butterflies and Moths)

As indicated in the project proposal, the Lepidoptera survey focused on butterflies, and six selected families of moths (Lasiocampidae, Saturniidae, Sphingidae, Lymantriidae, Notodontidae, Arctiidae). For all butterflies (Papilionoidea und Hesperioidea), a total of 515 species could be recorded for the entire Kakamega Forest area, based on the results from our own field work and museum specimens examined during this study. In addition, another 54 butterfly species could possibly occur in the area, but their presence has yet not been confirmed for the Kakamega Forest area proper. More than five butterfly species recorded at Kakamega are new to Kenya, and at least one species is possibly new to science.

A total count of >515 butterfly species would represent almost 60% of the total number of butterfly species known for Kenya. Based on this figure alone, the area clearly represents a regional biodiversity hotspot, at least for butterflies but probably also for many other groups of insects. For individual butterfly subfamilies and families, between 20 and 45% of the species occurring at Kakamega can be classified as true forest species, which appear closely linked or limited to undisturbed, primary forest habitats. For each of five butterfly families (Papilionidae, Pieridae, Nymphalidae, Lycaenidae, Hesperiidae) several of those species could already be identified as good potential indicators for assessing and monitoring the degree of forest habitat change.

Similarly high scores for species diversity can be demonstrated for the six moths families (Lasiocampidae, Saturniidae, Sphingidae, Lymantriidae, Notodontidae, Arctiidae) focussed on during this study. For these six families, in total 342 species have yet been identified (Lasiocampidae: 69 spp.; Saturniidae: 26 spp.; Sphingidae: 44 spp.), but several samples are still to be analysed. For most moths groups the comparatively poor state of taxonomic and faunistic knowledge impedes any in depth analysis: for just one genus of Tiger Moths (Arctiidae: *Asura* Walker, 1854), for example, five out of twelve species recorded for Kakamega appear to be new for the Kenyan fauna, and two are possibly new to science. A summary list for all Lepidoptera recorded with species numbers by subfamilies is annexed below.

Orthoptera (Grasshoppers and Crickets)

During the initial survey undertaken for Orthoptera, a total of 122 specimens of crickets and katydids (Ensifera) were recorded for the Kakamega Forest. Most of the specimens were obtained by netting during the day or collected while running light traps at night. According to available literature, the web-based Orthoptera Species File (OSF), and the examination of collection holdings at the National Museums of Kenya (NMK) in Nairobi, about 200 species of crickets and katydids occur in Kenya.

For the Kakamega Forest, 33 species from 7 families have yet been recorded, based on the NMK collections and the preliminary results from this study. Taking into account the short survey period, the actual number of Ensifera species occurring in the Kakamega Forest area will probably be no less than 60 species. A list of identified species of Ensifera from Kakamega Forest is provided in the annex.

Dermaptera (Earwigs)

As the last general survey of Dermaptera for Kenya dates from more than 50 years ago, it was first attempted to compile an updated species inventory at the country level. Based on the examination of the collections at the National Museum of Kenya (NMK), Nairobi, a comprehensive literature search and a distributional database developed by F. Haas (http://www.earwigs-online.de), a total of 46 Dermaptera species in 23 genera and 10 families has yet been recorded for the whole of Kenya.

For the Kakamega Forest, with the use of light trapping as well as by manual collecting and selective searching of the vegetation, seven Dermaptera species could so far be documented. Two of the species recorded, *Diplatys ugandanus* Hincks, 1955 and *Haplodiplatys kivuensis* (Hincks, 1951), prove to be first records for Kenya. Further field work and sampling and more research on these often neglected insects should reveal a much higher species inventory of Dermaptera for Kakamega, as well as for Kenya. A complete listing of the earwig species recorded from Kakamega Forest is provided in the annex.

2.2 Interdisciplinary components

As provided in the project outline, the results from this project are expected to make a specific contribution to the overriding interdisciplinary project framework of BIOTA East. For the present project, a regular exchange of data and information was most relevant with partners from BIOTA East projects E01, E03, E04, E07, E09 and E10 (see separate reports in this volume). For relevant elements of interdisciplinary co-operations with Kenyan counterparts and institutions, see below under item 3 (capacity building).

The available results and forthcoming analysis of the data from this study, should already provide valuable baseline information and argumentative support for developing future strategies for the conservation and sustainable use of the natural biodiversity of the Kakamega Forest N.R., and beyond.

2.3 Likely benefits and applicability of results

The results from this project provide a valuable knowledge base for the future assessment and valuation of the insect biodiversity of the Kakamega Forest, as well as solid baseline information and a stimulus for further research on the taxonomy and ecology of East African Lepidoptera in general. The data obtained thereby also will contribute to the national inventorying and valuation of natural biodiversity resources by the responsible Kenyan authorities as required in fulfilment of the Convention of Biodiversity (CBD).

The extraordinarily high number of butterfly species occurring at Kakamega Forest representing close to 60% of the entire Kenyan fauna clearly indicate the high value and potential of this area for nature conservation. Several butterfly species once distributed in other parts of Kenya as shown by historical records in entomological collections have disappeared from larger areas and are currently restricted to very few sites or only to Kakamega. It seems likely that this situation is valid for many other groups of insects, but the lack of taxonomic and faunistic information this is difficult to prove. Still, the present study emphasises the importance of the Kakamega Forest area for biodiversity at local and regional scale, and should provide relevant arguments for all stakeholders involved in nature conservation in Kenya.

In addition to the collection of primary occurrence data and the compilation of species inventories many individuals of the insect groups studied for this project were also documented by digital macro-photography. Augmented with short descriptive notes, these documentation will facilitate the future identification of species both in museum collections and under field conditions. They are expected to enable local counterparts to continue to work on these groups, and in particular to implement an independent long-term monitoring of those species identified as indicators. Digital species characterisations will also provide an important tool for other BIOTA East projects and for further scientific studies by third parties. BIOTA is currently developing data standards and tools to improve the sharing of both primary data, as well as digital images and media to all partners.

The analysis of several groups of the recorded moth families has not been completed during the reporting period and is still continued. This concerns the taxonomy of particular groups, especially in the families Arctiidae and Geometridae, as well as the characterisation of species communities of differently disturbed forest habitats and the evaluation of single species for their potential indicator function. The extremely weak taxonomic and faunistic knowledge base for Orthoptera and Dermaptera as well as further groups of Lepidoptera should be improved by continued data collection in the study area, and by working on East African insect materials stored in research collections. In collaboration with and support of Kenyan counterparts, especially the National Museums of Kenya, it is intended to establish a long-term monitoring of selected Lepidoptera groups in the BIOTA project plots in Kakamega Forest, in order to further substantiate the results of the present study.

2.4 Publications resulting from the project

Scientific papers published or in press

Cieslak, A. & Häuser, C. L. [2005]. Die Präimaginalstadien und Zucht von *Asura neavi* Hampson, 1914 (Lepidoptera: Arctiidae: Lithosiinae). – Entomologische Zeitschrift [in press].

Haas, F., Häuser, C. & Kinuthia, W. 2004. Earwigs (Dermaptera: Insects) of Kenya – new species and check-list. In: Huber, B.A. (ed): 5th International Symposium on Tropical Biology – African Biodiversity: Molecules, Organisms, Ecosystems. Bonn; p. 56.

Haas, F., Holstein, J., Zahm, A., Häuser, C. L. & Kinuthia, W. [2005]. Earwigs (Dermaptera: Insects) of Kenya - Checklist and species new to Kenya. In: Huber, B. A., Sinclair, B. J. & Lampe, K.-H. (eds): African Biodiversity: Molecules, Organisms, Ecosystems. Springer Verlag, Heidelberg [in press].

Häuser, C., Kühne, L., Njeri, F. & Holstein, J. 2003. Lepidoptera as indicators of human impact of tropical rainforest ecosystems in Eastern Africa. In: Federal Ministry of Education and Research (BMBF) & German Aerospace Center, Project Management (DLR - PT) (eds): Sustainable use and conservation of biological diversity – A challenge for society. International Symposium, 1-4 December 2003, Berlin. Symposium Report, Part A. Deutsches Zentrum für Luft- und Raumfahrt, Projektträger des BMBF (DLR-PT), Bonn; pp. 110-111.

Holstein, J., Haas, F., Zahm, A., Häuser, C. L. & Kinuthia, W. [2005]. Katydids and Crickets (Orthoptera: Ensifera) of the Kakamega Forest Reserve, western Kenya. In: Huber, B. A., Sinclair, B. J. & Lampe, K.-H. (eds): African Biodiversity: Molecules, Organisms, Ecosystems. Springer Verlag, Heidelberg [in press].

Kühne, L., Häuser, C. & Holstein, J. 2001. Lepidoptera as indicators of human impact of tropical rainforest ecosystems in Eastern Africa. In: Federal Ministry of Education and Research (BMBF) & German Aerospace Research Establishment (DLR) (eds): BIOLOG Status Report 2001. Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bonn; pp. 158-159.

Namu, F. N. 2004. Effects of forest disturbance on butterfly diversity in Kakamega Forest Nature Reserve, Kenya. In: Huber, B.A. (ed): 5th International Symposium on Tropical Biology – African Biodiversity: Molecules, Organisms, Ecosystems. Bonn; p. 106.

Zahm, A. & Häuser, C. L. 2003. Die Präimaginalstadien und Zucht von *Asura discocellularis* Strand, 1912 (Lepidoptera: Arctiidae: Lithosiinae). – Entomologische Zeitschrift, 113 (11): 331-338.

Presentations and posters at scientific meetings and congresses

Haas, F., Holstein, J., Zahm, A., Häuser, C. L. & Kinuthia, W. 2004. Earwigs (Dermaptera: Insects) of Kenya - Checklist and species new to Kenya. 5th International Symposium on Tropical Biology – African Biodiversity: Molecules, Organisms, Ecosystems. Bonn, 02.-06.05.2004; poster.

Holstein, J. 2004. Kakamega Forest – Bergregenwald im Herzen Afrikas. [German Coleopterists' Meeting] Deutsches Koleopterologentreffen 2004 (47. Tagung der Arbeitsgemeinschaft südwestdeutscher Koleopterologen), Weinstadt-Beutelsbach, 29.-31. Oktober 2004; invited paper.

Holstein, J., Haas, F., Zahm, A., Häuser, C. L. & Kinuthia, W. 2004. Katydids and Crickets (Orthoptera: Ensifera) of the Kakamega Forest Reserve, western Kenya. 5th International Symposium on Tropical Biology – African Biodiversity: Molecules, Organisms, Ecosystems. Bonn, 02.-06.05.2004; poster.

Kühne, L., Freund, W., Häuser, C.L., Holstein, J. & Wagner, T. 2001. Insects as Biodiversity Indicators in Africa: Standardized Methods for Assessing Lepidoptera and Phytophagous Coleoptera. BIOLOG Status Seminar, 04.-07.12.2001, Bonn; poster.

Namu, F. N. 2004. Effects of forest disturbance on butterfly diversity in Kakamega Forest Nature Reserve, Kenya. 5th International Symposium on Tropical Biology – African Biodiversity: Molecules, Organisms, Ecosystems. Bonn, 02.-06.05.2004; poster.

Unpublished thesis

Namu, F. N. 2004. Effects of forest disturbance on butterfly diversity in the Kakamega Forest National Reserve (K.F.N.R.), Western Kenya. M.-Sc. Thesis, University of Nairobi, Faculty of Science, Department of Zoology; 88 pp.

Thielmann, J. 2003. Diversität der Thyretini (Lepidoptera: Arctiidae) verschieden genutzter Standorte im tropischen Regenwald des Kakamega Forest N. R. in Kenia. [Scientific project paper in preparation for Government Teachers' Examination in Biology, Chemistry, and Pharmacy] Wissenschaftliche Hausarbeit im Rahmen der ersten Staatsprüfung für das Lehramt (Biologie, Chemie, Pharmazie), Freie Universität Berlin; 63 + 9 pp.

Contributions in preparation

Collins, S.C., Kühne, L., Häuser, C., Bartsch, D. & Kinuthia, W. A preliminary check-list of the butterflies of the Kakamega Forest N.R., Western Kenya.

Häuser, C.L., Bartsch, D., Holstein, J., & Kühne, L.: An annotated check-list of the Hawk Moths and Emperor Moths (Lepidoptera: Sphingidae, Saturniidae) of the Kakamega Forest N.R. in western Kenya.

Häuser, C.L., Cieslak, A., Bartsch, D., Holstein, J., & Kühne, L.: A preliminary species inventory of Tiger Moths (Lepidotpera: Arctiidae) for the Kakamega Forest, Western Kenya.

Namu, F.N., Collins, S. C. & Häuser, C.L.: New and interesting records of butterfly species for Western Kenya.

Namu, F.N., Häuser, C.L., Bartsch, D., & Holstein, J.: Ecological characterisation of the butterfly community of an East African highland forest – species diversity and indicator values.

3. Capacity building

3.1 Technical capacity building

For most of the field work carried out for this project, Kenyan field assistants could be employed who were trained in the recording and collecting techniques employed, and introduced to the equipment used. Such training of field techniques included conducting transect walks, observing diurnal Lepidoptera at natural aggregations such as mud puddles and hilltops, constructing and installing bait traps, and ways how to set up and run light traps and to operate the associated equipment such as portable generators, battery chargers, different fluorescent and UV light bulbs.

Field assistants received further training in general techniques for collecting, handling and preserving of insect specimens, e.g., how to pin, set and dry specimens of Lepidoptera and Orthoptera, and their subsequent curation. Documentation and analytical procedures demonstrated included the use of digital cameras, basic digital image processing, the use of spreadsheets and relational databases, and general advice with use of computer hardware. The technical equipment purchased for this project such as two portable generators and different light traps has also been provided for use by partners and counterparts from other BIOTA projects, and will continue to be available for field work at the Buyangu campsite.

Technical capacity building was also possible during the collaboration with the Department of Invertebrate Zoology of the National Museums of Kenya, Nairobi (NMK). In addition to the determination of materials from Kakamega Forest present in the NMK collections, some attention could also be given to other parts of the entomological holdings to determine unidentified material and to help improve collection management by donations of consumables and smaller equipment.

3.2 Students and scientific staff trained

As provided by the Memorandum of Co-operation between Kenyan authorities and the BIOTA project management, a Kenyan student was to be employed as field assistant for each BIOTA East project. The first student chosen as field assistant for the present project, Flora N. Namu, proved to be a very skilful and highly motivated collaborator. After some brief training, Ms. Namu was put in charge with operating the light traps, and continued to work throughout the first year of the project. Following her graduation at University of Nairobi in 2002, the opportunity arose to provide support for enrolling in a M.Sc. program. As her thesis project she embarked on a comparative study of butterfly diversity of different forest types at Kakamega, for which she could be partly supervised from the present project. Paying the tuition fees and a small scholarship was made possible by transferred funds originally allocated to BIOTA East project E09 (“Influence of land use modes on diversity, abundance and guild structure of coprophagous beetles in the African forest-savannah-mosaic”; project leader: Dr. F.-T. Krell, The Natural History Museum, London), which is herewith gratefully acknowledged.

Field assistants trained

Flora Njeri Namu, c/o Dept. of Invertebrate Zoology, National Museums of Kenya; Nairobi, Kenya (2001/02).

Joseph Mugambe, Dept. of Invertebrate Zoology, National Museums of Kenya; Nairobi, Kenya (2002).

Students trained and/or supervised

Flora Njeri Namu (M.Sc. student), Faculty of Biology, University of Nairobi (Thesis: Effects of Forest disturbance on the butterfly fauna – a case study from the Kakamega Forest).

Juliane Thielmann (graduating student, 1st Teacher's exam), Faculty of Sciences, Freie Universität Berlin (Thesis: Diversität der Thyretini (Lepidoptera: Arctiidae) verschieden genutzter Standorte im tropischen Regenwald des Kakamega Forest N. R. in Kenia): apart from her thesis project, was involved in preparation, sorting, and identification of Lepidoptera specimens.

Anja Wolf (undergraduate student), Faculty of Sciences, Freie Universität Berlin: employed for preparation, sorting and identification of Lepidoptera specimens.

Anja Zahm (postgraduate student), Staatliches Museum für Naturkunde, Stuttgart (SMNS): employed as scientific assistant at SMNS, was charged with identification and taxonomic analysis of Lepidotpera specimens, particularly Arctiidae.

Lars Kühne (postgraduate student), Zoologisches Museum Berlin: Diversity patterns of Lepidoptera in a West Kenyan highland rain forest.

Annex

a) Number of Lepidoptera species recorded for the Kakamega Forest N.R. by family and subfamily. Figures in parentheses refer to possible additional species present [state of analysis as of October 2004]:

Rhopalocera:	**515** (- 580) **spp.**	(= Papilionoidea + Hesperioidea)
Papilionidae:	**13** (- 15) spp.	
Pieridae:	**43** (- 46) spp.	
Coliadinae:	8 (- 9) spp.	
Pierinae:	35 (- 37) spp.	
Nymphalidae:	**210 (**- 236) spp.	
Apaturinae:	1 sp.	
Charaxinae:	30 (- 36) spp.	
Danainae:	9 spp.	
Heliconiinae:	50 (- 58) spp.	
Libytheinae:	1 sp.	
Nymphalinae:	87 (- 99) ssp.	
Satyrinae:	30 (- 32) spp.	
Lycaenidae:	**148 (**- 171) spp.	
Miletinae:	7 (- 9) spp.	
Polyommatinae:	50 (- 63) spp.	
Poritiinae:	45 (- 47) spp.	
Theclinae:	46 (- 52) spp.	
Hesperiidae:	**101 (**- 112) spp.	
Coeliadinae:	2 (- 4) spp.	
Hesperiinae:	66 (- 72) ssp.	
Pyrginae:	33 (- 36) spp.	
ZYGAENOIDEA		
Limacodidae:	35 spp.	
Chrysopolominae:	4 spp.	
Limacodinae:	31 spp.	
BOMBYCOIDEA		
Eupterotidae:	7 spp.	
Saturniidae:	26 spp.	
Sphingidae:	44 spp.	
Smerinthinae:	10 spp.	
Sphinginae:	8 spp.	
Macroglossinae:	26 spp.	
Lasiocampidae:	69 spp.	
Lasiocampinae:	25 spp.	
NOCTUOIDEA		
Arctiidae:		
Lithosiinae:	> 17 spp.	
Asura:	12 spp.	
Thyretinae:	> 20 spp.	
Lymantriidae:	100 spp.	
Notodontidae:	64 spp.	
Notodontinae:	62 spp.	
Phalerinae:	2 spp.	
Thaumetopoeinae:	2 spp.	
GEOMETROIDEA		
Drepanidae:		
Drepaninae:	15 spp.	

b) List of cricket and katydid species (Orthoptera: Ensifera) recorded from the Kakamega Forest N.R.

	Gryllidae
	Gryllinae, Gryllini
1.	Grylloderes maurus (Afzelius & Brannius, 1804)
2.	Acheta spec.
3.	Scapsipedus marginatus (Afzelius & Brannius, 1804)
4.	Teleogryllus gracilipes (Saussure, 1877)
5.	Teleogryllus xanthoneurus Gerstaecker, 1869)
	Oecanthidae
	Oecanthinae, Oecanthini
6.	Oecanthus spec.1
7.	Oecanthus spec.2
	Phalangopsidae
	Homoeogryllinae, Endacustini
8.	Phaeophilacris spec.
	Podoscirtidae
	Euscyrtinae
9.	Euscyrtus bivittatus Guerin-Meneville, 1884
	Trigonidiidae
	Nemobiinae, Pteronemobiini
10.	Pteronemobius spec
	Trigonidiinae, Trigonidiini
11.	Trigonidium spec.
12.	Trigonidium (Trigonidomorpha) spec.
	Gryllotalpidae
	Gryllotalpinae, Gryllotalpini
13.	Gryllotalpa africana Beauvois, 1805
14.	Gryllotalpa microptera Chopard, 1939
	Tettigoniidae
	Conocephalinae, Conocephalini
15.	Megalotheca longiceps (Peringuey, 1918)
16.	Conocephalus (Anisoptera) maculatus (Le Guillou, 1841)
17.	Conocephalus (Anisoptera) spec.
18.	Conocephalus (Conocephalus) spec.
	Conocephalinae, Copiphorini
19.	Ruspolia spec.
	Hetrodinae, Enyaliopsini
20.	Enyaliopsis carolinus Sjœstedt, 1913
21.	Enyaliopsis durandi (Lucas, 1884)
	Meconematinae
22.	Amytta spec.
	Mecopodinae, Mecopodini
23.	Anoedopoda erosa Karsch, 1891
	Phaneropterinae, Acrometopini
24.	Horatosphaga leggei (Kirby, 1909)
25.	Horatosphaga meruensis (Sjœstedt, 1909)
	Phaneropterinae, Phaneropterini
26.	Phaneroptera nana Fieber, 1853
	Phaneropterinae, unassigned
27.	Arantia rectifolia Brunner von Wattenwyl, 1878
28.	Eurycorypha prasinata Stål, 1874
29.	Eurycorypha spec. 1
30.	Eurycorypha spec. 2
31.	Gelatopoia bicolor Brunner von Wattenwyl, 1891
32.	Tetraconcha banzyvilliana Griffini, 1909
	Pseudophyllinae, Pleminiini
33.	Lichenochrus spec.

c) List of Dermaptera species recorded from the Kakamega Forest N.R.

	Family, species
	Karschiellidae
1.	*Bormansia* sp. [nymph]
	Diplatyidae
2.	*Diplatys ugandanus* Hincks, 1955
3.	*Haplodiplatys kivuensis*(Hincks, 1951)
	Pygidicranidae
4.	*Dacnodes* sp. [nymph]
5.	*Echinosoma afrum*(Palisot de Beauvois, 1805)
	Spongiphoridae
6.	*Spongovostox assiniensis*(Bormans, 1893)
7.	*Spongovostox* sp.

Subproject E07

Diversity and species composition of Odonata as indicators of biotope quality of East African rain forests and their replacement communities

Subproject leader: Prof. Dr. G. Miehe, Dr. V. Clausnitzer, University of Marburg	
Short title: BIOTA E07	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

The aims of this project were manifold and will be given in a condensed overview:

- inventory of forest dragonflies in various forests of East Africa (montane, highland, coastal, Eastern Arc, Miombo forest)
- comparison of the forest-dragonfly-communities with those of forest-replacement habitats
- ecology of selected and forest species, e.g. habitat requirements and seasonality
- based on the results from the aforementioned aims, selection of indicator species for habitat quality and disturbance
- assessment of the status of rare and localised forest species, recommendation of conservation activities
- capacity building through various approaches: work shops, poster distribution, public talks, identification of material in collections (National Museums of Kenya, Makerere University), preparation of an identification key for the dragonflies of eastern Africa

The following table briefly shows the project objectives according to the announcement in the proposal and their realisation.

Objectives formulated in the proposal	**Methods and/or results to achieve the objectives**
Conservation of biodiversity with special references to ecological aspects	see publication list under 2.4
Change of biodiversity as a result of global environmental disturbances	see publication list under 2.4
Identification of indicator species and evaluation of species composition	see publication list under 2.4
Identification manual for East African Odonata	nearly completed: Clausnitzer & Dijkstra in prep., Dijkstra & Clausnitzer in prep.
Inventory of ζ- and η diversity of dragonflies	see publication list under 2.4
Development of monitoring systems for a rapid assessment of ecosystems	see publication list under 2.4
Establishing of infrastructure and networks for long-term studies	cooperation with several conservation orientated projects (IUCN, Conservation International, DANIDA, UWA, KWS)
Capacity building in East Africa (developing local expertise)	training workshops; public talks; distribution of information posters to institutions, organisations, projects and communities; PhD project in Uganda

Planning and conduction

According to the aims given above, surveys in various habitats were conducted in Kenya, Tanzania, Uganda and Ethiopia. The fieldwork in Uganda was largely done by John Joseph Kisakye (PhD student from Uganda) and by Klaas-Douwe B. Dijkstra (PhD student from The Netherlands and project collaborator). To gather information on seasonality, most habitats were visited in different seasons of the year.

Special focus was put on following habitat types:

- rain forest (Kakamega, Mabira, Semliki; Bwindi Impenetrable)
- montane forest (Mt. Kenya, Mt. Elgon, Mt. Kilimanjaro, Bwindi, Marsabit, Bale, West Usambara Mts)
- coastal forests (Arabuke Sokoke, Shimba Hills, Buda, Muhaka, Gongoni, lower East Usambara Mts, Rufiji, Kichi Hills)
- Eastern Arc Mts (Taita Hills, East Usambara Mts, West Usambara Mts, Uluguru Mts, Udzungwa Mts)

This resulted in a total of 18 months of field work by Viola Clausnitzer, plus the field work done by John Joseph Kisakye for his PhD project (mainly in Bwindi, Mabira, Mt. Elgon – all Uganda) and by Klaas-Douwe Dijkstra (Semliki in West Uganda and joint field trips with John Joseph Kisakye and with Viola Clausnitzer in Kenya, Uganda and Ethiopia).

Quite some time was devoted to the dragonfly communities of coastal and the Eastern Arc forests in Kenya and Tanzania, which resulted in a number of publications. Here a special focus was put on distribution, ecology and conservation status of the endemic species *Coryphagrion grandis*, *Amanipodagrion gilliesi*, *Hadrothemis scabrifrons*, *Micromacromia miraculosa* and on representatives of the genus *Gynacantha*.

Another focus were montane species and their altitudinal distribution as well as the ecology and biogeography of the endemic *Pseudagrion bicoerulans*. This species was intensely studied on Mt. Elgon, Mt. Kenya, the Aberdare Mts and on Mt. Kilimanjaro.

Details of the methodology for the various studies can be taken from the publications as well as results achieved.

The major project was and still is the preparation of an identification key for the dragonflies of eastern Africa, which includes an entire revision of the dragonfly fauna (systematics, biogeography, ecology). This work, which is done by Klaas-Douwe Dijkstra and Viola Clausnitzer, includes entirely new keys for all dragonflies from eastern Africa (ca. 450 species); for several genera even continent-wide keys have been processed. Loads of new characters and hundreds of new illustrations accomplish his work. This is without doubt a major and a long-lasting benefit to the odonatological community. Once all contributions (see publication list below) are published, the identification, taxonomy and biogeography of Afrotropical dragonflies will be largely solved for eastern Africa and consequently the African Odonata will have a taxonomic basis unequalled in any other invertebrates and most vertebrates in the tropics.

Cooperations with other institutions

Conservation International (CI): dragonfly surveys in central Democratic Republic of Congo (DRC)

The World Conservation Union (IUCN): dragonfly surveys in different areas, assessment of the dragonflies of eastern Africa (Kenya, Malawi, Tanzania, Uganda), global Red Listing

International Centre for Insect Physiology and Ecology, Nairobi, Kenya: project leader has the status as „visiting scientist" within ICIPE

National Museums of Kenya, Nairobi, Kenya: re-identification of the entire dragonfly collection, equipping the collection with new specimen.

Nationaal Natuurhistorisch Museum Naturalis, Leiden, The Netherlands: collection work.

Africa Museum, Tervuren, Belgium: collection work.

Museum für Naturkunde der Humboldt-Universität, Berlin, Germany: collection work

The Natural History Museum, London, England: collection work.

Makerere University, Institute for Environment and Natural Resources, Kampala, Uganda: re-identification of the entire dragonfly collection, equipping the collection with new specimen.

Uganda Wildlife Service, Kampala, Uganda: surveys in National Parks.

Kenya Wildlife Service, Nairobi, Kenya: training of staff, equipping National Parks, Information Centres and guide books with dragonfly poster and photos.

Prof. Dr. Andreas Martens, Department for Biology, Pedagogical University of Karlsruhe, Germany: BIOTA project S08, cooperation in respect of biogeography and ecological traits along latitudinal gradients of African dragonflies; sampling of alcohol material of agreed species for molecular genetic analysis.

Prof. Dr. Michael May, Department of Entomology, Rutgers University, New Brunswick, USA: molecular genetic and morphological analysis of the genus *Enallagma*.

Prof. Dr. Michael Samways, Department of Conservation Ecology and Entomology, University of Stellenbosch, South Africa: cooperation on conservation and biogeography related issues of African dragonflies.

Dr. Charly Williams, Makerere University, Institute for Environment and Natural Resources, Kampala, Uganda. Dragonfly surveys in Uganda; development of a reference collection at the University.

Dr. Frank Suhling, Institute of Geoecology, Department for Environmental System Analysis, Technical University of Braunschweig, Germany: BIOTA project S08, cooperation in respect of biogeography and ecological traits along latitudinal gradients of African dragonflies; sampling of alcohol material of agreed species for molecular genetic analysis.

Dr. Heike Hadrys, Institute for Animal Ecology and Cell biology, Tierärztliche Hochschule Hannover, Germany: BIOTA project S08, molecular genetic analysis of certain species and genera for biogeography, population ecology and conservation biology related topics.

Linn Fenna Groenefeld, Institute for Zoology, Anthropology and Developement Biology, Uinversity of Göttingen, Germany: BIOTA project S08, molecular genetic analysis of certain species and genera for biogeography, population ecology and conservation biology related topics.

Klaas-Douwe B. Dijkstra, Nationaal Natuurhistorisch Museum Naturalis, Leiden, The Netherlands: cooperation in most studies of the project, largely involved in the preparation of the identification key for the dragonflies of eastern Africa.

Dino Martins, East African Wild Life Society & National Museums of Kenya, Nairobi, Kenya: production of information material on dragonflies for the public.

Brian Finch, East African Wild Life Society, Nairobi, Kenya: surveys of East African dragonfly fauna, production of information material on dragonflies for the public.

2. Results

2.1 Scientific results

Most of the results have already been published or will be published. Therefore the results presented here are kept short and tables, figures and statistical analyses are not presented. For more information please consult the given references.

The dragonflies (Odonata) of Eastern Africa, an identification manual

This work is based on museum work in all relevant collections, a thorough literature survey and field work (surveys, ecology), in combination thus covering many aspects of African odonatology. The project has already led to many publications, solving a number of taxonomic problems. Major outputs over the next year will be "*The dragonflies of Eastern Africa (Odonata), an identification manual*" (Clausnitzer & Dijkstra in prep.) and "*An annotated checklist of the dragonflies (Odonata) of Eastern Africa: with critical lists for Ethiopia, Kenya, Malawi, Tanzania and Uganda, new records and taxonomic notes*" (Dijkstra & Clausnitzer in prep.). The latter paper will be a complete review of taxonomy of about 450 species (= half of African species and nearly all genera!). This (and the aforementioned manual) will be landmark papers, like Pinhey's survey of the dragonflies of East Africa from 1961 and his catalogue of the Odonata of Africa from 1962. As a result of these contributions a number of Africa-wide genus revisions have been published or are in preparation, e.g. for the genera *Gynacantha*, *Heliaeschna*, *Hemicordulia*, *Atoconeura*, *Diplacodes*, *Porpax* and *Olpogastra*, while important contributions are made to *Chlorocypha*, *Notogomphus*, *Phyllogomphus*, *Idomacromia*, *Phyllomacromia*, *Micromacromia* and *Trithemis*. New species descriptions due to be published, are based on both museum work and own field collections (e.g. *Notogomphus*, *Paragomphus*, *Idomacromia*). All these contributions are accompanied by ecological observations from the field on habitat, behaviour and distribution.

Studies (ecology, conservation biology) on dragonflies from coastal and Eastern Arc forests, Kenya and Tanzania

A study on the ecology and morphology of the dendrolimnetic damselfly *Coryphagrion grandis* was undertaken in coastal forests of East Africa (Clausnitzer & Lindeboom, 2002, Clausnitzer, 2004). The results are compared with other dragonfly species, known to breed in phytotelmata as well. These ecological and additional morphological and genetic results of this study show, that the monotypic *Coryphagrion grandis*, which was placed for conveniences within the Megapodagriidae, belongs to the otherwise South and Central American Pseudostigmatidae. Although the separation from the Neotropical Pseudostigmatidae occurred at least 100 million years ago, the morphology and biology of *Coryphagrion grandis* is still very similar to the former. These findings support biogeographical considerations about historical forest distribution in Africa, stability of East African coastal forests and the species loss due to extinction in West and Central Africa. The future of *Coryphagrion grandis* depends on the survival of the last coastal and lower Eastern Arc forests.

New records of *Teinobasis alluaudi* Martin, 1896 have been made from coastal forests of Kenya and Tanzania and from Pemba and Zanzibar Islands, Tanzania. Habitat and reproduction of this species are described. The systematic status of *Teinobasis alluaudi*, *T. alluaudi berlandi* Schmidt, 1951 and *T. malawiensis* Pinhey, 1966 are discussed (Clausnitzer, 2003).

Amanipodagrion gilliesi was known previously only from four males collected in 1959 and 1962 in the Usambara Mountains, south-east Tanzania. Recently it has been rediscovered at two shady streams in that area. The species is not living in swamps, as previously stated, but is apparently restricted to a small area in the Amani-Sigi Forest. Data on ecology, behaviour and reproductive habitat are presented for the first time (Clausnitzer, 2003).

The new species, *Platycnemis palmipes*, is described from a series of 8 males and 2 females from Ngezi Forest, Pemba Island, Tanzania. The species is closest related to the Malagasy platycnemidids *P. hova* Martin and *P. aurantipes* Lieftinck and allows an insight of the biogeographical relation between Pemba and Madagascar (Clausnitzer & Martens, in prep.).

Dragonflies of the Arabuke-Sokoke Forest were studied in respect of their response to the seasonality of their reproduction sites. The 31 recorded species were divided into 3 groups according to where they were reproductively active: 1) those restricted to pools within the forest; 2) those active at open, sunny pools; and 3) those breeding in phytotelmata. Different strategies to cope with the lack of permanent water sources in the forest are outlined. Some general arguments for the usefulness of dragonflies as indicator organism for habitat destruction are given (Clausnitzer, submitted).

In Clausnitzer (2003) the species diversity of Odonata from coastal forest in southern Kenya is highlighted, indicator species for certain habitats identified and the importance of conserving the last remaining coastal forest areas emphasised. A total of 78 species were recorded from coastal habitats in southern Kenya; five species for the first time in East Africa. Dragonfly communities relative to different habitat types from indigenous forest to cultivated landscapes are described and compared. The forest species are often confined to coastal forests of East Africa. They are stenotopic and highly sensitive to disturbance. With increasing habitat disturbance the species richness increases at first, but most of the colonisers are euryotopic species that are common and widely distributed in Africa. The species assemblages between different habitat types in the disturbed landscape are more or less the same; the beta-diversity is much lower than in different habitat types of the natural coastal landscape. Management implications are briefly discussed.

Oviposition in water-filled tree holes and mating behaviour of *Hadrothemis scabrifrons* was observed in a lowland coastal forest in Kenya. Conforming with the predominant mode of oviposition in the Libellulidae, females of *H. scabrifrons* touch the water with their ovipositor while hovering above tree holes. Male behaviour is opportunistic: usually males perch and patrol in clearings away from tree holes but at exceptionally large tree holes males are territorial and guard mates. Larvae and adults were found in different seasons; the species seems to be non-seasonal (Clausnitzer, 2002).

Trithemis bifida is reported for the first time from East Africa. Previously there were only two Afrotropical records of this species: one male from Zambia and one male from the Ivory Coast. The male of *T. bifida* is described and compared with the closely related *T. donaldsoni* which is also found in East Africa. Taxonomically relevant structures are figured, differential features between both species are described and notes on the ecology of *T. bifida* are given (Clausnitzer, 2001).

Dragonflies of the Kakamega forest, Kenya

A total number of 71 dragonfly species have been recorded from the forest, of which 21 species are of regional importance for Kenya. Nevertheless the dragonfly fauna of the Kakamega Forest is impoverished if compared to more western Guineo-Congolian rainforest areas. The problem of forest fragmentation and isolation hindering any migration from western rainforest patches is addressed in Clausnitzer (submitted).

Dragonflies of Bwindi Impenetrable and Semliki NP, Uganda

The diversity, geography and ecology of the Odonata of Bwindi Impenetrable National Park (BINP) and Semliki National Park (SNP) were investigated in May and June 2003. The sites are important because of their position within or along the Albertine Rift, the wide range of habitats they include, their high degrees of species richness, endemism and complementarity (considering other taxonomic groups than Odonata), their status as priority sites for forest conservation in Uganda (as identified by scientists of the Uganda Forest Department) and their insufficiently known dragonfly fauna. Both areas have rich odonate faunas, with 65 species known from BINP and 91 from SNP. About 220 species occur in Uganda with certainty Dijkstra & Clausnizer (in prep.b), and at least 250 may be expected. 122 species, over 55% of Uganda's known odonates, occur in the two national parks investigated, but only 28% of these species have been found in both areas. 28% of BINP's fauna and 11% of SNP's are restricted in range, with ranges centred on the Albertine Rift or Uganda. This amounts to 23 species, only 5 of which occur in both parks. Their importance for the conservation of these insects is therefore great and highly complementary. Further comparison of the ecological and biogeographic composition and conservation importance of the sites were made. Both areas have rather equal proportions of forested/open habitat and running/standing water species, but differences come to light when their ranges and specialisation are considered. All 6 Albertine Rift highland endemics occur only in BINP, the logical result of SNP containing no highland habitats. The majority of the Albertine and Uganda-centred species are specialists of forested running waters. The western species, which reach their eastern range limit in Uganda, also include many species with this speciality, but also contain a high proportion of species of standing forested waters. Because SNP is low-lying and flat, but BINP is mountainous, the former area is much richer in these species. The eastern species, which mainly include inhabitants of highland swamps, are found principally in BINP. The higher species richness of SNP is explained by greater numbers of widespread and western species. Most of the approximately 100 Ugandan species that have yet to be recorded from either area are widespread or western in range. Therefore the SNP list has a greater potential to grow in the future than that of BINP. Moreover, numerous species from the adjacent Congolese lowlands may be expected.

The dragonflies (Odonata) of Ethiopia,
with special notes on the status of its endemic species

A survey of Odonata in the highlands of central and Southwest Ethiopia, as well as along some Rift Valley lakes was undertaken in March 2004 (Clausnitzer & Dijkstra, submitted). The endemic species were the main target, as almost no information other than descriptions existed. Some type localities were visited, as were other habitats, to gather information on the species' distribution, habitat requirements and conservation status. 29 sites were sampled and 69 species recorded. Of 11 known endemics, 9 were found, all at sites other than their type localities. One new species assumed to be endemic was found, and is described as *Paragomphus crenigomphoides* spec. nov. A revised checklist of Ethiopian Odonata is presented: 96 species have been reliably recorded. *Ischnura hilli* and *Enallagma caputavis* are considered synonyms of *I. abyssinica* and *Pseudagrion niloticum* respectively. The taxonomy and nomenclature of an undescribed *Aeshna* species (near *A. meruensis* and *A. yemenensis*), *Notogomphus ruppeli* (frequently spelt as *N. rueppeli*) and *Orthetrum kollmannspergeri* (probably confused with Asian *O. taeniolatum*) are discussed. Ethiopia's odonate fauna is compared with that of other East African highlands: It is impoverished (especially forest species) but rich in endemics.

Taxonomic results

Several new species were and will be described, as can be seen from the publication list. *Notogomphus cataractae* and *N. immisericors* are placed in synonymy of *N. lecythus*. This is based on examination of the holotypes and on fresh material from Kenya (Clausnitzer, 2003). Status and records of *Aeshna meruensis* are published for the first time. This species has been confused with *A. rileyi* for a long time, although A.R. Waterston separated and labelled specimens of both species in the collection of the Natural History Museum, London, as early as 1974. *A. meruensis* is known from seven localities in East Africa so far, but a wider distribution is anticipated (Clausnitzer & Peters, 2003).

Conservation of dragonflies from eastern Africa

In eastern Africa, ranging from Somalia and Ethiopia south to Mozambique and Zimbabwe and west to eastern Democratic Republic of Congo and Botswana, ca 500 species of Odonata are known. Comments on species and sites of conservation concern are given in Clausnitzer (2004) as well as recommendations for future research and conservation activities. Due to the rapid and ongoing destruction of forests, especially of coastal, Guineo-Congolian and Eastern Arc forests, species confined to these habitats are the most threatened.

2.2 Interdisciplinary components

Interdisciplinary co-operations can be divided in three groups:

1) data and/or sample transfer for odonatological scientific studies
2) presentation of data, information and photos for public issues and/or capacity building
3) data transfer for interdisciplinary studies

Since dragonflies are carnivorous and need aquatic habitats for their larval development, there is not much interaction with the research topics of the other projects, which study botany or plant-animal interaction related topics. Thus with in BIOTA East data transfer was and is realised with E02 (GIS) and E08 (Anura). Together with E02 a GIS based data base for dragonflies from eastern Africa shall be established. A joint paper with E02 is in preparation "*Decrease of species diversity with increasing altitude*".

A high degree of cooperation was achieved with S08 from BIOTA Southern Africa. Here the genetic similarity of pan-African species of high and very low mobility was and is compared along the BIOTA transect from South to East Africa. Dragonflies occurring in Namibia and in East Africa are compared in respect of reproduction sites, behaviour, seasonality and colonisation potential. Very good results were achieved by the genetic studies conducted in cooperation with S08, which resulted in a Master's thesis "*Molecular approaches to systematics, speciation, and population genetics of four African damselfly species* "and several publications (Groeneveld et al. submitted, in prep.a, in prep.b).

This project was more involved in cooperations outside BIOTA, as the following brief overview shows:

Conservation International (CI): participation in an expedition into Northeast Congo

The World Conservation Union (IUCN): surveys in various areas, evaluation of habitat quality, recommendations for conservation actions, assessment of the dragonfly fauna of East Africa, global red listing of East African species, 1-week dragonfly training workshop in Nairobi

Makerere University, Institute for Environment and Natural Resources: inventory and assessment of the dragonfly fauna in open land habitats of Important Bird Areas (IBA), co-founded by DANIDA

Kenya Wildlife Services (KWS): inventory of the dragonfly fauna in various National Parks, preparation of information posters and chapters for guide books

Uganda Wildlife Authority (UWA): inventory of the dragonfly fauna in various National Parks

National Museums of Kenya (NMK): identification and stocking of the dragonfly collection, 1-week dragonfly training workshop

2.3 Likely benefit and applicability of results

As already mentioned earlier will be "*The dragonflies of Eastern Africa (Odonata), an identification manual*" (Clausnitzer & Dijkstra in prep.) and "*An annotated checklist of the dragonflies (Odonata) of Eastern Africa: with critical lists for Ethiopia, Kenya, Malawi, Tanzania and Uganda, new records and taxonomic notes*" (Dijkstra & Clausnitzer in prep.) the major outputs over the next year. The identification key for the dragonflies of eastern Africa, which includes an entire revision of the dragonfly fauna (systematics, biogeography, ecology) and all other publication accompanying this work will be without doubt a major milestone and a long-lasting benefit for any studies, surveys, assessments, etc. on the dragonflies of eastern Africa. The identification, taxonomy and biogeography of Afrotropical dragonflies will be largely solved for eastern Africa and consequently the African Odonata will have a taxonomic basis unequalled in any other invertebrates and most vertebrates in the tropics.

Some results have already been used for a "Wetland Assessment in Eastern Africa" and for the "Rufiji Environmental Management Project" – both projects financed and conducted by the World Conservation Union (IUCN). Photos and general information have been and are still used for national park guide books in Kenya (produced by the Kenya Wildlife Service and Nature Kenya).

As chair of the IUCN/SSC Odonata Specialist Group (SSC: Species Survival Commission of the IUCN), the project leader is currently coordinating a total update of the global Red List of Odonata. This of course also involves species from Eastern Africa. The information for globally threatened species are results from studies during the first BIOTA phase (see also publication list and enclosed publications).

For a DANIDA funded inventory and assessment of open land IBA's (Important Bird Areas) of Uganda, dragonflies were surveyed as well. This work was done by Dr. Charlie Williams and the help of the people involved with the BIOTA project (Dr. Viola Clausnitzer, John Joseph Kisakye and Klaas-Douwe Dijkstra).

2.4 Publications resulting from the project

Note, that no internal BIOTA related publications have been listed and that some publications from the sections "2004", "in press", "submitted" and "in prep" are already results from the second project phase, which started in June 2004.

Clausnitzer, V. (2001) Notes on the species diversity of East African Odonata, with a checklist of species. *Odonatologica* 30(1): 49-66.

Clausnitzer, V. (2001) Notes on *Trithemis bifida* and *T. donaldsoni* (Odonata: Libellulidae). *International Journal of Odonatologogy* 4(2): 179-189.

Clausnitzer, V. (2001) A preliminary inventory of the dragonfly fauna of the Mtanza-Msona village lands, Rufiji District. *IUCN, Rufiji Environment Management Project Report*: 7.

Clausnitzer, V. (2001) Afrotropical Region: Eastern Africa. *IUCN Odonata Specialists Group: Regional Report*.

Clausnitzer, V. (2001) Mock Emerald – *Olpogastra lugubris*. *Agrion* 5(1): 12.

Clausnitzer, V. (2002) Reproductive behaviour and ecology in the dendrolimnetic *Hadrothemis scabrifrons* (Odonata: Libellulidae). *International Journal of Odonatologogy* 5(1): 1-14.

Clausnitzer, V. (2002) Dragonflies of East Africa. *IDF Report - Newsletter of the International Dragonfly Fund* 4(1): 11-17.

Clausnitzer, V. (2002) The dragonflies (Odonata) of the Kichi Hills, Nyamwete and Kiwengoma Forests, Rufiji District. *IUCN, Rufiji Environment Management Project Report*.

Clausnitzer, V. & Lindeboom, M. (2002) Natural history and description of the dendrolimnetic larvae of *Coryphagrion grandis* (Odonata). *International Journal of Odonatology* 5(1): 35-50.

Dijkstra, K.-D.B. (2002) The identity of the West African zygopterans *Pseudagrion emarginatum* and *P. camerunense* (Odonata: Coenagrionidae). *International Journal of Odonatology* 5: 105-110.

Clausnitzer, V. (2003) Dragonfly communities in coastal habitats of Kenya: indication of biotope quality and the need of conservation measures. *Biodiversity and Conservation* 12: 333-356.

Clausnitzer, V. (2003) The identity of the East African *Notogomphus lecythus*, *N. cataractae* and *N. immicericors* (Odonata: Gomphidae). *Odonatologica* 32(1): 85-87.

Clausnitzer, V. (2003) Rediscovery of *Amanipodagrion gilliesi* with notes on habitat, behaviour and conservation (Odonata: Megapodagrionidae). *International Journal of Odonatology* 6(1): 1-8.

Clausnitzer, V. (2003) Status, ecology and distribution of *Teinobasis alluaudi* (Odonata: Coenagrionidae). *Odonatologica* 32(4): 321-334.

Clausnitzer, V. (2003) Flying Jewels. *SWARA* 26(3):23-27

Clausnitzer, V. (2003) Odonata of African humid forests – a review. *Cimbebasia* 18: 173-190.

Clausnitzer, V. (2003) Dragonflies of Rufiji District. *IUCN, Rufiji Environment Management Project Report*.

Clausnitzer, V. (2003) Bying collections via internet? *Agrion* 7(1): 4.

Clausnitzer, V. & G. Peters (2003) Identity and distribution of the little known *Aeshna meruensis* (Odonata: Aeshnidae). *International Journal of Odonatology* 6(1): 9-15.

Dijkstra, K.-D.B. (2003) Fooled by the double: *Brachythemis liberiensis* is *Parazyxomma flavicans*, with a note on the Zyxommatini (Odonata: Libellulidae). *International Journal of Odonatology* 6: 17-21.

Dijkstra, K.-D.B. (2003) Problems in *Chlorocypha* classification: four cases from West Africa and a discussion of the taxonomic pitfalls (Odonata: Chlorocyphidae). *International Journal of Odonatology* 6: 109-126.

Dijkstra, K.-D.B. (2003) A review of the taxonomy of African Odonata: finding ways to better identification and biogeographic insight. *Cimbebasia* 18: 191-206.

Dijkstra, K.-D.B. & Lempert, J. (2003) Odonate assemblages of running waters in the Upper Guinean forest. *Archiv für Hydrobiologie* 157: 397-412.

Dijkstra, K.-D.B., A. Martens & Parr, M.J. (2003) Proceedings of the 1st PHAON Meeting on African Odonata, Gällivare, 26 July 2001, Foreword, African Odonatology: past, present and future. *Cimbebasia* 18: 161-166.

Clausnitzer, V. (2004) Critical species of Odonata in eastern Africa. In: Clausnitzer, V. & Jödicke, R. (eds) “Guardians of the watershed. Global status of dragonflies: critical species, threat and conservation”. *International Journal of Odonatology* 7: 189-206.

Clausnitzer, V. (2004) Ecology and biogeography of the dendrolimnetic *Coryphagrion grandis* (Odonata). In: Breckle, S.-W., Schweizer, B. & Fangmeier, A. (eds) "*Results of worldwide ecological studies*". Heimbach, Stuttgart. 243-256.

Clausnitzer, V. & K.-D.B Dijkstra (2004) On the trail of Ethiopia's endemic dragonflies. *Agrion* 8(2): 23-24.

Clausnitzer, V., Dijkstra, K.-D.B. & Finch, B. (2004) Planned fieldguide for eastern African Odonata. *Agrion* 8(2): 23.

Clausnitzer, V. & Martens, A. (2004) Critical species of Odonata in the Comoros, Seychelles, Mascarenes and other small western Indian Ocean islands. In: Clausnitzer, V. & Jödicke, R. (eds) “Guardians of the watershed. Global status of dragonflies: critical species, threat and conservation”. *International Journal of Odonatology* 7: 207-218.

Clausnitzer, V. & Jödicke, R. (2004) “Guardians of the watershed. Global status of dragonflies: critical species, threat and conservation”. *International Journal of Odonatology* 7: 111-428.

Dijkstra, K.-D.B. (2004) Odonates. In: Louette, M., D. Meirte & R. Jocqué, 2004. La faune terrestre de l'archipel des Comores. *Studies in Afrotropical Zoology* 293.

Dijkstra, K.-D.B. (2004) Dragonflies (Odonata) of Mulanje, Malawi. - *IDF Report, Newsletter of the International Dragonfly Fund* 6: 23-29.

Dijkstra, K.-D.B. & Clausnitzer, V. (2004) Critical species of Odonata in Madagascar. In: Clausnitzer, V. & Jödicke, R. (eds) "Guardians of the watershed. Global status of dragonflies: critical species, threat and conservation". *International Journal of Odonatology* 7: 219-228.

Dijkstra, K.-D.B. & Vick, G.S. (2004). Critical species of Odonata in western Africa. In: Clausnitzer, V. & Jödicke, R. (eds) "Guardians of the watershed. Global status of dragonflies: critical species, threat and conservation". *International Journal of Odonatology* 7: 229-238.

Garcia, G. & Dijkstra, K.-D.B. (2004) Odonata collected in the Ankarafantsika Forest, Madagascar. - *IDF Report, Newsletter of the International Dragonfly Fund* 6: 7-22.

Reinhardt, K. & Dijkstra, K.-D.B. (2004) Auf der Jagd nach Libellennamen in Malawi. - *IDF Report, Newsletter of the International Dragonfly Fund* 6: 31-34.

Tchibozo, S. & Dijkstra, K.-D.B. (2004) Rapport d'inventaire préliminaire des libellules des zones humides du Sud-Benin. - *IDF Report, Newsletter of the International Dragonfly Fund* 6: 1-6.

in press

Dijkstra, K.-D.B. & Kisakye, J.J. (in press) *Idomacromia jillianae*, a new species of Corduliidae from Uganda (Odonata). *International Journal of Odonatology.*

submitted

Clausnitzer, V. (submitted_a) Dragonflies (Odonata) and seasonality in the Arabuke-Sokoke Forest and notes on their usefulness as indicators. *Journal of East African Natural History*.

Clausnitzer, V. (submitted_b) Dragonflies (Odonata) of the Kakamega Forest. *Journal of East African Natural History*.

Clausnitzer, V. (submitted_c) Dragonflies – guardians of the watershed. *Lake Nakuru National Park Guide book*. KWS.

Dalitz, H., Musila, W., Todt, H., Uster, D. & Clausnitzer, V. (submitted) Spatial heterogeneity – a key feature for ecological processes.

Dijkstra, K.-D.B, (submitted_a) Taxonomy and identification of the continental African *Gynacantha* and *Heliaeschna* (Odonata: Aeshnidae). *International Journal of Odonatology.*

Dijkstra, K.-D.B. (submitted_b). The identity of some widespread and variable *Phyllomacromia* species, with a revised grouping of the genus (Odonata: Corduliidae). *Odonatologica.*

Dijkstra, K.-D.B. & Clausnitzer, V. (submitted) The dragonflies (Odonata) of Ethiopia, with notes on the status of its endemic species and the description of a new one. *Entomologische Zeitschrift.*

Dijkstra, K.-D.B., van Tol, J., Legrand, J. & Theischinger, G. (submitted) *Tramea* Hagen, 1861: proposed conservation (Insecta, Odonata). *Bulletin of Zoological Nomenclature.*

Groeneveld, L.F., Clausnitzer, V. & Hadrys, H. (submitted) Phylogenetic niche conservatism restricts speciation in *Coryphagrion grandis* (Odonata: Zygoptera). *Conservation Biology*.

Hadrys, H., Groeneveld, L.F. & Clausnitzer, V. (submitted) Gigantism in damselflies of Africa and South America: convergent evolution or homologous structures? Evidence from nuclear and mitochondrial sequence data. *Molecular Phylogenetics and Evolution*.

in prep

Clausnitzer, V. & Dijkstra, K.-D.B. (in prep.) The dragonflies of eastern Africa – an identification key. *Studies on Afrotropical Zoology*.

Clausnitzer, V. & Dijkstra, K.-D.B. (in prep.) The biogeography of Africa: perspectives from the Odonata.

Clausnitzer, V. & Martens, A. (in prep.) A new species of *Platycnemis* (Odonata: Platycnemididae) from Pemba Island, Tanzania and its message for biogeography. *International Journal of Odonatology*.

Clausnitzer, V. & Lötters, A. (in prep.) Decrease of species diversity with increasing altitude.

Dijkstra, K.-D.B. (in prep.) African *Diplacodes*: re-evaluation of the small species and the genus *Philonomon* (Odonata, Libellulidae).

Dijkstra, K.-D.B. (in prep.)Distribution, status, habitat and behaviour of Malawi's Mulanje Damselfly *Oreocnemis phoenix* (Odonata: Platycnemididae). *International Journal of Odonatology*.

Dijkstra, K.-D.B. (in prep.) Notes on Congolese Odonata. *Journal of Afrotropical Zoology, Tervuren.*

Dijkstra, K.-D.B. (in prep.) The *Atoconeura* Karsch problem revisted (Odonata, Libellulidae). *Tijdschrift voor Entomologie.*

Dijkstra, K.-D.B. (in prep.) The Basitincta-group of the genus *Trithemis* Brauer (Odonata, Libellulidae). *Tijdschrift voor Entomologie.*

Dijkstra, K.-D.B. (in prep.) The genus *Porpax* Karsch (Odonata, Libellulidae). *Tijdschrift voor Entomologie.*

Dijkstra, K.-D.B. (in prep.) The *Hemicordulia* Selys of Africa, India and the Indian Ocean Islands (Odonata: Corduliidae). *Tijdschrift voor Entomologie.*

Dijkstra, K.-D.B. (in prep.) The taxonomic status of *Neodythemis*, *Micromacromia* and related genera (Odonata, Libellulidae).

Dijkstra, K.-D.B. & Clausnitzer, V. (in prep.) Notes on Eastern African *Notogomphus*, with the description of two new species (Odonata: Gomphidae).

Dijkstra, K.-D.B. & Clausnitzer, V. (in prep.) An annotated checklist of the dragonflies (Odonata) of eastern Africa, with critical lists for Ethiopia, Kenya, Malawi, Tanzania and Uganda, new records, taxonomic notes and descriptions of new species. *Tijdschrift voor Entomologie.*

Dijkstra, K.-D.B., Clausnitzer, V. & Vick, G. (in prep.) Taxonomy of the three-striped species of *Phyllogomphus* (Odonata: Gomphidae).

Dijkstra, K.-D.B. & Olsvik, H.A. (in prep.) The Odonata of Ghana, with notes on their identification, habitat and behaviour. *Tijdschrift voor Entomologie.*

Dijkstra, K.-D.B., F. Suhling & Müller, O. (in prep.) Reassessment of the genera *Olpogastra* Karsch and *Zygonoides* Fraser, with the description of the larvae and notes on 'zygonychine' Libellulidae (Odonata). *Tijdschrift voor Entomologie.*

Groeneveld, L.F., Clausnitzer, V. & Hadrys, H. (in prep.) Habitat specificity and population characters among 3 African damselfly specie of the genus *Pseudagrion*.

Abstracts of scientific talks

Clausnitzer, V. (2001) On the trail of *Coryphagrion grandis*. European Regional Meeting of the Worldwide Dragonfly Association, Darmstadt, 7.-9. June. 2001

Clausnitzer, V. (2001) Aspects of the ecology of *Coryphagrion grandis*. 2nd WDA International Symposium of Odonatology, Gällivare, Sweden, 22-27 July.

Clausnitzer, V. (2001) African forests – speaking about hotspots and white-spots*2nd WDA International Symposium of Odonatology, Gällivare, Sweden, 22-27 July.*

Clausnitzer, V. (2002) Dragonflies – Guardians of the watershed. *National Museums of Kenya, Nairobi, 15 April 2002.*

Clausnitzer, V. (2002) Ecology and biogeography of the dendrolimnetic *Coryphagrion grandis* (Odonata). 2nd Symposium of the A.F.W. Schimper-Foundation, Hohenheim, 23-25 October 2002.

Clausnitzer, V. (2003) Dragonflies in East Africa: distribution patterns and concerns about conservation. *3rd WDA International Symposium of Odonatology, Beechworth, Australia, 07-13 January.*

Dijkstra, K.-D.B. & Clausnitzer, V. (2003) Towards a new identification manual for Eastern African Odonata. *3rd WDA International Symposium of Odonatology, Beechworth, Australia, 07-13 January.*

Clausnitzer, V. (2003) Diversity of dragonflies in the Rufiji Delta. Environmental Committee meeting, Utete, Rufiji, Tanzania, 7 February 2003.

Clausnitzer, V., Suhling, F. & Martens, A. (2003) From desert to forest: diversity of African Odonata. *16. Jahrestagung der Gesellschaft für Tropenökologie (gtö). Rostock, 19-22 February 2003.*

Clausnitzer, V. (2004) Libellen der Küstenwälder Ostafrikas: Zeugen ausgedehnter Wälder, Gigantismus und Gondwana. Angefragter Vortrag im biogeographischen, geobotanischen Kolloquium der Universität Trier. *Trier, 09 February 2004.*

Clausnitzer, V. (2004) Gigantismus bei Kleinlibellen Ostafrikas und Südamerikas: ein Beispiel für konvergente Entwicklung? Angefragter Vortrag im Kolloquium "Konzepte in der Evolutionsbiologie, Zoologie und Genetik" der Universität Essen. *Essen, 03 February 2004.*

Clausnitzer, V. (2004) Dragonflies in East Africa's coastal forests and Eastern Arc Mts – indicators of habitat health and landscape history. *5th International Symposium on Tropical Biology – African Biodiversity. Bonn, 2-6 May 2004.*

Clausnitzer, V. (2004) The IUCN Red List: goals, objectives and advantages. *16th International Symposium of Odonatology. Schwerin, 26-30 July 2004.*

Dijkstra, K.-D.B. & Clausnitzer, V. (2004) Flying colours: getting a grip on the diversity of Eastern African Odonata. *5th International Symposium on Tropical Biology – African Biodiversity. Bonn, 2-6 May 2004.*

Dijkstra, K.-D.B. & Clausnitzer, V. (2004) Flying colours: getting a grip on the diversity of Eastern African Odonata. *16th International Symposium of Odonatology. Schwerin, 26-30 July 2004.*

Abstracts of poster presentations

Clausnitzer, V. (2002) Dragonflies (Odonata) as indicator for habitat quality in coastal Kenya. *15. Jahrestagung der Gesellschaft für Tropenökologie (gtö). Göttingen, 19-22 February.*

Clausnitzer, V. (2003) Dragonflies in the East African public. 3rd WDA International Symposium of Odonatology, Beechworth, Australia, 07-13 January.

3. Capacity building

3.1 Technical capacity building

Counterparts in Uganda and Kenya were equipped with collection equipment (nets, vials, envelopes for storing specimen and chemicals) and information on field work and collection work techniques as well as with identification and general literature on dragonflies. Specially the literature is usually very difficult obtain in Kenya and Uganda.

A number of posters with general and scientific information on dragonflies either in general or for certain areas have been produced. These posters were distributed to various institutions, organisations and local communities. Photos and general information are also used for National Park guide books in Kenya (produced by the Kenya Wildlife Service and Nature Kenya).

3.2 Students and scientific staff trained

Doctoral thesis: John Joseph Kisakye, Makerere University, Institute for Environment and Natural Resources, Kampala, Uganda – The diversity and ecology of dragonflies in Bwindi Impenetrable, Mabira and Mt. Elgon Forests (finalisation August 2005)

Doctoral thesis: Klaas-Douwe B. Dijkstra, Nationaal Natuurhistorisch Museum Naturalis, Leiden, The Netherlands - cumulative dissertation on the biogeography, ecology and systematics of African dragonflies; general title: Incursion and expansion of dragonflies (Odonata) in tropical Africa.

Master’s thesis: Linn Fenna Groeneveld, Veterinary University Hannover, Germany – cumulative thesis, general title: Molecular approaches to systematics, speciation, and population genetics of four African damselfly species.

From the 22nd – 26th September 2003 a dragonfly training workshop was conducted at the National Museums of Kenya, Nairobi. The participants came from Uganda, Tanzania, Malawi and Kenya: John Joseph Kisakye (Uganda), Stanley George Kyobe (Uganda), Richard O. Odhiambo (Tanzania), Joshua S. Valeta (Malawi), Yolice L.B. Tembo (Malawi), Laban Njoroge (Kenya), Cecilia M. Gichuki (Kenya), Ann Mbogo (Kenya), J. R. Silver (Kenya), Edwin Selempo (Kenya), Zacchaeus Mugambi (Kenya), Philip Ochieng Mbeke (Kenya), Samuel M.Mwangi (Kenya), Odeny Dicken Onyango (Kenya), Reuben Mwakodi (Kenya), Dino J. Martins (Kenya).

Subproject E08

Biodiversity change in frogs from eastern Africa: global, regional or local causes?

Subproject leader: HD Dr. M. Veith, University of Mainz	
Short title: BIOTA E08	**FKZ:** 01LC0025
Duration of project: 01.03.2001 – 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

The subproject BIOTA E08 refers to the question if there is currently taking place a global amphibian population decline related to the same cause(s). The latter has been under debate for more than a decade now. A global amphibian decline would mean a severe threat to a wide array of ecosystem stability.

There is no doubt that in different places all over the world amphibian population declines take place. However, different methods and findings currently suggest the presence of different reasons (e.g. climatic change, pathogens etc.). A general problem in this respect is that our understanding of mechanisms and interactions is still poor.

BIOTA E08 tests the hypothesis if biodiversity change in anuran amphibians (frogs) is more linked to local or regional non-related phenomena. It may be analysed

- whether in regions, in which no population decline has been detected so far, different anuran communities in various habitats undergo same changes.
- whether patterns of regional or local amphibian diversity change correspond with those found in other regions of the world.

Linking standardised long-term amphibian monitoring data gained at different sites in East Africa (i.e. of different interaction with human activity within Kenya and Uganda) with those from other regions in the world that were taken with same efforts and methods, are the focus of BIOTA E08. There exist similar projects as BIOTA E08 in West Africa (BIOTA W08) and in Borneo. Others are intended to be established in South America (Ecuador, Bolivia) and Madagascar.

In the initial BIOTA phase, the aims of BIOTA E08 were

(i) to identify suitable study sites,

(ii) to obtain species lists and to resolve complicated taxonomic issues especially based molecular genetics (i.e. installation of a DNA database for African amphibians),

(iii) to identify species found throughout all study sites or those that replace each another in terms of eco-functional aspects, and to learn about their life history, to run comparative monitoring at the species level (demography, genetics).

(iv) to evaluate which methods are most practicable and successful to start a long-term monitoring at the community level,

(v) starting long-term monitoring.

Planning and conduction

From 2001 to 2003, apart from the Kakamega Forest (Kenya), in which BIOTA E08 works in biodiversity observatories along with other BIOTA subprojects, different sites in the Kenyan central and western highlands and in Uganda were tested for suitability. This included especially species surveys. Simultaneously, different field methods to conduct standardised monitoring efforts were tested. Since 2002, standardised monitoring has started along two transects in the Kakamega Forest using visual and acoustic encounters. Runda-Gigiri and Mount Elgon in Kenya and Mabira Forest and Budongo Forest in Uganda have been identified as suitable sites to carry out comparative monitoring undertakings (Fig. 1).

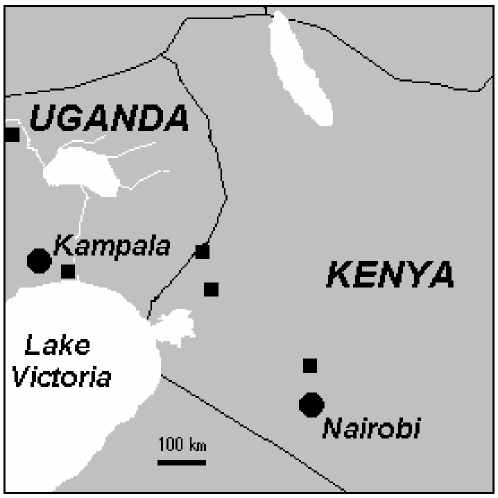

Fig. 1. Locations of Budongo Forest, Mabira Forest, Mount Elgon, Kakamega Forest and Runda-Gigiri (squares from left to right).

Cooperation with other institutions

Counterparts of BIOTA E08 include the Herpetology Department of the National Museums of Kenya, Nairobi (NMK), Kenya Wildlife Service (KWS) and Makerere University, Kampala (the latter only became an official counterpart of BIOTA during the subsequent project phase). Otherwise, logistics or data are shared with the BIOTA subprojects E01, E02, E04, E06, E07, E10. Moreover, BIOTA E08 cooperates with the Amsterdam and Würzburg Universities (at Würzburg University, BIOTA W08 is based), the University of the Western Cape, Belville, and the Laboratoire d'Ecologie des Sols Tropicaux, Bondy Cedex, France (Institut de Recherche pour le Développement).

2. Results

2.1 Scientific results

Suitable sites had to be well accessible (roads, availability of rangers for protection against wildlife etc.) and had to have most species in common with the Kakamega Forest, Kenya (at least in terms of eco-functional types). The following sites have been tested: Kenya — Runda-Gigiri, Aberdare Salient, Mount Kenya Chogoria, Mount Kenya Naru Moro, Thompson Falls, South-western Mau Forest, South Nandi Hills and Mount Elgon; Uganda - Mabira, Budongo and Kibale Forests. After all, merely Runda-Gigiri, Mount Elgon, Mabira Forest, Budongo Forest, apart from the Kakamega Forest, remained by fulfilling the above-mentioned premises.

All study sites mentioned have been intensively sampled using opportunistic sampling. Voucher specimens (both adult and larval stages) were deposited at the National Museums of Kenya, Nairobi (NMK), Makerere University, Kampala, and at the Alexander Koenig Research Institute and Museum of Zoology, Bonn (ZFMK). In addition, for each site, data from literature sources and from scientific collections (i.e. NMK; ZFMK; California Academy of Sciences, San Francisco) were used to produce species lists. For the above-mentioned study sites (see Fig. 1) species lists are given in Table 1.

For species identifications, comparative scientific material (see museums listed above), voice recordings of males and especially DNA samples were used. Work on taxonomically difficult taxa included species of the anuran genera *Afrana*, *Hyperolius, Leptopelis, Phrynobatrachus, Ptychadena* and *Xenopus.* Cryptic species have been detected among all these genera. For such purposes, BIOTA E08 subjected tissue sampling during all field trips to molecular analyses. The BIOTA molecular database was supplemented through GenBank searches and currently comprises 141 anuran species from East Africa and adjacent regions. The database enables already to identify 76 out of the approximately 150 Kenyan plus Ugandan species.

Table 1. Frog species lists of BIOTA E08 study sites in Kenya and Uganda (cf. Fig. 1).

Species	Kakamega Forest	Runda-Gigiri	Mount Elgon	Mabira Forest	Budongo Forest
Afrana angolensis	x		x	x	x
Afrana wittei			x		
Afrixalus quadrivittatus complex	x			x	x
Afrixalus laevis					x
Afrixalus osorioi	x				x
Amnirana cf. *albolabris*	x				
Arthroleptides dutoiti			x		
Arthroleptis adolfifriederici			x		x
Arthroleptis stenodactylus					x
Arthroleptis sp. 1	x				
Arthroleptis sp. 2	x				
Bufo gutturalis		x		x	x
Bufo cf. *maculatus*	x			x	x
Bufo kisoloensis	x		x		
Hemisus marmoratus		x			x
Hoplobatrachus occipitalis	x				x
Hyperolius acuticeps	x	x			x
Hyperolius balfouri					x
Hyperolius cf. *cinnamomeoventris*	x			x	x
Hyperolius glandicolor		x			
Hyperolius kivuensis	x			x	x
Hyperolius lateralis	x				x
Hyperolius langi					x
Hyperolius viridiflavus	x		x	x	x

Species	Kakamega Forest	Runda-Gigiri	Mount Elgon	Mabira Forest	Budongo Forest
Kassina senegalensis	x	x	x		x
Leptopelis bocagii	x				x
Leptopelis christyi				x	x
Leptopelis kivuensis	x				x
Leptopelis sp. 1	x				
Leptopelis oryi					x
Phlyctimatis verrucosus					x
Phrynobatrachus acridoides				x	
Phrynobatrachus auritus					x
Phrynobatrachus graueri	x		x		
Phrynobatrachus cf. *mababiensis*	x				
Phrynobatrachus natalensis	x			x	x
Phrynobatrachus cf. *scheffleri*	x	x			
Ptychadena anchietae	x	x			x
Ptychadena chrysogaster					x
Ptychadena cf. *mascareniensis*	x	x	x	x	x
Ptychadena porosissima	x				x
Ptychadena taenioscelis	x				
Ptychadena tellini	x				x
Schoutedenella discodactyla					x
Schoutedenella poecilonotus					x
Xenopus borealis		x	x		
Xenopus laevis	x			x	x
Xenopus muelleri					x
Total	**28**	**9**	**10**	**12**	**34**

With the purpose to identify species with similar eco-functionality (i.e. life styles) for later monitoring at the species level, as much information as possible was gained opportunistically or through focused studies (diploma theses). A catalogue of species characteristics was compiled that comprises ecological traits. In Kenya and Uganda, most frog species are terrestrial or arboreal, nocturnal and seasonally reproduce in lentic water, having exotrophic, herbivorous or omnivorous larvae. The following species (pairs) were chosen as suitable taxa for monitoring efforts at the population level: *Hyperolius* cf. *cinnamomeoventris, H.*

viridiflavus/glandicolor, *Kassina senegalensis, Ptychadena* cf. *mascareniensis* and *Xenopus laevis/borealis* (see Table 1).

To define monitoring standards for the community level, different field methods need to be tested. Field methods must be adequate for amphibian monitoring in different regions of the world for a thorough comparison of data. So called quadrate sampling, pitfall trapping and tadpole dipping have been found less useful for most East African frog species. Instead, transect walks revealed to be suitable to meet the majority of species and to be most practicable with respect to efforts and costs. Also they are less invasive and do not disturb habitats.

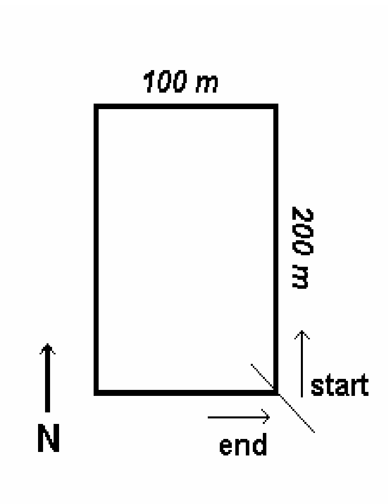

Fig. 2. Details of transects established in the Kakamega Forest. The start/end point was chosen at random

In 2002, two 600 m-long transects have been established in the Kakamega Forest (Buyangu Hill and Colobus Trail, which both lay within biodiversity observatories), in the way as shown in Figure 2. They are walked every 14 days, both day and night using GPS technology. Figure 3 gives some examples of data obtained and how they are processed. Additional transects are working at the other BIOTA E08 study sites since the beginning of the subsequent BIOTA phase.

2.2 Interdisciplinary components

BIOTA E01 provided any kind of necessary infrastructure to fulfil fieldwork in Kenya. Digital GIS-ready maps, necessary to locate areas of different degree of human interaction with the landscape, for the establishment of monitoring transects, were made available through BIOTA E02. Detailed information about vegetation and land-use in the chosen areas were permanently added through knowledge of members of BIOTA E03 and E04. BIOTA E03 also provided canopy photographs of established transects, being used to standardise their description. With BIOTA E07, data about location and condition of waters bodies for were shared for comparative analyses (not yet ran). BIOTA E08 transects at Kakamega Forest were also used by BIOTA E10 to run analyses. Experiences with monitoring methods and monitoring data were exchanged with BIOTA W08, resulting in a joint paper about monitoring standards.

2.3 Likely benefit and applicability of results

BIOTA E08 has been able to provide information about species, their distributions and their taxonomy in western Kenya and part of Uganda. Species lists and life history (eco-functional types) and DNA data are available and have in part been published (see below). They can be used for meta-analyses with macroecological, biogeographic or conservation focus.

Apart from this, these data and the circumstance that transects have been installed and are regularly walked, first monitoring data from the Kakamega Forest are available now. Moreover, the standard method for amphibian monitoring evaluated by BIOTA E08 (and BIOTA W08) can be replicated by other amphibian monitoring undertakings in tropical forests all over the world.

Training of African students in field techniques of a standardised amphibian monitoring was successfully performed during a workshop in 2003 (see below). It addressed pan-East-African students and highly motivated local monitoring at several remote places through young African scientists in the field of amphibians research.

Field data of BIOTA E08 and data from the herpetological collection of the National Museums of Kenya (NMK) form the basis for a bilingual field-guide on conservation of East-African amphibians. It will be a major task of the main project phase to assure that all requirements for its realisation are met.

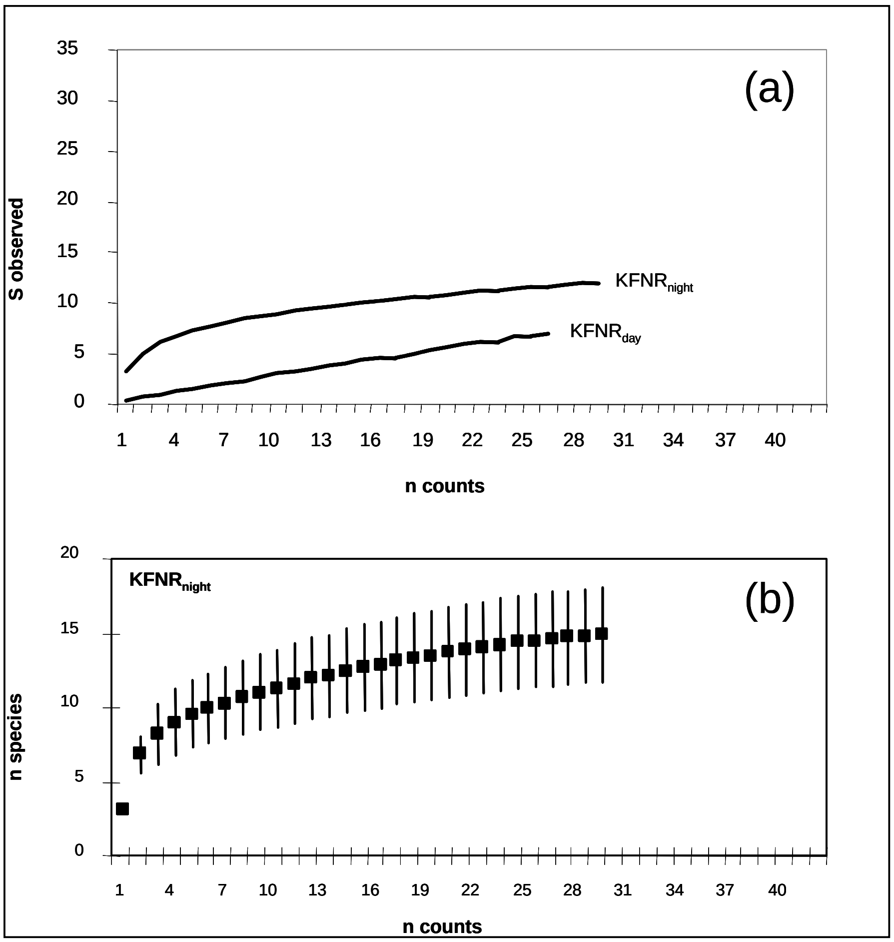

Fig. 3. Result of the transect walks at the Buyangu Hill transect, Kakamega Forest (KFNR): **(a)** The observed number of species during day walks steadily increases even after 26 observations, while for night walks there a plateau is reached at n = 12. **(b)** The 1st order jacknife estimator of species richness indicates a maximum number of 15 species for the transect (see below: Veith et al. 2004b).

2.4 Publications resulting from the project

[publications submitted have but in preparation have not been considered here]

Behangana, M. & S. Lötters (2003): Froschlurche aus dem Budongo Forest in Uganda. ∝ Amphibia, 2(1): 23-26.

Bwong, B.A., R. Chira, M. Veith, D. Rotich & S. Lötters (2004): Light at the end of the tunnel – preliminary results of a taxonomic revision of Ridged Frogs (Ranidae: *Ptychadena*) in Kenya. ∝ 5th International Symposium on Tropical Biology “African Biodiversity – Molecules, Organisms, Ecosystems”, Bonn (Germany) [Poster].

Köhler, J., K. Scheelke, S. Schick, M. Veith & S. Lötters (in press): Contribution to the taxonomy of hyperoliid frogs (Amphibia, Anura, Hyperoliidae): advertisement calls of twelve species from East and Central Africa. — African Zoology.

Lötters, S. (2001): Auf Frosch-Safari in Kenia. ∝ Arbeitssitzung Deutsche Gesellschaft f. Herpetologie u. Terrarienkunde (DGHT) Arbeitsgruppe Anuren, Weibersbrunn (Germany) [Abstract].

Lötters, S. (2001): Sterben uns die Frösche aus? ∝ Schülervortrag zum Thema “Lebenslinien“ im Jahr der Lebenswissenschaften (Bundesministerium für Bildung und Forschung, BMBF), Köln (Germany) [Abstract].

Lötters, S. (2002): Über Frösche und Froschforschung in Kenia. ∝ Arbeitssitzung, Deutsche Gesellschaft f. Herpetologie u. Terrarienkunde (DGHT) Arbeitsgruppe Anuren, Weibersbrunn (Germany) [Abstract].

Lötters, S. (2003): Amphibian monitoring standards – a workshop for African students. ∝ Froglog, 58: 4.

Lötters, S. (2003): *Boulengerula fischeri* Nussbaum and Hinkel, 1994 is an objective junior synonym and a homonym of *Boulengerula fischeri* Nussbaum and Hinkel *in* Fischer and Hinkel, 1992 (Amphibia, Gymnophiona). — Herpetological Review, 34 (3): 211.

Lötters, S. (2004): Amphibiensterben: Einblick in die Geschichte und die aktuelle Forschung. ∝ Reptilia, 46 (4): 16-23.

Lötters, S., J. Kosuch, M.-O. Rödel & M. Veith (2003): Multiple evolution of conditional mature colour change in African tree frogs, genus *Hyperolius.* — 96. Jahrestagung, Deutsche Zoologische Gesellschaft (DZG), Berlin (Germany) [Abstract].

Lötters, S., J. Kosuch, D. Rotich & M. Veith (2001): Measuring and monitoring amphibian diversity in East Africa: separating global from regional and local causes. *In:* Bundesministerium für Bildung und Forschung (BMBF) (ed.): BIOLOG. German Programme on Biodiversity and Global Change (Phase I, 2000-2004) Funded by BMBF. Status Report 2001. ∝ BMBF Environmental Research Programme, Berlin (Germany), and DLR – German Aerospace Research Establishment, Bonn (Germany), 247 pp.: 162-163.

Lötters, S., M.-O. Rödel, J. Kosuch & M. Veith (2001): Measuring and monitoring amphibian diversity change: separating global from regional and local causes. ∝ 2001 Joint Annual Meeting, Herpetologists’ League (HL) and the Society for the Study of Amphibians and Reptiles (SSAR), Indianapolis (USA) [Abstract].

Lötters, S., D. Rotich, T.E. Koester, J. Kosuch, V. Muchai, K. Scheelke, S. Schick, P. Teege, V.D. Wasonga & M. Veith (submitted): What do we know about the amphibians from the Kenyan central and western highlands? — Salamandra.

Lötters, S., D. Rotich, J. Kosuch & M. Veith (2002): Initialisation of a long-term anuran amphibian survey in the Kenyan highlands. ∝ 11th Meeting of the African Amphibian Working Group (AAWG), Watamu (Kenya) [Abstract].

Lötters, S., D. Rotich, J. Kosuch & M. Veith (2003): Measuring and monitoring amphibian diversity in East Africa: separating global from regional and local causes. BIOTA East Africa (E-08). *In:* “Anonymous“ (ed.): Sustainable use and conservation of biological diversity. A challenge for society. Symposium Report, Part A. ∝ German Federal Ministry of Education and Research (Berlin) and PT DLR (Bonn), 464 pp.: 114-115.

Lötters, S., D. Rotich, K. Scheelke, S. Schick, P. Teege, J. Kosuch & M. Veith (2004): Bio-sketches and partitioning of syntopic reed frogs, genus *Hyperolius* (Amphibia: Hyperoliidae), in two humid tropical African forest regions. ∝ Journal of Natural History, 38: (15): 1969-1997.

Lötters, S., D. Rotich & M. Veith (2003): Non-finding of the Kenyan endemic frog *Arthroleptides dutoiti*. ∝ Froglog, 60: 3.

Lötters, S., S. Schick, M.-O. Rödel, A. Schmitz & M. Veith (2004): How is community resemblance in Afrotropical frogs linked to life style? ∝ 5th International Symposium on Tropical Biology “African Biodiversity – Molecules, Organisms, Ecosystems”, Bonn (Germany) [Abstract].

Oberst, M., A. Baumgart, S. Lötters & M. Veith (2004): Larvalmorphologische Mundfeldvariation beim Riedfrosch *Hyperolius viridiflavus* (Amphibia: Hyperoliidae). ∝ Jahrestagung, Deutsche Gesellschaft f. Herpetologie u. Terrarienkunde (DGHT), Norderstedt (Germany) [Abstract].

Rödel, M.-O., S. Lötters, J. Kosuch & M. Veith (2002): Amphibian monitoring in Africa (Côte d’Ivoire, Kenya) and Asia (Borneo). ∝ Froglog, 49: 2.

Scheelke, K., S. Schick, S. Lötters, D. Rotich & M. Veith (2003): Annual and acoustic partitioning of anuran species at a breeding pond in a mountain forest of western Kenya. — 96. Jahrestagung, Deutsche Zoologische Gesellschaft (DZG), Berlin (Germany) [Abstract].

Scheelke, K., S. Schick, S. Lötters & M. Veith (2003): Intraspecific spatial segregation in male Afrotropical treefrogs (*Hyperolius*)?. — 16th annual meeting, Gesellschaft für Tropenökologie (gtö), Rostock (Germany) [Abstract].

Schick, S. (2004): Froschsterben auf Afrikanisch. ∝ Reptilia, 46 (4): 39-44.

Schick, S., K. Scheelke, D. Rotich, S. Lötters & M. Veith (2003): How do frogs manage to coexist? A case study at a breeding pond in the Kakamega Forest, Kenya. — International Symposium “Sustainable use and conservation of biological diversity. A challenge for society”, Bundesministerium für Bildung und Forschung (BMBF), Berlin (Germany) [Abstract].

Schürkes, I., V. Wasonga & S. Lötters (2002): Auf Herpeto-Safari in Kenia. ∝ Reptilia, 37 (7): 55-60.

Teege, P., S. Lötters & M. Veith (2003): Crowding of tadpoles in a temporary pond? A study of an Afrotropical anuran. — 16th annual meeting, Gesellschaft für Tropenökologie (gtö), Rostock (Germany) [Abstract].

Veith, M., J. Kosuch, S. Lötters & M.-O. Rödel (2003): Small genes for big problems – coping with challenges in Afrotropical amphibian taxonomy. — 16th Annual Meeting, Gesellschaft für Tropenökologie (gtö), Rostock (Germany) [Abstract].

Veith, M., J. Kosuch, M.-O. Rödel, A. Schmitz & S. Lötters (2004a): Beauty and the beast – the evolution of sexual colour polymorphism in Afrotropical tree frogs. ∝ 5th International Symposium on

Tropical Biology "African Biodiversity – Molecules, Organisms, Ecosystems", Bonn (Germany) [Abstract].

Veith, M., S. Lötters, M.-O. Rödel & F. Andreone (2004b, in press): Measuring and monitoring amphibian diversity in tropical forests. II. Estimating species richness from standardised transect census. — Ecotropica.

Vences, M., J. Kosuch, M.-O. Rödel, S. Lötters, A. Channing, F. Glaw & W. Böhme (2004): Phylogeography of *Ptychadena mascareniensis* suggests transoceanic dispersal in a widespread African-Malagasy frog lineage. — Journal of Biogeography, 31 (1): 593-601.

Wasonga, D.V., A. Bakele, S. Lötters & M. Balakrishnan (submitted): Amphibian abundance and diversity in Meru National Park, Kenya. — African Journal of Ecology.

Wasonga, D.V., A. Bakele, S. Lötters & M. Balakrishnan (submitted): Habitat association of amphibians in East African bush- and grassland: an example from Meru National Park, Kenya — Tropical Zoology.

Wasonga, D.V., S. Lötters, A. Bakele & M Balakrishnan (2004): Habitat association of amphibians in East African bush and grass land: an example from Meru National Park, Kenya ∝ Herpetological Association of Africa (HAA), Port Elizabeth (South Africa) [Abstract].

3. Capacity building

3.1 Technical capacity building

Capacity building and training of counterparts involved

- (i) species sampling for surveys.
- (ii) species identifications including adults and larvae, using morphology and bioacoustics.
- (iii) preservation techniques.
- (iv) census and monitoring methods, i.e. mainly GPS-based transect methods.
- (v) statistics to analyse monitoring data.
- (vi) scientific presentation (written and oral).
- (vii) their participation in scientific meetings.

3.2 Students and scientific staff trained

Diploma theses

Baumgart, A. (2004): Auswirkung der Umweltheterogenität auf die Variation larval-taxonomischer Merkmale einer afrotropischen Anurenart (*Hyperolius kivuensis*).

Oberst, M. (2004): Larvalmorphologische Mundfeldvariation bei dem afrotropischen Riedfrosch *Hyperolius viridiflavus* (Amphibia: Hyperoliidae).

Scheelke, S. (2003): Ökologische Untersuchungen an Anuren in einem montanen Regenwald in Ostafrika (Kenia, Kakamega Forest).

Schick, S. (2003): Ökologische Untersuchungen an einer Froschzönose eines stehenden Kleingewässers in einem montanen Regenwald in Ostafrika (Kenia, Kakamega Forest).

Teege, P. (2003): Ökologische Untersuchungen an einer Kaulquappengesellschaft in einem montanen Regenwald in Ostafrika (Kenia, Kakamega Forest).

MSc thesis

Bwong, B.A. (2004): Morphology and bioacoustics of the Ridged Frog species, genus *Ptychadena* (Amphibia: Ranidae), from the Kakamega Forest, Western Kenya.

Field assistants

Koester, Timo-E. (Mainz University), October 2002: field surveys, GPS technology.

Montero, Inka (Museum Alexander Koenig, Bonn), August 2001: taxonomy, field surveys.

Muchai, Vincent (National Museums of Kenya), 2001-2004: taxonomy, field surveys, monitoring methods, bioacoustics, GPS technology.

Wasonga, D. Victor (National Museums of Kenya), 2001, 2002: taxonomy, field surveys, monitoring methods.

Madscher, Melanie (University of Bonn), April 2002: taxonomy, field surveys.

Haase, Heike (University of Bonn), October 2002: taxonomy, field surveys.

Malonza, K. Patrick (National Museums of Kenya), 2003: field surveys, monitoring methods.

Behangaa, Mathias (Makerere University), 2003: taxonomy, field surveys, monitoring methods, bioacoustics, GPS technology.

Training course

From 1 to 5 April 2003, a workshop for African students was held at National Museums of Kenya, Nairobi, and the BIOTA field station at Kakamega Forest entitled “Amphibian monitoring standards – a workshop for African students”. Cooperation partners were the University of the Western Cape, Belville, the Laboratoire d’Ecologie des Sols Tropicaux, Bondy Cedex, France (Institut de Recherche pour le Dévelopement), the National Museums of Kenya, Nairobi, and Kenya Wildlife Service (KWS). A total of 21 students from Kenya, Uganda, Tanzania and South Africa participated.

Subproject E09

The influence of land use modes on diversity, abundance and guild structure of coprophagous beetles in the African forest-savannah mosaic

Subproject leader: Dr. F.-T. Krell, Prof. Dr. C. M. Naumann, University of Bonn, BMNH London	
Short title: BIOTA E09	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

The flora and fauna of man-made landscapes and anthropogenically changed habitats generally differ from those of natural environments. These changes can be demonstrated most easily in species and individual rich animal assemblages. Dung beetles have their worldwide highest biodiversity and abundance in the Afrotropical forest-savannah mosaic region. This region is of utmost importance for African economies, since it is densely populated, extensively burned annually and almost completely used for agriculture and farming. The abundant and speciose dung beetles are an ideal model system to diagnose the influence of land use modes on animal assemblages in this region and to develop an indicator system for habitat changes. Dung beetles are not only a user-friendly group for applied ecology and conservation, in savannah regions and pasturelands they also are a vital part of the ecosystem because they recycle enormous masses of vertebrate dung by dispersing and bringing it into the soil. This activity increases the soil fertility and decreases the amount of soil surface covered by dung. The project took the unique opportunity presented by the geographical structure of BIOTA to collect data in Kenya and Ivory Coast, which allows us to distinguish between regional and general patterns.

Main aims of the project are:

- to describe dung beetle assemblages along a disturbance gradient (from national park to urban areas) and identify constant and significant differences in abundance, guild structure and species richness;

- to identify the influence of human land-use and activities, such as livestock farming, poaching, logging, slash and burn agriculture, bush fires, and urbanization on dung beetle assemblages and ultimately on nutrient cycling and maintenance of soil fertility;

- to define indicator assemblages for different factors of disturbance.

During the pilot phase, all necessary baseline data for these questions were collected and evaluated, the implications of which will be identified in ongoing and successive projects outside the BIOLOG programme.

Planning and conduction

The project was planned to produce comparable results from West and East Africa. During the initial visit to the study area in Kakamega it became clear that all the work at this site could be done during a Masters Thesis, which was then successfully carried out by Vincent Mahiva (ICIPE/NMK) in 2003/2004. Although the political uprising in Côte d'Ivoire forced us to rearrange the work schedule and postpone a part of the work until after the funding period, E09 was the only BIOTA project that had been running continuously in Côte d'Ivoire for the whole period. Two Ivorian DEA students 2002-2004 successfully submitted their theses, and the fieldwork for two PhD projects (2001-2004) was completed. Two months worth of samples for Workpackage 1 and 3 were destroyed by airport authorities in Brussels in 2003 despite valid export permits. With additional funding of the Natural History Museum London after the pilot phase, the planned data collecting for all proposed parts of the project was completed. However, the evaluation of the data for Workpackage 1 and all species level data evaluations are still ongoing.

Cooperations with other institutions

Cooperations with the following institutions ensured the smooth realization and successful conclusion of the project. MSc and PhD projects were co-supervised with the University of Reading, UK (D. Newman; supervisor Prof. V. Brown), International Centre of Insect Physiology and Ecology (ICIPE) and University of Nairobi, Nairobi, Kenya (V. Mahiva; local supervisors Prof. Khamala and Dr. I. Gordon) and Université d'Abobo-Adjamé, Abidjan, Ivory Coast (P. N'goran, C. Kouakou; local supervisor Dr. M. Doumbia). The Centre Suisse de Recherches Scientifiques en Côte d'Ivoire, Adiopodoumé, Ivory Coast, and the CIPE supported the project students with infrastructure and logistic help. National Museums of Kenya and Kenya Wildlife Service, Nairobi, Kenya, were vital partners for the local organization and administration of the projects. The Soil Biodiversity Programme of The Natural History Museum London, UK (Dr. F. Krell) helped with identification of the material and data evaluation, and also with the day-to-day organization of the work.

2. Results

2.1 Scientific results

The overall pattern emerging from our standardized sampling along a disturbance gradient in West- and East Africa is an impoverishment at species and higher taxonomic level and a reduction in numbers of dung beetles with increasing disturbance (Fig. 1). Despite plenty of available resources, anthropogenically degraded habitats are not suitable for the maintenance of a dung beetle community which would be capable of removing the constantly produced faeces sufficiently. Another general pattern is the preference for open areas (savannas) over close canopy habitats (forests, plantations) (Krell *et al.*, 2003).

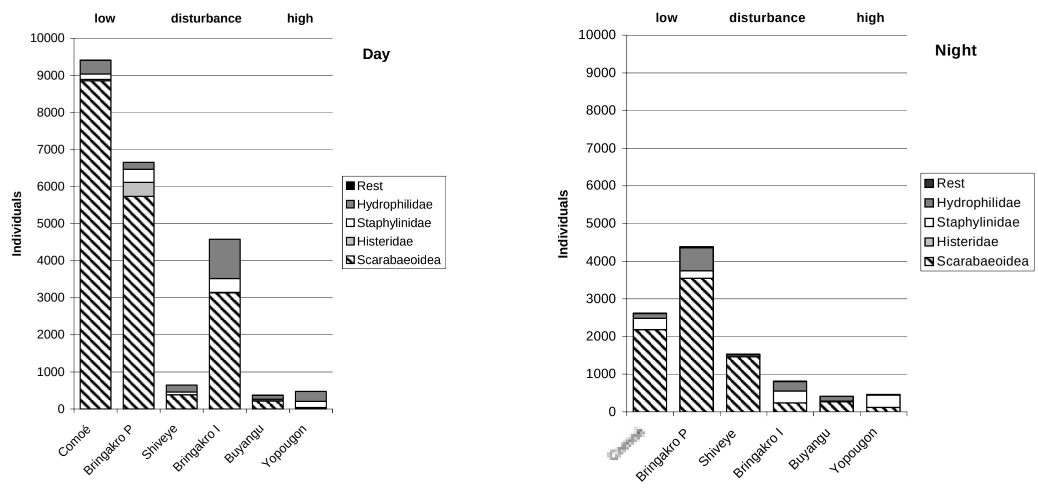

Fig. 1. Cumulative abundance of beetles in 10 kg of herbivore dung in habitats along a disturbance gradient from a national park (Comoé), a savannah with extensive cattle farming (Bringakro P), a small cattle farm (Shiveye), an ungrazed grassland (Bringakro I), farmland where 80% of dung is regularly collected by the local farmers (Buyangu) and an urban area (Youpogon). Day and night samples separated.

Workpackage 1: How does the reduction of the native game fauna influence the dung beetle fauna? Can cattle farming compensate any possible effect? (Sylvia Krell-Westerwalbesloh, Vincent S. Mahiva, Célestin Kouakou & Frank-T. Krell; "pasture")

We studied the dung beetle fauna in areas with native mammals (Comoé, Ivory Coast), livestock (Bringakro, Ivory Coast and Shiveye, Kenya), without large herbivores (Kakamega, Kenya) and with livestock but where dung is regularly removed by the local farmers for manuring and building purposes (Buyangu, Kenya). Dung beetles are similarly abundant in grasslands with indigenous wild herbivores and with extensive cattle farming. However, if herbivore dung is regularly removed or not present locally at all, the abundance of dung beetles decreases.

Fig. 2. Lifestock exclusion plot (back) in a heavily grazed savanna in Bringakro, Ivory Coast.

In the agricultural area of Bringakro in Ivory Coast, we established plots from which we excluded cattle and other livestock. In comparison with the surrounding grazed areas, ungrazed plots showed a slightly lower abundance of dung beetles.

Within this workpackage, we also studied the differences between an old, mature forest and a secondary forest in Kakamega both of which are deprived of their native large herbivores. Here we found, that the dung beetle assemblages consist of fewer species than in areas with herbivores, and that in the secondary forest showed a higher abundance (as expected in a more open habitat), but the species diversity was lower, as shown by a rarefaction curve (Fig. 3). In summary, regular grazing by a variety of large herbivores helps to maintain a species rich and abundant dung beetle fauna better than livestock farming only.

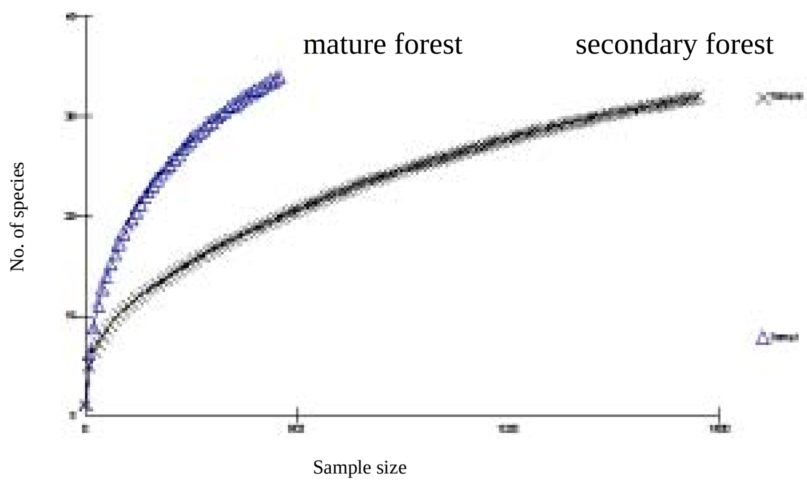

Fig. 3. Rarefaction plots for the day samples of dung beetles in different forest types of Kakamega, Kenya.

Workpackage 2: How does bush fire and agriculture (slash and burn type) influence the dung beetle fauna? (Dorothy Newman, Paul N'goran & Frank-T. Krell; "fire")

Burning is a major structuring factor of vegetation in the Ivory Coast savannah, and normally occurs in January, during the dry season. Burning and protecting savannah from fires does not dramatically alter the structure of coprophilous beetle communities, however it does have a moderate effect on dung beetle abundance.

Diurnal communities: The abiotic variables measured accounted for 41% of the variation in the community, of which 5% was explained by treatments, and only 2% by season. In the dry season, abundance is higher on burned and cut savannah sites (with, effectively, the herbaceous layer removed), compared to lower abundances in unburned sites with high vegetation. In the rainy season, this pattern is reversed, those sites with higher vegetation having higher abundances of dung beetles than those sites in which the vegetation is removed. It is possible that these differences are due to predator avoidance (migratory avian predators being present in the rainy season), though this was not investigated.

Nocturnal communities: Nocturnal community structure in the savannah does not appear to follow an obvious pattern, neither are there large differences in community structure between sites or seasons. 38% of the variation in the community was explained by abiotic variables, treatment explained 13%, and season 10%. However, as with the diurnal communities, unseasonal burning (i.e. during the wet season) appears to have a general negative effect on dung beetle abundance.

Slash and burn agriculture in the forest biome has a strong effect on coprophilous beetle community structure during the day, though it has a much lower influence on nocturnal communities.

Diurnal communities: When areas of forest are cleared, these sites are invaded by groups, which are associated with low canopy cover, and those groups associated with forest habitats disappear. Seasonal effects on community structure are much greater in these recently disturbed and open sites than in nearby areas of secondary forest, where the communities are more representative of a natural forest system. 58% of the variation in community structure during the day was explained by the variables measured, of which 38% was attributable to sites rather than abiotic variables, with season explaining only 1%. Habitat and canopy cover were more important determiners of community structure in the rainy season. In the dry season, temperature parameters had greater influence (see Fig. 4).

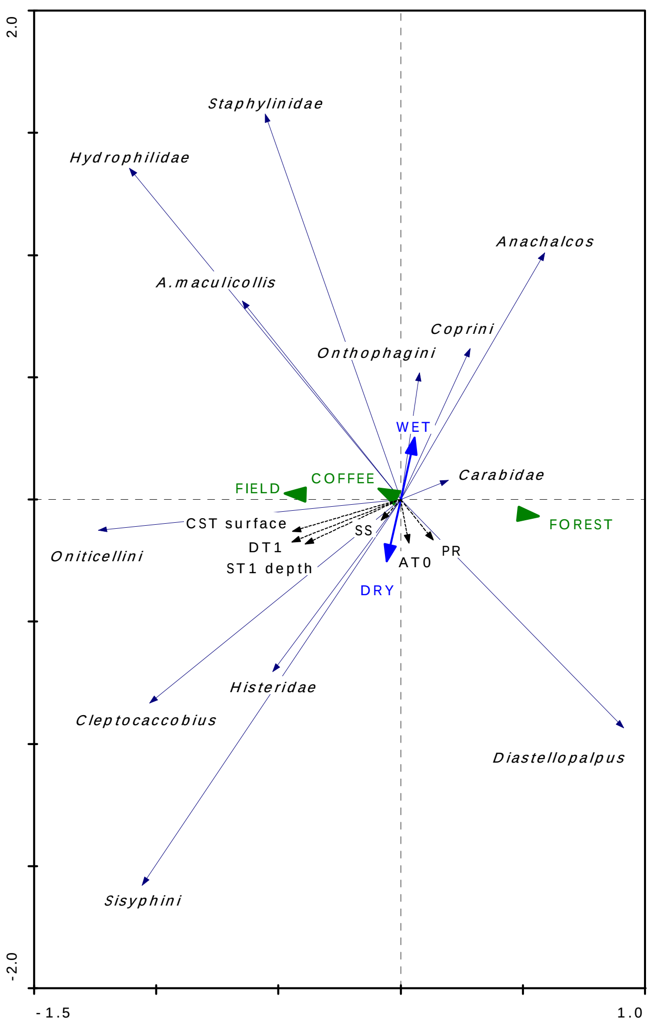

Fig. 4. Ordination diagram for redundancy analysis of diurnal forest experiment. Comparing communities in a field, coffee plantation and secondary forest in 2 dry season and 2 rainy season experiments. Eigenvalue axis 1 = 0.443, eigenvalue axis 2 =0.084.

The coffee plantation (canopy 2-5m in height) studied showed strong similarities with the secondary forest (canopy 7-10m in height) in the high rainy season, when the foliage of the coffee bushes was dense, suggesting that the height of the canopy is less important than its density. During the dry season, and early rainy season, when the foliage in the coffee plantation was less dense, the site showed more similarities with the field.

Nocturnal communities: Community structure was more strongly influenced by season than by site, though in all seasons there were few differences between sites. 41% of the variation in community structure was explained by the parameters measured, of which 23% was contributed by season, and 8% by sites. Abiotic factors have a much higher effect on diurnal communities in terms of structure and overall abundance, than on nocturnal communities in both forest and savannah systems.

Workpackage 3: The influence of urbanization on the dung beetle fauna (Célestin Kouakou, Paul N'goran & Frank-T. Krell; "urban")

Fig. 5. Green island in town: Cassava field in Youpogon (site CMY).

To study the effect of urbanization on dung inhabiting insects, we sampled at 7 sites along an urbanization gradient in Abidjan, Ivory Coast (from street borders in settlement areas to green spaces and cassava fields). In urbanized areas, we found a strong decrease of abundance and diversity of dung beetles. Only two tribes (Onthophagini and Aphodiini) were present at all sites. As in disturbed or fragmented natural habitats, other dung users like water beetles (Hydrophilidae) were present in increased numbers in urban areas, sometimes in proportions of 75% (Fig. 6). Since these other users are not as efficient in dung recycling as dung beetles, the dung is not removed from the soil surface and might cause sanitary problems. Green islands (ruderal plots, gardens, small agricultural plots; Fig. 5) in urban areas have a much more diverse and abundant dung beetle fauna and can serve as reservoirs for dung beetle populations.

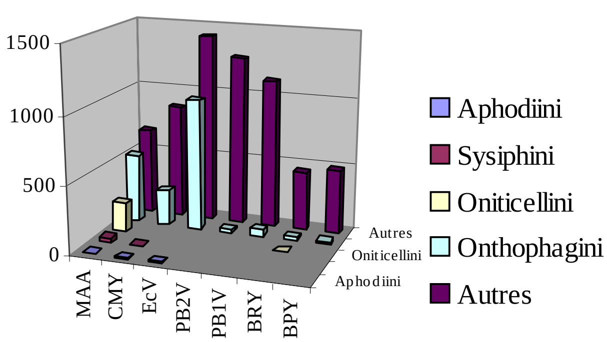

Fig. 6. Abundance of dung insects in urbanized areas of Abidjan at daytime. CMY (Fig. 5) and EcV are 'green islands'. MAA a experimental field on the University cam-pus. Aphodiini, Sisyphini, Oniticellini and Onthophagini are the proper dung beetles.

Workpackage 4: Developing and testing a Rapid Biodiversity Assessment protocol for dung beetles. (Frank-T. Krell; ”RBA”)

Baseline data have been collected in a primary forest (Parc National de Tai, CI), a disturbed but mature forest (Kakamega, Kenya), a secondary forest (Kakamega), a wet gallery forest (Comoé, CI), a dry gallery forest (Comoé), and a pastureland (Bringakro, CI). All material (29.500 specimens) is mounted and pre-sorted, but species identification is still ongoing. These extensive data, complemented by four data sets from Borneo, will lead to a reliable estimate about the minimum number of traps necessary for an estimate of local species richness.

2.2 Interdisciplinary components

The political unrest in Ivory Coast caused our project as well as all BIOTA West projects to abandon the study sites in the Parc National de la Comoé. Our established fire exclusion plots, which were supposed also to be used by botanists for comparative studies, could not be sampled. Envisaged fire ecological experiments with E12 were impossible to carry out in the Kakamega area. Although our subproject has failed so far to produce cumulative results with other BIOTA East projects, our affiliation with BIOTA East continues and will eventually lead to interdisciplinary data evaluations at species level, particularly in cooperation with E04 and E06.

2.3 Likely benefit and applicability of results

Workpackage 1: Pasture

Our results indicate that a diverse mammal fauna supports a more diverse dung beetle fauna. We need some more experimental data to be collected in a subsequent project with the Mpala Research Centre in Laikipia, Kenya, but our results might be used to promote land use strategies which allow livestock farming and wildlife in the same plots.

Workpackage 2: Fire

Although our results reveal a deep insight in the factors structuring dung beetle assemblages, so far we have not been able to deduce any advantageous management regime. As soon as the data are evaluated at species level, we expect to see clearer patterns, particularly in the slash and burn sites (comparable to the forest sites in Kakamega).

Workpackage 3: Urban

We have shown that a diverse dung remover fauna can survive in ‘green’ islands (agricultural plots or forest islands) in urbanized areas. This is a further argument to rate these elements highly in urban planning, particularly considering sanitary aspects. The applicability of these results will be studied in a subsequent project with the Centre Suisse de Recherches Scientifiques.

Workpackage 4: RBA

The established RBA protocol will help any biodiversity and conservation projects to assess the diversity and species richness of one of the most speciose and ecologically important insect groups in a very cost-efficient manner. Together with the almost finished illustrated key to East African dung beetle genera, the RBA protocol makes dung beetles in East Africa accessible for a vast variety of assessments (ecological studies, biodiversity and conservation value assessments, inventories).

2.4 Publications resulting from the project

(publications 'in prep.' likely to be submitted within 12 months)

Kouakou, Y.C. (2002): Effet de l'anthropisation sur les communautés des coléoptères coprophages en zone urbaine : Cas d'Abidjan-Vridi.- Mémoire de fin de cycle de maîtrise, Université d'Abobo-Adjamé, UFR Science de la Nature. 34 pp., annexe. Abidjan.

Kouakou, Y.C. (2004): Influence des perturbations anthropiques sur les coléoptères coprophages : cas du pâturage et de l'urbanisation respectivement en regions de savane (Toumodi) et de forêt (Abidjan) de la Côte d'Ivoire. - Mémoire DEA (MSc. Thesis), Université d'Abobo-Adjamé, UFR Sciences de la Nature. Abidjan, Ivory Coast. 86 pp.

Krell, F.-T. (2003): *Onthophagus mankonoensis* Balthasar from Côte d'Ivoire, a junior synonym of *Onthophagus mocquerysi* d'Orbigny (Coleoptera: Scarabaeidae). - Casopis Národního Muzea, Rada Prirodovedná 172: 51-54.

Krell, F.-T. (in press). East African dung beetles (Scarabaeidae) attracted by defensive secretions of millipedes. - Journal of East African Natural History.

Krell, F.-T. (in prep.): Introduction to the study of dung beetles (Coleoptera: Scarabaeidae): Key to the genera of Eastern Africa and standardized sampling protocols. - For: Journal of East African Natural History.

Krell, F.-T. (in prep.): *Onthophagus vinctoides* Frey from Congo, a junior synonym of *Onthophagus sulcipennis* d'Orbigny (Coleoptera: Scarabaeidae). - For: Entomologia Basiliensia.

Krell, F.-T. (in prep.): Rapid biodiversity assessment and monitoring of dung beetles, a group indicating mammal abundance and diversity.

Krell, F.-T. (in prep.): New dung beetles of the genus *Onthophagus* Latreille from Côte d'Ivoire and Kenya (Insecta: Coleoptera: Scarabaeidae). For: Systematics and Biodiversity.

Krell, F.-T., Doumbia, M., N'goran, P., Kouakou, C. & Dosso, K. (in prep.): Impoverishment of dung remover fauna in tropical urban habitats. - For: Urban Ecosystems.

Krell, F.-T., Mahiva, V.S., Kouakou, C., N'goran, P., Krell-Westerwalbesloh, S., Newman, D.H., Weiß, I. & Doumbia, M. (in press). Human influence on the dung fauna in Afrotropical grasslands (Insecta: Coleoptera). - In: Huber, B.A. (ed): African Biodiversity: Molecules, Organisms, Ecosystems. Proceedings of the 5th International Symposium on Tropical Biology, Museum Koenig, Bonn. Kluwer.

Krell, F.-T., Mahiva, V., Krell-Westerwalbesloh, S. (in prep): The influence of human land use on a diverse insect community – dung beetles in a relic tropical rain forest and surrounding farmland. - For: Biodiversity and Conservation.

Krell, F.-T., Krell-Westerwalbesloh, S., Weiß, I., Eggleton, P. & Linsenmair, K.E. (2003). Spatial separation of Afrotropical dung beetle guilds: a trade-off between competitive superiority and energetic constraints (Coleoptera: Scarabaeidae). - Ecography 26: 210-222.

Krell, F.-T. & Krell-Westerwalbesloh, S. (2003): First record of the genus Eusaproecius Branco from West Africa (Col., Scarabaeidae, Coprinae). - Entomologist's Monthly Magazine 139: 13-14.

Krell-Westerwalbesloh, S., Kouakou, C., Doumbia, M., N'Goran, P., Newman, D. & Krell, F.-T. (in prep.): The effect of grazing on abundance and diversity of dung beetle assemblages in West African grasslands.

Krell-Westerwalbesloh, S., Krell, F.-T. & Linsenmair, K.E. (2004): Diel separation of Afrotropical dung beetle guilds – avoiding competition and neglecting resources. - Journal of Natural History 38: 2225-2249.

Mahiva, S.V. (2004): A survey of the dung beetles of Kakamega Forest and the surrounding farmlands: a biodiversity and land use assessment.- MSc. Thesis, University of Nairobi, Department of Zoology. Nairobi, Kenya.

Mahiva, V., Krell, F.-T. & Krell-Westerwalbesloh, S. (in prep.) Seasonality in buffered and open habitats – dung beetles in and around a relic tropical rainforest.

Newman, D.H. & Krell, F.-T. (in prep.) The effect of seasonal and unseasonal savanna burning on the structure of coprophagous beetle assemblages.

Newman, D.H. & Krell, F.-T. (in prep.): Experimental design in dung beetle ecology: when is trapping appropriate?

Newman, D.H., N'goran, P., Doumbia, M., Kouakou, C., Krell-Westerwalbesloh, S. & Krell, F.-T. (in prep.): The effect of agricultural land use on the structure of coprophagous beetle assemblages in the forest of southern Ivory Coast.

N'goran, K.P. (2002): Effet de l'anthropisation sur les communautés des coléoptères coprophages (bousiers) en zone urbaine: Commune de Yopougon (Abidjan).- Mémoire de fin de cycle de maîtrise, Université d'Abobo-Adjamé, UFR Science de la Nature. Abidjan. 29 pp., annexe.

N'goran, K.P. (2004): Influence des exploitations agricoles sur les communautés de coléoptères coprophages en zone forestières : cas de l'Université d'Abobo-Adjamé en forêt primaire (Abidjan) et de Bringakro en forêt secondaire (Toumodi) en Côte d'Ivoire.- Mémoire DEA (MSc. Thesis), Université d'Abobo-Adjamé, UFR Sciences de la Nature. Abidjan, Ivory Coast. 77 pp.

Abstracts and reports

Krell, F.-T., Boutros, M., Krell-Westerwalbesloh, S. & Linder, C. (2004): Rainfall events determine the abundance of carrion feeding beetles in a West African savanna. - Entomology, Strength in Diversity, XXII International Congress of Entomology, 15-21 August 2004, Brisbane Queensland Australia. [CD-ROM]

Krell, F.-T., Mahiva, V., Kouakou, C., N'goran, P., Newman, D., Krell-Westerwalbesloh, S., Simkhada, B. & Doumbia, M. (2003): Influence of land use modes on diversity, abundance and guild structure of coprophagous beetles in African forest-savanna mosaics. - Sustainable use and conservation of biological diversity. A challenge for society. Symposium Report Part A, International Symposium 1-4 December 2003, Berlin: 116-117.

Krell, F.-T., Newman, D., Krell-Westerwalbesloh, S. & Mahiva, V. (2001): The influence of land use modes on diversity, abundance and guild structure of coprophagous beetles in the African forest-savanna-mosaic. - BIOLOG. German Programme on Biodiversity and Global Change (Phase I, 2000-2004) Funded by BMBF. Status Report 2001: 164-165.

Krell, F.-T., Newman, D., Krell-Westerwalbesloh, S., Mahiva, V., N'goran, P., Kouakou, C. & Doumbia, M. (2002): Dung Beetle Research in Tropical Africa – A Project of the BIOLOG

Programme (Biodiversity and Global Change). - Entomology 2002, The 6th National Meeting of the Royal Entomological Society, Cardiff University, 12th-13th September 2002: 4, 13.

Krell, F.-T., Newman, D., Krell-Westerwalbesloh, S., N'Goran, K.P., Kouakou, Y.C. & Doumbia, M. (2004): Projet BIOTA E09. L'influence de différents modes d'exploitation humaine des habitats sur la diversité, l'abondance et la structure des guildes des Coléoptères coprophages dans la mosaïque forêt-savane de l'Afrique. - Centre Suisse de Recherches Scientifiques en Côte-d'Ivoire (CSRS), Rapport d'activité 2001-2003: 56-57.

Krell-Westerwalbesloh, S., Newman, D. & Krell, F.-T. (2002): Ungenutzte Ressourcen trotz extremer Konkurrenz: Koprozönosen im afrikanischen Wald-Savanne-Mosaik. - Tagungsband, 15. Jahrestagung der Gesellschaft für Tropenökologie, Göttingen, 20.-23. Februar 2002: 53.

Krell-Westerwalbesloh, S., Newman, D., Mahiva, V., N'goran, P., Kouakou, C., Doumbia, M. & Krell, F.-T. (2002): The influence of land use modes on diversity, abundance and guild structure of coprophagous beetles in the African forest-savanna-mosaic. - Abstract Booklet, The First Annual Student Poster Display by PhD Students at The Natural History Museum London, Friday 19th July 2002, Flett Lecture Theatre NHM: no. 11.

Krell-Westerwalbesloh, S. & Krell, F.-T. (2004): L'influence des différentes faunes des grands mammifères sur les coprocenoses. - Centre Suisse de Recherches Scientifiques en Côte-d'Ivoire (CSRS), Rapport d'activité 2001-2003: 58.

Mahiva, V., Krell, F.-T. & Krell-Westerwalbesloh, S. (2004): The influence of human land use on a diverse insect community – dung beetles in a relic tropical rain forest and surrounding farmland in Kenya. - Entomology, Strength in Diversity, XXII International Congress of Entomology, 15-21 August 2004,Brisbane Queensland Australia. [CD-ROM]

Mahiva, V., Krell, F.-T. & Krell-Westerwalbesloh, S. (2004): The influence of human land use on a diverse insect community – dung beetles in a relic tropical rainforest and surrounding farmland. - Abstracts (incl. Programme), 5th International Symposium on Tropical Biology, African Biodiversity, Molecules, Organisms, Ecosystems (ed. B.A. Huber): 87.

Newman, D. & Krell, F.-T. (2004): L'influence de feu de brousse et de brûlis de forêt sur les coprocénoses. - Centre Suisse de Recherches Scientifiques en Côte-d'Ivoire (CSRS), Rapport d'activité 2001-2003: 57.

Newman, D., Krell, F.-T., N'goran, P. & Kouakou, C. (2003): The influence of fire on the community structure of dung beetles in the Ivory Coast. - International Symposium Insect Evolutionary Ecology and Entomology 2003, 28th-31st July. The University of Reading: 47.

Newman, D., Krell, F.-T., N'goran, P. & Kouakou, C. (2002): The Influence of Fire on the Community Structure of Savanna Dung Beetles in the Ivory Coast. - Entomology 2002, The 6th National Meeting of the Royal Entomological Society, Cardiff University, 12th-13th September 2002: 13.

Newman, D., Krell, F.-T., N'goran, P. & Kouakou, C. (2002): The influence of fire on the community structure of dung beetles in the Ivory Coast. - Abstract Booklet, The First Annual Student Poster Display by PhD Students at The Natural History Museum London, Friday 19th July 2002, Flett Lecture Theatre NHM: no. 6.

N'Goran, K.P., Kouakou, Y.C., Krell, F.-T. & Doumbia, M. (2004): L'influence de l'agriculture, de la pâturage et de l'urbanisme sur les coprocenoses. - Centre Suisse de Recherches Scientifiques en Côte-d'Ivoire (CSRS), Rapport d'activité 2001-2003: 58.

3. Capacity building

3.1 Technical capacity building

Since in Ivory Coast E09 cooperated with the Centre Suisse de Recherches Scientifiques, which offers good working conditions and infrastructure for local students, we supported existing capacities by contributing to their maintenance (by paying bench fees). The infrastructure in Kenya was poorer. Thus, E09 supplied a notebook computer to our Kenyan MSc student to enable him to submit his thesis in time. After completion of the species identification, a reference collection of dung beetles will be supplied to the National Museums of Kenya, and, if the maintenance of the national insect collection of Ivory Coast is secured, to the CNRA Adiopodoumé.

3.2 Students and scientific staff trained

PhD thesis: Dorothy Newman, University of Reading – (to be submitted 2004)

Doctoral thesis: Sylvia Krell-Westerwalbesloh, University of Bonn – (not yet submitted)

MSc thesis: Vincent Shitakule Mahiva, ICIPE Nairobi/University of Nairobi – A survey of the dung beetles of Kakamega Forest and the surrounding farmlands: a biodiversity and land use assessment (submitted 2004).

DEA thesis: Paul N’goran, Université Abobo-Adjame, Abidjan – Influence des exploitations agricoles sur les communautés de coléoptères coprophages en zone forestières : cas de l’Université d’Abobo-Adjamé en forêt primaire (Abidjan) et de Bringakro en forêt secondaire (Toumodi) en Côte d’Ivoire (submitted 2004).

DEA thesis: Célestin Kouakou, Université Abobo-Adjame, Abidjan – Influence des perturbations anthropiques sur les coléoptères coprophages : cas du pâturage et de l’urbanisation respectivement en regions de savane (Toumodi) et de forêt (Abidjan) de la Côte d’Ivoire (submitted 2004).

Maîtrise: Paul N’goran, Université Abobo-Adjame, Abidjan – Effet de l’anthropisation sur les communautés des coléoptères coprophages (bousiers) en zone urbaine: Commune de Yopougon (Abidjan) (submitted 2002).

Maîtrise: Célestin Kouakou, Université Abobo-Adjame, Abidjan – Effet de l’anthropisation sur les communautés des coléoptères coprophages en zone urbaine : Cas d’Abidjan-Vridi (submitted 2002).

Technical assistant: Bishnu Simkhada (PhD Student, National Museum and Galleries of Wales, Cardiff), trained in insect preparation (now employed by the Natural History Museum, London).

Field Assistants Kenya: Fred Salano, Evans Savatia, Edward Masheti.

Field Assistants Côte d’Ivoire: N’guessan N’Dri Germain, Ahou-kan Veronique Tanno.

All students were trained in using statistical software packages for non-parametric testing and multivariate analyses. All students developed skills enabling them to proceed with their scientific career:

Paul N’goran and Célestin Kouakou were employed as PhD students with a conservation project in the Parc National de Tai;

Vincent Mahiva found a permanent position with the National Environment Management Authority, however, we have applied for funding for his PhD with NERC (UK);

Sylvia Krell-Westerwalbesloh whose project suffered most from the political unrest in Ivory Coast and the destruction of the most important samples by Brussels airport, got a stipend from the Natural History Museum London to continue her studies;

Dorothy Newman will work as a postdoc in the Centre Suisse de Recherches Scientifiques in Ivory Coast from 2005, after submission of her PhD thesis later this month; we envisage establishing a Darwin Initiative Project (UK) with her as the principal scientist;

Bishnu Simkhada, technical assistant of the project, got a contract from the Natural History Museum London to continue her work.

Subproject E10

Effects of habitat fragmentation on plant-pollinator interactions in East African rainforests

Subproject leader: Dr. M. Kraemer, Prof. Dr. C. M. Naumann, University of Bonn	
Short title: BIOTA E10	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

As a major step in the life-history of most flowering plants, pollination is of high significance to the organization of plant communities and to the long-term maintenance of entire vegetational units. Almost 100 percent of the flowering plant species in tropical forests are pollinated by animals, with bees being among the most important pollinators. The conversion of formerly continuous forests into small-scaled fragments most predictably leads to a disruption of the mutualistic pollinator-plant interactions. Consequently, certain species of plants and pollinators may not survive in fragments. In the long term, this may lead to extinction cascades due to the web-like structure of plant-pollinator systems, and thus cause a severe collapse of biodiversity.

During this project, by comparing different-sized forest fragments to continuous forests and concentrating on common understorey plants, we wanted to analyse the disruption of plant-pollinator interactions that is caused by habitat fragmentation and other related factors, like, e.g., disturbance, and of the consequences for the long-term maintenance of tropical biodiversity related to it. One of the most important aspects in this regard is the pollination success, that is, pollinator visiting frequency and the plants´ fruit and seed production. Furthermore, we were interested in questions related to differences in population size or isolation of populations, and in small- and large-scale heterogeneity in floral characters and reproductive success.

As Kakamega Forest is protected to a certain degree, the forest is allowed to regenerate at many places. Consequently, besides forests of near-natural appearance, secondary forests of different age regrow, giving a unique opportunity to study succession processes. A second aspect of our study was the analysis of bee abundance and diversity and their changes along such a forest regeneration gradient.

Planning and conduction

The project started in April 2001. After a 2-months period of preparation, together with other BIOTA members we conducted a kick-off trip to explore the forest and to determine study sites. Field work on fragmentation effects started in July 2001; several field stays of 3-4 months followed, continuing until spring 2003. In January 2002 we employed Mrs. Mary Gikungu in the project as a PhD student and we began investigating the diversity and abundance of bees and their food plants along a forest regeneration gradient. Here, data were sampled on a monthly base for a complete two-year period. In total, around 20 co-workers contributed to the project. So far, the project resulted or will result in eight diploma and three doctoral theses. Additionally, we gave thirteen oral presentations and ten poster presentations at different national and international conferences or workshops. Publications for the scientific community are yet to be prepared.

Cooperations with other institutions

Important information on landscape structure was provided by Prof. Gertrud Schaab (Karlsruhe University of Applied Science, Dept. of Geoinformation), information on plant identification, vegetation structure and succession by A. Althof and Prof. E. Fischer (Dep. of Botany, Koblenz University). With E11 (Institute of Zoology, Mainz University) and E03 (Institute of Botany, Bielefeld University) we conducted a survey of the state of disturbance at several forest sites.

Together with the National Museums of Kenya we are expanding the reference collection for Kenyan bees (and other arthropods that still await processing). Dr. Connal Eardley (African Pollinator Initiative, Plant Protection Research Institute, South Africa) and Dr. Terry Griswold (USDA Bee Laboratory) helped with bee identification. Dr. Neil Springate (The Natural History Museum, London) collaborated in the analysis of parasitoid hymenoptera.

2. Results

2.1 Scientific results

Effects of fragmentation on the reproductive success of understorey plants

With regard to the main objective of the study, we concentrated on four plant species that are abundant enough to allow for statistical analyses (*Acanthopale pubescens*, *Acanthus eminens*, *Heinsenia diervilleoides* and *Dracaena fragrans*). With the exception of *D. fragrans*, in all species studied so far the frequency of animal visits to flowers is much higher in fragments than in continuous forest. This is supposedly due to a higher proportion of forest edge effects in fragments. In an experimental approach using potted plants we could show that both the distance to a neighbouring population and the size of a population can negatively affect pollinator visitation behaviour as well as fruit and seed production of the plants; differences in visitation behaviour are, however, dependent on the food requirements of the pollinator species and seems to play a role only in small plant populations. As disturbance directly affects the population size of certain species and their abundance, it may indirectly affect their pollination. However, in this study, visitation frequency does not seem to influence pollination success in a consistent manner, if at all. For example, fruit set in *Acanthus eminens* is not affected at all, while *Heinsenia* produces much more fruits in fragments. In *Acanthopale* and *Dracaena* fruit set in fragments is strongly reduced. In contrast, seed set remains almost unaffected by fragmentation in *Acanthopale* and *Acanthus*, while in the case of the other species it is elevated in forest fragments. Therefore, other factors than fragmentation seem to influence the reproductive success of the plants. In a multiple regression analysis we analysed the role of different factors like fragment size, local density of target plant species and degree of disturbance. These factors differentially affect the different stages of reproduction of the species. For instance, the degree of disturbance of a certain site seems to positively influence fruit set and negatively influence seed set in *Acanthus eminens* (Fig. 1), while fragment size appears to control fruit set in *Acanthopale pubescens*. Obviously, it is very difficult to generalize such results. It is rather necessary to take the biology of every species into consideration, especially their habitat requirements, before a general conclusion can be drawn.

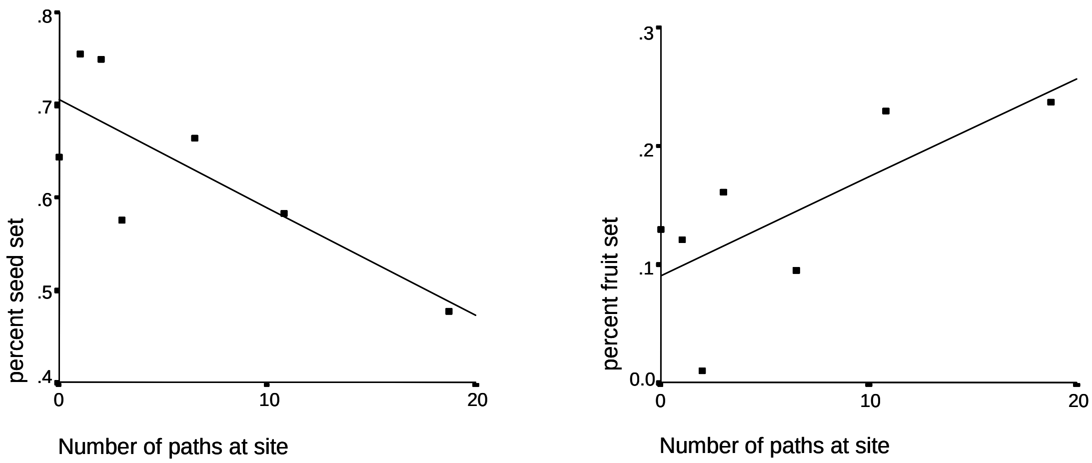

Fig. 1. Influence of disturbance on seed set (left) and fruit set (right) of *Acanthus eminens*

Another example of the possibly deleterious effects of forest fragmentation are the two simultaneously flowering *Acanthus*-species under study, with *A. eminens* flowering inside the forest along trails, and *A. pubescens* growing at forest edges. Forest fragmentation and the resulting higher influence of forest edges increase the possibility of cross-pollination between the two species. The occurrence of such interspecific pollen transfer is furthermore fostered by the fact that both species share the same pollinators, i.e., large carpenter bees (*Xylocopa*), which are highly mobile organisms that may easily cover long distances. This may have large negative effects, and, as the two *Acanthus*-species are closely related, it even may eventually lead to introgression. Our results indeed show that flower visitors almost freely move between the two habitats, but that the bees more often change to a heterospecific plant when coming from *Acanthus pubescens* (Fig. 2). Thus, pollen flow is much higher from the open landscape into the forest than vice versa. Both species, but

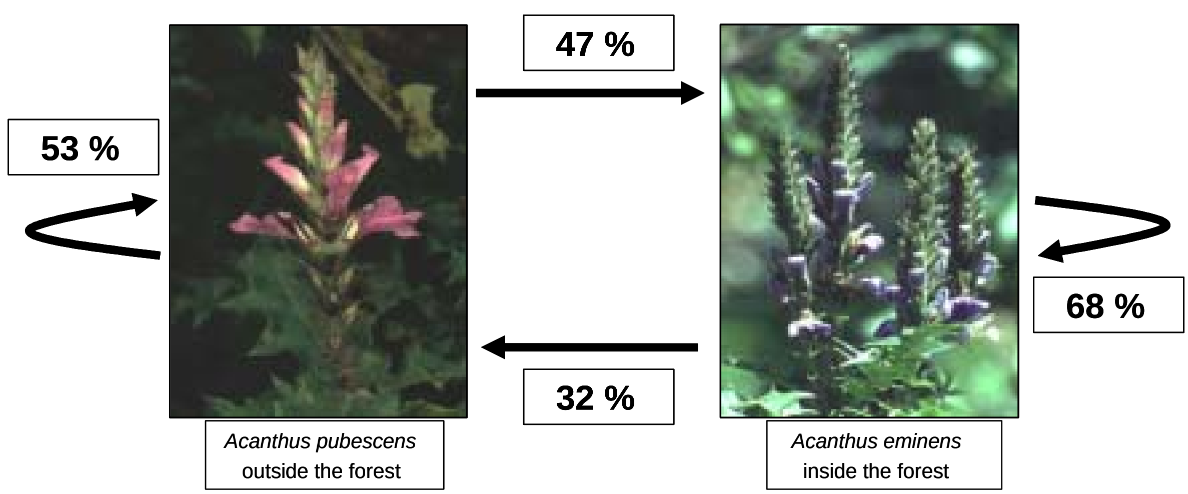

Fig. 2. Proportion of flight directions of carpenter bees after visiting a flower of *Acanthus eminens* or *A. pubescens*.

especially the forest species *A. eminens*, are able to develop seeds when pollinated with pollen from the congener, rendering introgression into the forest very likely.

In an additional study we investigated differences in floral characters and resource production (pollen & nectar) in at various sites between the two species (*Acanthus eminens, A. pubescens*). Resulting from the above, i.e. if introgression into the forest actually happens, we should expect a higher variability in floral characters at sites where the two species occur closely to one another compared to sites where both species grow more separately. Although not significantly so (p=0.086), this actually appears to be the case for *Acanthus eminens*, the forest-growing species (Fig. 3).

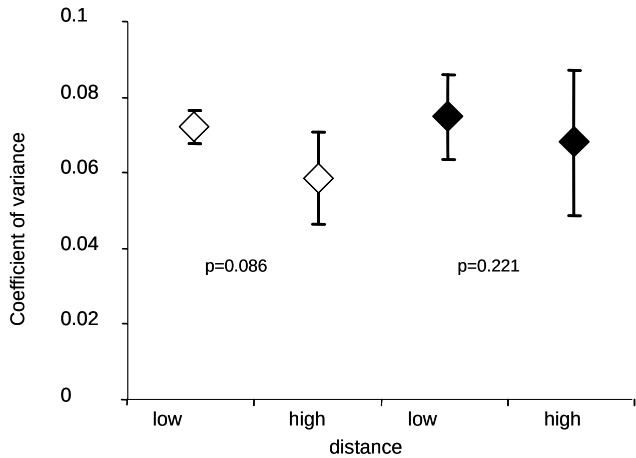

Fig. 3. Differences in the variability of an important floral character, i.e. total flower length, measured at sites where the two species co-occur (low distance) and where only one species occurs (high distance. Open rhomb: *A. eminens*, closed rhomb: *A. pubescens*.

Density and diversity of bees along a forest regeneration gradient

In many ecosystems – if not most – bees have been found to be the most important pollinators of plants, thus playing a crucial role in the propagation of natural vegetation. Due to the disturbance of natural habitats - especially of tropical forests - plant-pollinator interactions are highly threatened. In Kakamega Forest, we tried to get an overview over the bee fauna by sampling along a forest regeneration gradient. Seven sites were selected on the basis of

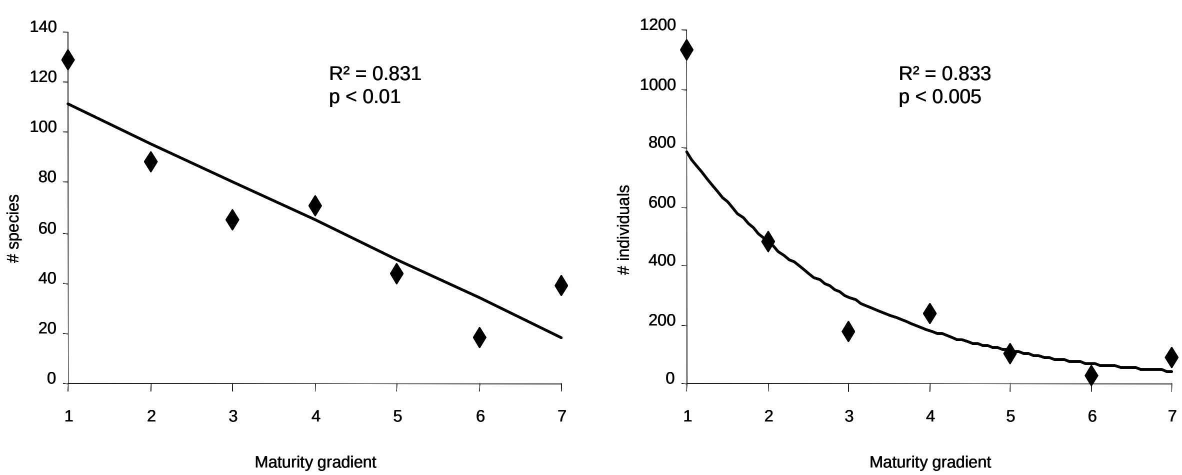

Fig. 4. Decrease in number of bee species and number of bee individuals with degree of forest maturity.

differences in plant physiognomy and the dominant plant species, including old growth, secondary high growth, moderate secondary growth, bush land and farming areas. Bee abundance and diversity was studied using the belt transect method. In each site four plots comprising three 100 m transects were established. A total of more than 190 species of bees (> 4 000 individuals) represented in four families were documented so far, some of them still unknown to science. The distribution of bees was found to be influenced by environmental factors as well as local floral density. While we expected an increase in bee diversity with increasing forest age, the reverse of this trend was observed in the study. The highest species richness and diversity of bees was recorded in the open farmland and in early secondary forests. This pattern is true for the number of both species and individuals (Fig. 4) and might be attributed to an increase in floral density and diversity in open forests as compared to forests with closed canopies. Apart from site-specific differences the Kakamegan bee diversity is highly dynamic in time (Fig. 5).

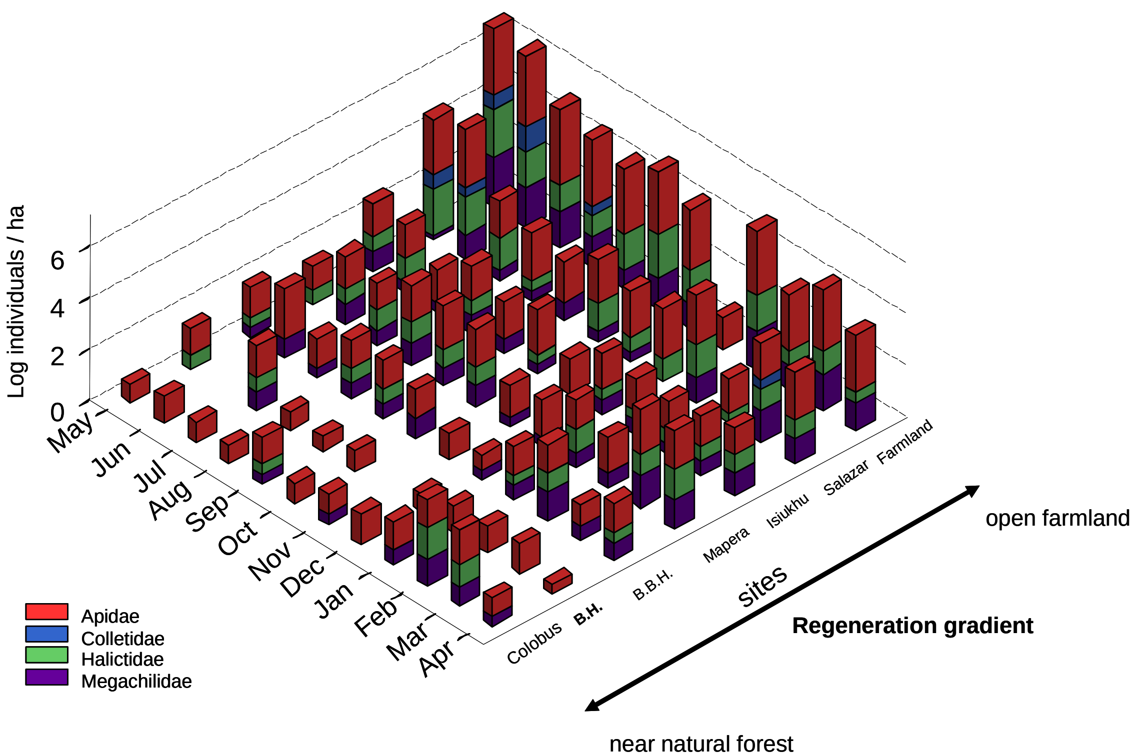

Fig. 5. Spatio-temporal variability in bee abundance along a forest regeneration gradient.

Up to now, some 140 under- to midstorey plant species have been documented to act as floral resources for the Kakamegan bees. The visitation data (a matrix of roughly 140 x 190 species) as well as phenological data of food plants are yet to be analysed.

The degree of bee specialization on plants was found to increase with forest age and vice versa. The surrounding farming land seemed to support certain bee species especially during the seasons when the flowering plants in the forest were not in bloom. The mosaic habitats of Kakamega forest therefore seem to play a very important role for the bee communities.

Of further interest

As a tool of identification of pollinator food plants in forthcoming investigations on plant-pollinator interactions, we set up a pollen reference collection. To date, the collection contains SEM images of some 160 species of higher plants.

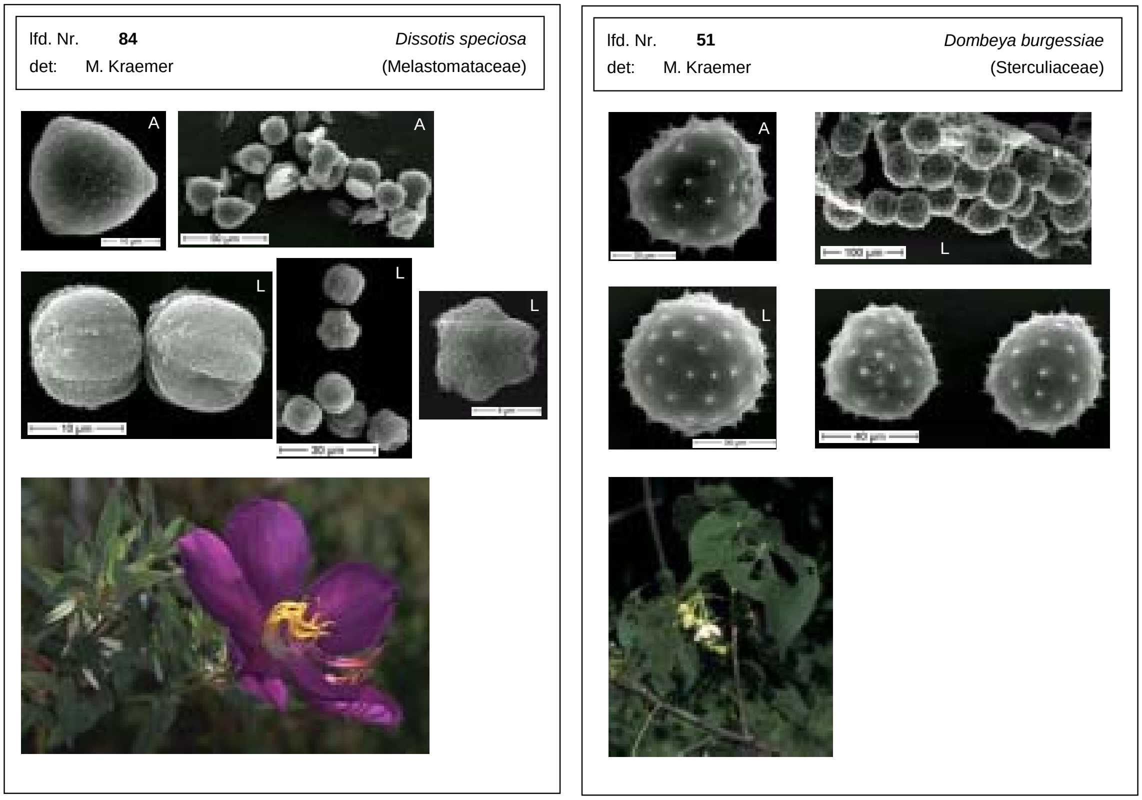

Fig. 6. Examples from the Kakamega pollen reference catalogue. SEM-Images show views from different angles and different pollen sampling techniques, i.e. air dried (L) vs. ethanol storage (A).

Furthermore, several studies were carried out under the frame of E10, that investigated the diversity of, e.g., canopy arthropods (especially beetles) and parasitoid hymenoptera. We also established a research project that addresses the role of ground-dwelling ants (army ants) and their influence on forest biodiversity. We could clearly demonstrate, that these important top-predators are highly susceptible to forest fragmentation, supposedly resulting in a strong effect on ground-layer arthropods.

2.2 Interdisciplinary components

Cooperation among BIOTA East Africa projects proved to be very effective. This is especially true for the information sharing amongst the student members and field assistants of both Kenya and Germany. Regarding the pollination project, data sharing with our main partners, i.e. projects E02, E04 and E11 turned out to be very smooth. Data on landscape structure, vegetation succession, fruiting and flowering phenology were provided by these projects. With E03 and E11 we conducted a survey of the state of disturbance at several sites, which resulted in joint publications (Bleher *et al*. 2003, and in press).

Collaboration with the National Museums of Kenya, our main Kenyan partner, proved highly satisfactory just as well. As the former Head of the Invertebrate Department, Dr. W. Kinuthia, is deeply involved in various pollination activities all over the country and internationally, our project was regarded a partner important enough for getting involved in PanAfrican activities like the African Pollinator Initiative. More recently, we were was asked to participate as an affiliated institution in an attempt to file an application to the GEF for the *Conservation and Management of Pollinators for Sustainable Agriculture through an Ecosystem Approach*, a programme launched by several countries from Africa, Asia, and South America.

2.3 Likely benefit and applicability of results

Apart from specialized publications for the scientific community, results can be used as an important contribution to a better understanding of habitat fragmentation in general and of the ecology of Kakamega Forest and its´ remnants in particular. This is especially true for the knowledge about Kakamegan bees that serve as major pollinators. This information is necessary for the understanding of crop production and can thus serve as a basic requirement for production improvement. As pollination can furthermore be regarded an essential ecosystem service the results may be used for the adjustment of current management plans for a better preservation of biodiversity.

2.4 Publications resulting from the project

Bensch, C. 2004. Abundance of epigaeic and hypogaeic army ants in different habitats in Kakamega Forest National Reserve (Kenya). MSc thesis, Bonn University.

Bergsdorf, T. 2005 (in prep.) Forest fragmentation and plant-pollinator interactions in Western Kenya. Doctoral dissertation, Bonn University.

Bergsdorf, T. & Kraemer, M. 2002. Differences in reproductive success of *Acanthopale pubescens* (Engl.) C.B.Cl. (Acanthaceae) among rainforest fragments. Abstract: 16th meeting of the Scandinavian Association of Pollination Ecology, Kongskilde, Danmark.

Bergsdorf, T. & Kraemer, M. 2002. Differences in reproductive success of *Acanthopale pubescens* (Engl.) C.B.Cl. (Acanthaceae) among rainforest fragments. Verhandlungen der Gesellschaft für Ökologie 32: 152.

Bergsdorf, T. & Kraemer, M. 2003. Plant-pollinator interactions in East African rainforest fragments. Abstract, 16th meeting of the German Society for Tropical Ecology, Rostock.

Bleher, B., Bergsdorf, T . & Uster, D. 2003. Rapid assessment of human disturbance in Kakamega Forest, Kenya: effective management reduces logging. Abstract, 17th meeting of the German Society for Tropical Ecology, Bayreuth.

Bleher, B., Uster, D. & Bergsdorf, T. (in press): Assessment of threat status and management effectiveness in Kakamega Forest, Kenya. Biological Conservation.

Dietzsch, A. 2004. Effects of interspecific pollen transfer on seed set in two East African *Acanthus* species (Acanthaceae). MSc thesis, Bonn University.

Dietzsch, A. & Kraemer, M. 2004. Effects of interspecific pollen transfer in two *Acanthus* species in Kakamega Forest, Western Kenya. Abstract, 17th meeting of the German Society for Tropical Ecology, Bayreuth.

Freund, W. 2004. Effects of fragmentation and degradation of an afrotropical rain forest on the diversity structure of leaf beetle communities (Coleoptera, Chrysomelidae). Abstract, African Biodiversity – 5th International Symposium on Tropical Biology, Bonn.

Freund, W. 2005 (in prep.) Effects of fragmentation and degradation of an afrotropical rain forest on the diversity structure of leaf beetle communities (Coleoptera, Chrysomelidae). Doctoral dissertation, Bonn University.

Freund, W., Patt, A., Misof, B. & Wagner, T. 2004. Effects of fragmentation in a Kenyan rainforest on the diversity and population structure of beetles. Poster presentation given at the International Symposium on Sustainable Use and Conservation of Biological Diversity, Berlin.

Gebhardt, K. 2004. Intra- und interspezifische Unterschiede von Blütenmerkmalen zweier nah verwandter Acanthus-Arten in Westkenia. MSc thesis, Bonn University.

Gikungu, M.W. 2005 (in prep.) Differences in bee pollination among natural and successional habitat patches at Buyango Forest. PhD dissertation, Bonn University.

Gikungu, M.W. & Kraemer, M. 2004. Density and disturbance of Apoidea along a forest regeneration gradient in Western Kenya. Abstract, African Biodiversity – 5th International Symposium on Tropical Biology, Bonn.

Gikungu, M.W., Kraemer, M. & Wittmann, D. 2004. Effects of forest regeneration on leafcutter bees (Megachilidae) in Kakamega Forest, Kenya. Abstract, 8th IBRA International Conference on Tropical Bees, Sao Paolo.

Hagen, M. 2003. Bestäubungseffizienz unterschiedlicher Blütenbesucher an *Justicia flava* (Acanthaceae) im Kakamega Forest, Kenia. MSc thesis, Bonn University.

Hagen, M. & Kraemer, M. 2003. *Justicia flava* (Acanthaceae) and its flower visitors: Differences in pollination efficiency. Abstract, 16th meeting of the German Society for Tropical Ecology, Rostock.

Hagen, M. & Kraemer, M. (in prep.) Fruit set of *Justicia flava* (Acanthaceae) decreases with increasing diversity of pollinating bees.

Kaiser, C. 2002. Influence of wind and pollen gathering by bees on reproductive success of the tropical grass *Brachiaria platynota* K. Schum. (Poaceae: Paniceae) at Kakamega Forest Nature Reserve, Kenya. MSc-Thesis, Bonn University.

Kaiser, C. & Kraemer, M. 2002. Effects of bees and wind on the reproductive success of an anemophilous tropical grass. Abstract, 16th meeting of the Scandinavian Association of Pollination Ecology, Kongskilde, Danmark.

Kaiser, C. & Kraemer, M. (in prep.) Within-habitat heterogeneity of pollination success in the tropical grass *Brachiaria platynota* K. Schum.

Kraemer, M. 2002. The Biodiversity Monitoring Transect Analysis Project, BIOTA East Africa. Oral presentation, 1st meeting of the African Pollinators Initiative, Nairobi, Kenya.

Kraemer, M. 2002. Connectance within "generalist" plant-pollinator communities. Oral presentation, 1st meeting of the African Pollinators Initiative, Nairobi, Kenya.

Kraemer, M. 2002. Effects of habitat fragmentation on plant-pollinator interactions in East African rainforests. Oral presentation given at the BIOTA East Africa Cooperation meeting, Nairobi, Kenya.

Kraemer, M. 2003. Does rainforest fragmentation affect pollination of common understory plants? Abstract, Biotic Interactions in the Tropics, Symposium of British Ecological Society and Association for Tropical Biology and Conservation, Aberdeen.

Kraemer, M. & Bergsdorf, T. 2003. Bestäuber-Pflanze-Interaktionen in Regenwaldfragmenten Ostafrikas. In: Korn, H. & Veit, U. (eds.): Treffpunkt Biologische Vielfalt III. Bundesamt für Naturschutz, Bonn. Pp. 111-117.

Kraemer, M. & Bergsdorf, T. 2003. Does rainforest fragmentation affect the reproduction of common understorey plants? Poster presentation given at the International Symposium on Sustainable Use and Conservation of Biological Diversity, Berlin.

Kraemer, M. & Bergsdorf, T. (in prep.) Does habitat fragmentation affect the reproductive success of common understorey rainforest plants?

Peters, M. 2003. Habitatfragmentierung und ihre Auswirkung auf ostafrikanische Wanderameisen. MSc thesis, Bonn University.

Peters, M. & Kraemer, M. 2003. Decrease of a keystone species and predator community shift in East African rainforest fragments. Abstract, 16th meeting of the German Society for Tropical Ecology, Rostock.

Peters, M. & Kraemer, M. 2003. Shifts in army ant abundance in East African rainforest fragments. Abstract, Biotic Interactions in the Tropics, Symposium of British Ecological Society and Association for Tropical Biology and Conservation, Aberdeen.

Peters, M., Schaab, G. & Kraemer, M. (in prep.) Influence of habitat fragmentation and decreasing rainfall on swarm-raiding army ants.

Velten, G. 2002. Diversity and Abundance of Hymenoptera (Insecta) in a Guineo-Congolian Rainforest Fragment. MSc-Thesis, Bonn University.

Velten, G. & Kraemer, M. 2002. Diversität von Hymenopteren eines ostafrikanischen Regenwaldes. Verhandlungen der Gesellschaft für Ökologie 32: 258.

Velten, G., Springate, N. & Kraemer, M. (in prep.) A comparison of guild composition of four parasitoid communities in a Guineo-Congolian rainforest.

Wiedecke, C. 2004. Experimente zur Dichteabhängigkeit von Blütenbesuch und Reproduktionserfolg bei *Sinapis alba* L. MSc thesis, Bonn University.

3. Capacity building

3.1 Technical capacity building

Not applicable

3.2 Students and scientific staff trained

Doctoral thesis: Thomas Bergsdorf, University of Bonn – Forest fragmentation and plant-pollinator interactions in Western Kenya.

Doctoral thesis: Wolfram Freund, University of Bonn – Effects of fragmentation and degradation of an afrotropical rain forest on the diversity structure of leaf beetle communities (Coleoptera, Chrysomelidae).

PhD thesis: Mary W. Gikungu, National Museums of Kenya & University of Bonn – Differences in bee pollination among natural and successional habitat patches at Buyango Forest.

Diploma thesis: Christopher Bensch, University of Bonn – Abundance of epigaeic and hypogaeic army ants in different habitats in Kakamega Forest National Reserve (Kenya).

Diploma thesis: Anke C. Dietzsch, University of Bonn – Effects of interspecific pollen transfer on seed set in two East African *Acanthus* species (Acanthaceae).

Diploma thesis: Kristina Gebhardt, University of Bonn – Intra- und interspezifische Unterschiede von Blütenmerkmalen zweier nah verwandter Acanthus-Arten in Westkenia.

Diploma thesis: Melanie Hagen, University of Bonn – Bestäubungseffizienz unterschiedlicher Blütenbesucher an *Justicia flava* (Acanthaceae) im Kakamega Forest, Kenia.

Diploma thesis: Christopher Kaiser, University of Bonn – Influence of wind and pollen gathering by bees on reproductive success of the tropical grass *Brachiaria platynota* K. Schum. (Poaceae: Paniceae) at Kakamega Forest Nature Reserve, Kenya.

Diploma thesis: Marcell Peters, University of Bonn – Habitatfragmentierung und ihre Auswirkung auf ostafrikanische Wanderameisen.

Diploma thesis: Guido Velten, University of Bonn – Diversity and Abundance of Hymenoptera (Insecta) in a Guineo-Congolian Rainforest Fragment.

Diploma thesis: Caroline Wiedecke, Bonn University – Experimente zur Dichteabhängigkeit von Blütenbesuch und Reproduktionserfolg bei *Sinapis alba* L.

Training course: Thomas Bergsdorf, University of Bonn – The American Museum of Natural History Course in Bee Taxonomy and Biology, Southwestern Research Station, Arizona, USA.

Training course: Mary W. Gikungu, National Museums of Kenya - The American Museum of Natural History Course in Bee Taxonomy and Biology, Southwestern Research Station, Arizona, USA.

Training course: Mary W. Gikungu, National Museums of Kenya – Training in the identification of African bees. US State Department of Agriculture Bee Biology and Systematics Laboratory, Utah, USA.

Training course: Caleb I. Analo, Kakamega Environmental Education Programme – Monitoring and Evaluation in Development Projects / Programmes. By InWEnt Capacity Building International, Feldafing, Germany.

Field assistance: Daniel Karanja, National Museums of Kenya – Training in insect trapping and pinning, bee biology and taxonomy. Kakamega, Kenya.

Field assistance: Simon Githinji, Kakamega – Training in collecting, identifying, sorting and pinning of insects; methods for plant phenological surveys, plant collection, identification and storage. Kakamega, Kenya.

Field assistance: Caleb I. Analo, Kakamega Environmental Education Programme – Training in collecting, identifying, sorting and pinning of insects; methods for plant phenological surveys. Kakamega, Kenya.

Internship: Markus Halbach, University of Bonn – Training in pollination ecology and field methodology. Kakamega, Kenya.

Internship: Alice Kasprzik, University of Bonn – Training in pollination ecology and field methodology. Kakamega, Kenya.

Internship: Verena Ick, University of Bonn – Training in pollination ecology and field methodology. Kakamega, Kenya.

Internship: Julieta Peixoto Araujo, University of Bonn – Training in insect taxonomy; sorting and pinning; scanning electron microscopy. Bonn, Germany.

Internship: Nadja Riemoneit, University of Bonn – Training in pollination ecology and field methodology. Kakamega, Kenya.

Internship: Melanie Schloßberger, University of Bonn – Training in pollination ecology and field methodology. Kakamega, Kenya.

Subproject E11

Effect of fragmentation on seed dispersal, regeneration and dynamics of Kakamega Forest, Kenya

Subproject leader: Prof. Dr. K. Böhning-Gaese, University of Mainz	
Short title: BIOTA E11	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

The greatest threats to the biodiversity of tropical forests are habitat loss, fragmentation, and habitat degradation. A decline in biodiversity can result in a loss of species-species interactions and a change of ecosystem processes. However, these consequences have hardly been investigated. As most tropical plant species rely on animals for the dispersal of their seeds, seed dispersal plays a crucial role in forest regeneration and is essential for the long-term maintenance of tree populations in tropical forests. Therefore, the study of seed dispersal is an ideal approach to investigate the influence of fragmentation on both, biodiversity as well as on ecosystem functioning.

What might be possible consequences of fragmentation and degradation for seed dispersal and forest regeneration? Fragmentation might disrupt animal populations and might lead to a decline in frugivore diversity, e.g. in forest fragments. Consequently, this might result in a breakdown of dispersal processes influencing the regenerative potential of forest ecosystems. Declining regeneration can lead to changes in the abundance and spatial distribution of plants with far-reaching consequences for the diversity, dynamics and stability of forest ecosystems. Therefore, respective data and insight into these processes are crucial for future management decisions.

In this project we studied the influence of fragmentation and human disturbance on both, the diversity and the process level of interacting animals and plants. By comparing our data from study sites in the continuous main forest of Kakamega and in isolated forest fragments we asked whether forest fragmentation affected diversity of fruiting plants and of frugivores and whether this had consequences for dispersal processes and regeneration. Furthermore, an analysis on the extent of human disturbance in the forest demonstrated that sites managed by Kenya Wildlife Service showed lower levels of anthropogenic disturbance than sites managed by the Forest Department (see work package 2.1.2). Thus, in addition, we tested whether human disturbance affected fruit and frugivore diversity as well as seed dispersal and regeneration.

Planning and conduction

New work package 1: History of Kakamega Forest: Initiation of a study on „The exploitation and disturbance history of Kakamega Forest, Western Kenya“ carried out by N. Mitchell, mainly under the guidance of E11 (B. Bleher) and E03 (H. Dalitz). Analysis and publication of the results (Mitchell 2004) with B. Bleher and H. Dalitz as editors.

New work package 2: Assessment of current disturbance in Kakamega Forest: Initiation of a study on the human disturbance of Kakamega Forest in more recent times in cooperation with E03 (D. Uster) and E10 (T. Bergsdorf). Analysis and publication of the results (Bleher et al. 2004).

Establishment of study plots: During our first field campaign, establishment of nine study plots in Kakamega Forest (Fig. 1). Four of the plots were selected in the 8245 ha continuous main forest block and five in each of five peripheral forest fragments, i.e. Kisere and Malava in the North, and Yala, Ikuywa and Kaimosi in the South (Fig. 1).

Original work package 1: Fruit diversity and availability: Initiation of a study on the effect of fragmentation and human disturbance on fruit diversity and availability by monitoring fruit availability once per month from 09/2001 to 05/2004 on the nine study plots. Analysis and presentation of the results (see below).

Original work package 2: Frugivore and seed predator diversity: PhD of Nina Farwig on the effect of fragmentation and human disturbance on frugivore and predator diversity on the nine study plots. Analyses and submission of two publications (Farwig et al., submitted a, b).

Original work package 3: Seed dispersal, seed predation and regeneration: PhD of Nina Farwig on the effect of fragmentation and human disturbance on seed dispersal and seed predation in *Prunus africana*. Analyses and two submitted manuscripts (Farwig et al., submitted a, b). Master's thesis by Monika Melcher on seed predation in *Prunus africana* (Melcher 2004). Master's thesis of Jasper Kirika on seed dispersal in *Ficus thonningii*. Master's thesis is finished (Kirika 2004), a manuscript is in preparation (Kirika et al., in preparation). Monitoring of seedlings from 10/2001 until 04/2004, data analysis still in progress. Presentation of first results below.

Original work package 4: Characterisation of frugivores: This work package was omitted in favour of two new work packages (see above). The new work packages were decided to be more important because they provided more relevant data with regard to the BIOTA project as a whole and, especially, with regard to management applications.

Cooperations with other institutions

- National Museums of Kenya, Department of Ornithology (L. Bennun, A. Owino, M. Muchai)
- National Museums of Kenya, Department of Mammology (B. Akwanda)
- University of Nairobi, Department of Zoology (R. M. Chira)
- ICIPE (I. Gordon)
- KEEP (Kakamega Environmental Education Program) (C. Analo, N. Sajita, B. B. Chituy, B. Okalo)
- Kenyan Wildlife Service/Forest Department (Mr. Muteru, Mr. Mbaka, Mr. Mbeke, E.W. Kiarie, A. Oman)
- Zoologisches Forschungsinstitut und Museum Alexander Koenig, Department of Mammology (R. Hutterer)
- Universität Mainz, Institut für Botanik (C. Lenz)

- BIOTA East Projects: excellent co-operation among the sub-projects, for example
  - with E02 (G. Schaab)
  - with E03 (H. Dalitz, D. Uster)
  - with E04 (E. Fischer, A. Althof, B. Dumbo)
  - with E10 (M. Kraemer, T. Bergsdorf, M. Gikungu)
  - with E12 (S. Kiefer).

2. Results

2.1 Scientific results

New work package 1: History of Kakamega Forest

This work package was not in the original proposal. It became necessary because during the first year of research in Kakamega Forest, it was commonly recognised that Kakamega Forest, in the literature often cited as virgin tropical rainforest, has not only suffered from forest clearance and fragmentation, but also from many years of human disturbance. Therefore, an urgent need for in-depth information on the exploitation and disturbance history of Kakamega Forest was needed. This basic knowledge proved to be crucial to be able to put BIOTA East Africa research results into a broader perspective and to interpret them against the background of historical forest disturbance. Consequently, BIOTA East Africa, mainly under the guidance of E11 (B. Bleher) and E03 (H. Dalitz), initiated a study on „The exploitation and disturbance history of Kakamega Forest, Western Kenya“ carried out by N. Mitchell. This study covers Kakamega main forest as a whole and its various fragments with special reference to the ten study sites in which BIOTA East Africa research is conducted with standardised „biodiversity observatories“, namely Colobus, Buyangu, Salazar, Isecheno A, Isecheno B, Yala, Ikuywa, Malava, Kisere and Kaimosi.

Research was carried out between 10/2002 and 03/2003 and has drawn information from various Kenyan government institutions, British Colonial records, timber companies, from recent literature, from the local people living adjacent to the forest and from place-name evidence. The results indicate that forestation occurred after 12,000 years BP. However, the forests of Kakamega, Kisere, Malava and Bunyala appear to have not been joined in the recent past. In contrast, evidence suggests that the areas to the west and south of Kakamega Forest were once afforested but full forest cover probably extended not further east and north than approximately the marked forest boundaries today.

While the northern and eastern limits of the Kakamega Forest and Malava, Kisere and Bunyala may never have been reduced at all, the west and south has been depleted by the advance first of the Abaluhya, then by the Luhya. In 1930 commercial logging started in Kakamega Forest. The ten BIOTA study sites have received individual treatment due to the variance in the original forest structure, the differing treatment of the forest by local people, and the differing logging and planting policies of the forest authorities. Kisere Forest, Yala Nature Reserve and Isecheno Nature Reserve appear to be the most undisturbed parts of the Kakamega Forest. None of these areas have been subjected to large-scale timber extraction. The Buyangu area has been heavily exploited and is now regenerating. Kaimosi, Ikuywa and Malava have all experienced serious disturbance by logging and/or planting. For further information see Mitchell (2004).

New work package 2: Assessment of current disturbance in Kakamega Forest

Also this work package was not in the original proposal. It became necessary because first results demonstrated that the current management regime, especially differences in management between sites under the jurisdiction of the Kenya Wildlife Service and the Forest Department, had significant impact on the disturbance level of the forest. In a study conducted as a joined project of E11 (B. Bleher), E03 (D. Uster) and E10 (T. Bergsdorf) the human impact on Kakamega Forest in more recent times was evaluated.

To quantify levels of disturbance, in 02 and 04/2002 and in 06 and 07/2003 disturbance surveys were carried out at 22 forested sites in Kakamega main forest and its peripheral fragments. At each site, transects were run at least 1,000 m in length. Surveys included recording any of seven disturbance parameters in a belt of 10 m on each side of the transect thereby covering a total area of 56.6 ha. Disturbance parameters recorded were numbers of trees logged (distinguishing between trees logged either less or more than 20 years ago), number of trees exhibiting any signs of debarking for medicinal use, number of charcoal kilns, number of sawing pits, number of honey gathering sites, number of abandoned and current paths, and number of cattle tracks.

The results indicate a high level of human impact throughout the forest with illegal logging being most widespread. Furthermore, logging levels appear to reflect management history and effectiveness. From 1933 to 1986, Kakamega Forest was under management by the Forest Department and the number of trees logged more than 20 years ago was equally high at all sites. Since 1986, management of Kakamega Forest has been under two different organisations, i.e. Forest Department and Kenya Wildlife Service. The number of trees logged illegally in the last 20 years was significantly lower at sites managed by the Kenya Wildlife Service. Finally, logging was lower within highly protected National and Nature Reserves as compared to high logging within the less protected Forest Reserves. Reflecting management effectiveness as well as protection status in Kakamega Forest, logging was demonstrated to be a valuable quantitative indicator for human disturbance and thus an important tool for conservation managers. For further information see Bleher et al. (2004).

Original work package 1: Fruit diversity and availability

On a first diversity level, we monitored fruit diversity and availability in different parts of Kakamega forest. Our objective was to test whether fragmentation and disturbance affected fruit diversity. We monitored fruit availability once per month from 09/2001 to 05/2004 in nine different plots of 1 ha with four plots in the main forest block (two in the south and two in the north) and five in fragments with one in each of the five forest fragments Malava, Kisere, Ikuywa, Yala and Kaimosi (Fig. 1). The plots were dissected by five marked transects of 100 m length with neighbouring transects separated from each other by 20 m. All plants bearing ripe fruit, which might be consumed by frugivorous animals, were identified 10 m to the left and 10 m to the right of the five transects thereby covering a total area of 1 ha. Furthermore, all events of animals eating fruit were recorded.

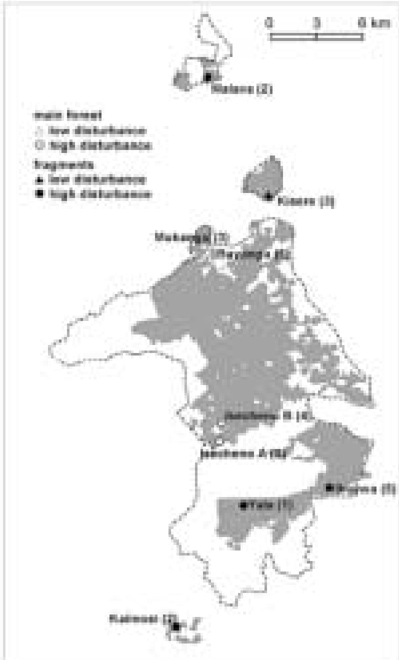

Fig. 1. Map of Kakamega forest and adjacent fragments with spatial position of the nine study plots. Numbers in parenthesis are numbers of observed *Prunus africana* trees per site for work package 2.1.5. Triangles stand for less disturbed sites, circles for highly disturbed sites, open symbols for main forest sites and full symbols for fragments. Dashed line represents former forest boundary (1933), grey shading represents actual forest cover. Courtesy of G. Schaab (E02).

Fruit availability was generally low with peaks from February to March in 2002, 2003 and 2004. Mainly trees of the genus *Ficus* were found to be major fruit resources and attractive to many animals. *Ficus* appeared to act as a keystone genus for frugivores as also demonstrated for other African and tropical forests. We found a difference in the number of trees bearing ripe fruit among the sampling months but no effect due to either fragmentation or disturbance (ANOVA # species: fragmentation: $P > 0.05$; disturbance: $P > 0.05$; month: $P < 0.001$). For further information see Farwig et al. (submitted manuscript a).

Original work package 2: Frugivore and seed predator diversity

On a second diversity level, we quantified the frugivore community of Kakamega Forest, i.e. all birds and primates, which might be possible frugivorous seed dispersers. Our objectives were to test whether fragmentation and human disturbance affected frugivore diversity. To monitor the diversity and abundance of animal dispersers we recorded all birds and primates once per month from 09/2001 to 08/2002 on the same nine plots of 1 ha as for monitoring the fruit diversity (see Fig. 1). We monitored all birds and primates in the early morning (07:00-08:30) using point counts recording all animals heard and seen for 10 minutes at nine points along the transects.

During the monthly census we recorded 103 bird and four monkey species. 49 of the species were categorised as frugivores. We found significantly fewer frugivorous species and individuals in fragments as compared to the main forest. Disturbance did not influence the frugivore community (ANOVA # species: fragmentation: $P < 0.001$; disturbance: $P > 0.05$; month: $P < 0.01$; # individuals: fragmentation: $P < 0.05$; disturbance: $P > 0.05$; month: $P < 0.001$). These results are part of the PhD of Nina Farwig. For further information see Farwig et al. (submitted manuscript a).

In a second step, we monitored the diversity of small mammals that can act as seed predators. To characterise the rodent diversity we trapped small mammals on the forest floor in the dry season from 24.01.-22.02.2003 and in the rainy season from 26.04.-22.05.2003. We set up Sherman live-traps in the same nine 1-ha plots as for monitoring the frugivore community. In each season 99 traps were set for 3 nights along the five transects placed on the plots. To confirm whether the small mammals caught act as possible seed predators we kept the species we caught separately in cages and offered *Prunus africana* seeds for a period of 24 h. We then tested whether the fragmentation or disturbance regime influenced the diversity of seed predators. In addition, we identified potential other seed predators by placing cameras with infra-red sensitive camera traps for 21 nights in the sites Buyangu and Mukangu in 01 and 02/2004.

In 5,346 trap nights we caught 991 individuals during the two trapping seasons. We trapped four different rodent species. The most frequent species was *Praomys* cf. *jacksoni* with 925 individuals. The other three species were *Hylomyscus* sp. (42 ind.), *Lophuromys laticepts* (20 ind.) and *Crocidura* sp. (4 ind). Individuals of *Praomys* cf. *jacksoni*, *Hylomyscus* sp. and *Lophuromys laticepts* ate the seeds of *Prunus africana* and were therefore identified as seed predators. The number of predators did not differ significantly between fragments and main forest sites and between less and highly disturbed sites, neither in the dry nor in the rainy season (ANOVA # individuals: fragmentation: $P > 0.05$; disturbance: $P > 0.05$, respectively). However, in the dry season there was a trend towards catching more individuals under the high than low disturbance regime. These results are part of the PhD of Nina Farwig. For further information see Farwig et al. (submitted manuscript b). The infrared sensitive cameras identified one additional species that might act as a rare seed predator, *Cricetomys* sp. (4 out of 76 pictures taken from small mammals) (Melcher 2004; see Fig. 2).

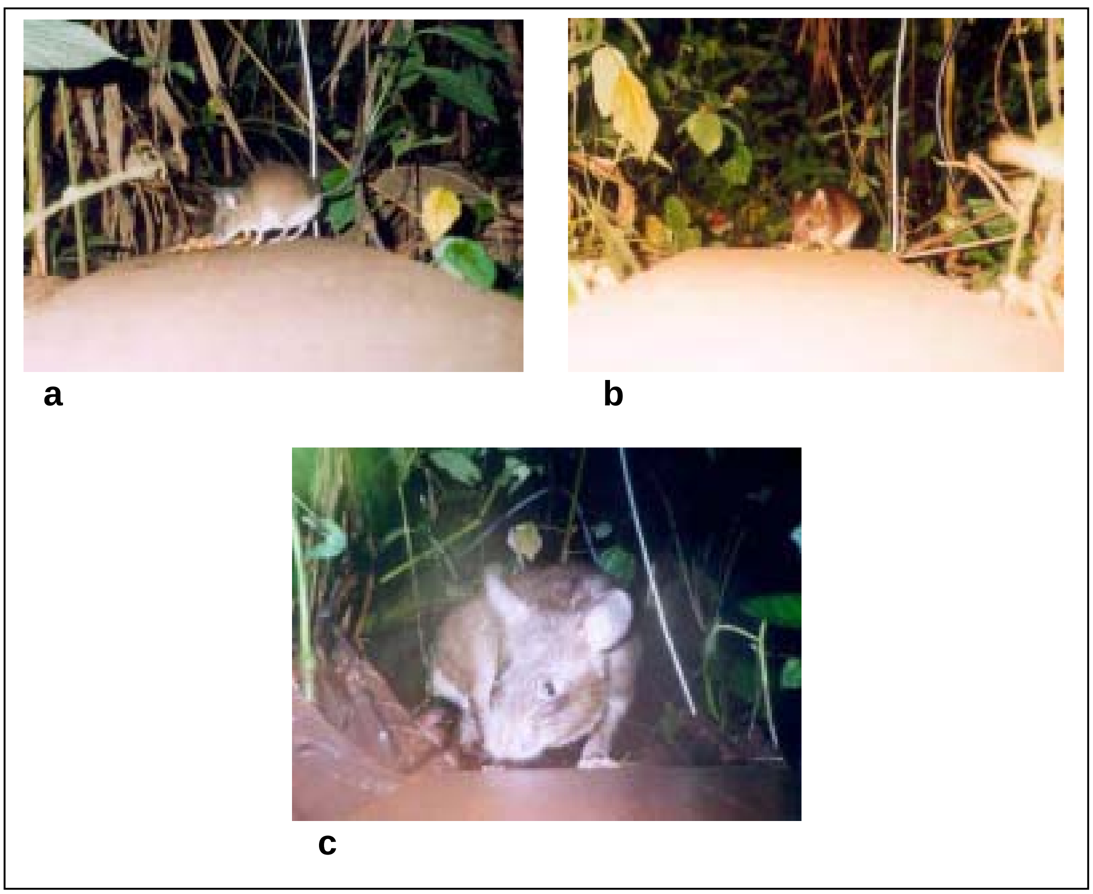

Fig. 2. Seed predators identified by infra-red sensitive cameras: a) *Praomys* sp. b) *Lophuro-mys* sp. c) *Cricetomys* sp.

Original work package 3: Seed dispersal, seed predation and regeneration

On the process level, we then studied in more detail seed dispersal and seed predation of two selected tree species, i.e. *Prunus africana* and *Ficus thonningii*. *Prunus africana* was selected as a model species because the species is threatened by extinction due to over-exploitation for their medicinally used bark. The species has been listed in Appendix II of CITES. In spite of its current threat status the species still occurs in all main forest plots of Kakamega forest as well as in all fragments. *Ficus thonningii* was selected because *Ficus* has been demonstrated to be a keystone plant genus in Kakamega forest supporting an over-proportional number of frugivorous animals. *Ficus thonningii* is the most abundant *Ficus* species in Kakamega forest and also occurs in all main forest sites as well as in all fragments. Finally, on the process level, we studied the influence of fragmentation and disturbance regime on tree regeneration.

Prunus africana

For *P. africana* we monitored the frugivorous animals visiting selected trees and dispersing seeds. In addition, we monitored seed predation by small mammals on both the nine study plots as well as predation by small mammals, insects, and fungi under and in the vicinity of selected trees. Our objective was to test whether seed dispersal and seed predation differed between main forest sites and fragments as well as between sites with different levels of anthropogenic disturbance.

To determine the frugivore assemblage of *P. africana* we observed all fruit-eating birds and monkeys on a total of 28 randomly chosen trees placed on or in the vicinity of the same nine plots (Fig. 1). The observations were conducted in the months March 2002, October 2002, March 2003 and December 2003. Observations were conducted on each tree from 07:00 to 19:00 using a combination of scan and focal sampling. To quantify the number of seeds dispersed per tree we multiplied for each species the number of individuals observed in the trees with the mean number of fruits eaten per individual and adding these numbers over all species.

During 336 h of observations, we recorded 75 bird and three monkey species visiting the *P. africana* trees. 36 species of them were categorised as frugivores. We found more frugivorous species and individuals on trees in fragmented than in main forest sites. Moreover, we recorded more frugivorous species and individuals in highly disturbed sites than in less disturbed sites (ANOVA, # species: fragmentation: $P < 0.05$; disturbance: $P < 0.01$; # individuals: fragmentation: $P < 0.05$; disturbance: $P < 0.05$).

With regard to seed dispersal we found slightly more seeds dispersed per tree in fragments compared to main forest and more seeds dispersed per tree in more disturbed sites than in less disturbed sites (ANOVA, # seeds per tree: fragmentation: $P < 0.1$, disturbance: $P < 0.05$). These results are part of the PhD of Nina Farwig. For further information see Farwig et al. (submitted manuscript a).

To assess the predation rates on *P. africana* seeds we arranged two plastic dishes in pairs at nine positions on the nice 1-ha plots following the trapping sessions of small mammals, i.e. from 19.03.-02.04.2003 (dry season) and from 15.05.-30.05.2003 (rainy season). One of the two dishes was baited with one seed and the other one with five *P. africana* seeds. We found a significant difference between highly and less disturbed sites for 1-seed dishes with more seeds preyed upon in highly disturbed than in less disturbed sites in the dry but not in the rainy season. We did not find any significant effect for fragmentation nor for the five-seed dishes (ANOVA: 1-seed dishes, dry season: fragmentation: $P > 0.05$, disturbance: $P < 0.05$;

all other effects P > 0.05). These results are part of the PhD of Nina Farwig. For further information see Farwig et al. (submitted manuscript b).

In addition, we mapped in 01 and 02/2004 seeds on 28 m^2 placed under the crown and in 3, 6, and 9 m distance from the crowns of 16 *P. africana* trees located in the main forest and in fragments under high and low levels of anthropogenic disturbance. For the seeds, we distinguished between "healthy" seeds, and seeds destroyed by small mammals or insects and seeds infected by fungi. Average loss of seeds to all predators was 25.2%. The overall predation rate was not influenced neither by fragmentation and disturbance regime nor by the distance to the tree. The same pattern was found when the different kinds of predation were analysed separately. The only exceptions were a decline of insect predation with increasing distance from the tree. For fungi infection, we detected an influence of fragmentation with higher rates of fungi infection in the main forest than in the fragments, and a decline of fungi infection with increasing distance from the tree. These results are part of the Master's thesis of Monika Melcher. For further information see Melcher (2004).

Ficus thonningii

To determine the frugivore assemblage of *F. thonningii* we observed all fruit-eating birds and monkeys on a total of 25 randomly chosen trees placed on or in the vicinity of the same nine plots (Fig. 1). The observations were conducted from 10/2003 to 04/2004. Observations were conducted on each tree from 07:00 to 15:00 using a combination of scan and focal sampling.

A total of 62 animal species were recorded in 25 *F. thonningii* trees with 56 bird and 6 mammal species. Out of these 36 (58%) were categorised as frugivores, 30 of these were birds while 6 were mammals. In contrast to data on *P. africana*, there were no significant differences in avian frugivores species and individuals neither between the continuous forest and forest fragments nor between differently disturbed sites (ANOVA: $P > 0.05$, respectively). These results are part of the master's thesis of Jasper Kirika. For further information see Kirika (2004). To study the impact of forest fragmentation and disturbance on seed predation of *F. thonningii* was not possible because the seeds of *F. thonningii* are, as *Ficus* species in general, very small and their fate cannot be easily be monitored.

Tree regeneration

Beyond the diversity level, we wanted to determine whether forest fragmentation and disturbance affects regeneration of tree species. The seedlings and saplings in a fragmented forest are mainly the result of regeneration from seeds after the fragmentation process took place. Consequently, density and spatial pattern of seedlings may provide clues to the possible effects of fragmentation on tree regeneration. Therefore, we started an inventory of seedlings. Tree seedlings were mapped, identified and counted in 90 1 m^2 seedling plots in each of the nine plots (Fig. 1, total mapped area of 810 m^2). Monitoring started in 10/2001 and was conducted every 3 months until 04/2004.

An analysis of data of the first survey indicates that seedling diversity per m^2 is slightly higher in continuous forest sites as compared to fragment sites (Fig. 3). Furthermore, there seems to be an even stronger association with management regime, i.e. higher species numbers are found at less disturbed as compared to heavily disturbed sites (Fig. 3). Overall, management appears to have a much stronger effect on seedling species numbers as compared to fragmentation (ANCOVA: all seedlings: fragmentation: $p < 0.1$, disturbance: $p < 0.001$).

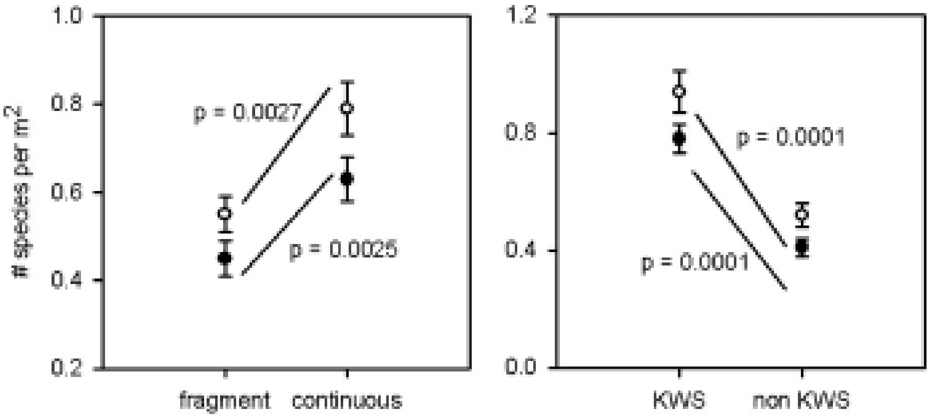

Fig. 3. Seedling species numbers per m^2 (Mean ∂ SE) recorded for all tree seedlings (open circles) and for typical primary forest seedlings (filled circles) at **a.** fragment sites and continuous forest sites, and at **b.** Kenyan Wildlife Service (KWS) and non KWS-managed sites. For each study plot the species numbers per station of each of the 30 stations per plot were added (1 station = 3 x 1 m^2 plots in close proximity mapped) and an average species number calculated over all stations. $n_{\text{continuous forest}} = 120$, $n_{\text{fragment}} = 150$.

Furthermore, data are currently being analysed with the objective

- ∉ whether seedling species found are congruent with tree species in our plots or whether mother trees as possible seed sources might already be lacking in fragments (trees have already been mapped for all our plots)
- ∉ whether seedling numbers might be correlated with density of understory species (such as *Dracaena fragrans, Acanthus eminii, Acanthopale pubescens*) or light regime (understory density and light regime at seedling plots has already been recorded)

Original work package 4: Characterisation of frugivores

In the proposal it was planned to characterise the importance of individual frugivorous bird species for seed dispersal. It was planned to capture birds by mist-netting, keeping them temporarily in aviaries and carrying out feeding experiments. However, this work package was omitted in favour of two new work packages. The new work packages were decided to be more important because they provided more relevant data with regard to the BIOTA project as a whole and, especially, with regard to management applications.

2.2 Interdisciplinary components

- *BIOTA East Projects:* excellent co-operation among the sub-projects, for example joint study on disturbance history with all other BIOTA projects, especially with E03 (Helmut Dalitz)
  joint study on current levels of disturbance with E03 (Dana Uster) and E10 (Thomas Bergsdorf)
  all spatial analyses conducted in very close collaboration with E02 (Gertrud Schaab)
  Determination of plant species and seedlings in collaboration with E03 (Dana Uster), E04 (Eberhard Fischer, Arnhild Althof, Bonny Dumbo), and E12 (Stefan Kiefer). Determination of insects in collaboration with E05 (Thomas Wagner) and E10 (Mary Gikungu)

- *Universität Mainz, Institut für Botanik*: Collaboration with Christoph Lenz building the infra-red sensitive camera traps.
- *Zoologisches Forschungsinstitut und Museum Alexander Koenig, Abteilung für Säugetiere:* Determination of small mammals in collaboration with Rainer Hutterer.
- *National Museums of Kenya, Department of Ornithology*: excellent communications with Leon Bennun and Alfred Owino (former heads of Dep. Ornithology) and Muchane Muchai (current head of Dep. Ornithology). Overall support by the Department on logistics as well as on scientific matters, purchase of computer system for the department.
- *National Museums of Kenya, Department of Mammology:* collaboration with Bernard Akwanda on determination of small mammals and patterns of small mammal diversity in Kakamega Forest.
- *University of Nairobi, Department of Zoology:* co-supervision of Master's project of Jasper Kirika together with Robert Chira.
- *ICIPE*: B. Bleher and N. Farwig are visiting scientists in ICIPE, excellent communications with Ian Gordon on issues on conservation and management of biodiversity in Kenya.
- *KEEP (Kakamega Environmental Education Programme):* Collaboration on community-based conservation of Kakamega forest, communication of research results to the general public, education of school-children etc., with Caleb Analo, Nixon Sajita, Benson B. Chituy, Benjamin Okalo.
- *Kenyan Wildlife Service / Forest Department*: strong support by the two Wardens-in-charge in Kakamega Forest, Mr. Muteru and Mr. Mbaka, and the Forrester-in-charge in Isecheno, Mr. Mbeke. Collaboration collecting data on historical disturbance of Kakamega forest with Mrs. E.W. Kiarie (Senior Warden Kakamega National Reserve) and A. Oman (Assistant District Forest Officer).

2.3 Likely benefit and applicability of results

New work package 1: History of Kakamega Forest

This new work package proofed to be crucial to put BIOTA East Africa research results into a broader perspective and to interpret them against the background of historical forest disturbance. The joint study by all BIOTA East projects under the guidance of E11 (B. Bleher) and E03 (H. Dalitz) and conducted by M. Mitchell demonstrated that the forests of Kakamega, Kisere, Malava and Bunyala appear to have not been joined in the recent past. While the northern and eastern limits of the Kakamega Forest and Malava, Kisere and Bunyala may never have been reduced at all, the west and south has been depleted by local human populations. Commercial logging, and planting policies by the forest authorities had heavy impact on forest structure and composition. The 10 BIOTA study sites have received individual treatment due to the variance in the original forest structure, the differing treatment of the forest by local people, and the differing logging and planting policies of the forest authorities. This work package demonstrated, that by working on the 10 BIOTA study sites, a wide range of different forest types and disturbance histories is covered in the BIOTA East projects. For further information see Mitchell (2004).

New work package 2: Assessment of current disturbance in Kakamega Forest

Also this new work package was of a very applied nature. In this work package conducted as a joined project of E11 (B. Bleher), E03 (D. Uster) and E10 (T. Bergsdorf) the human impact on Kakamega Forest in more recent times was evaluated. The results indicate that current management regime had a significant influence on forest disturbance levels. Since 1986, management of Kakamega Forest has been under two different organisations, i.e. Forest Department and Kenya Wildlife Service. The number of trees logged illegally in the last 20 years was significantly lower at sites managed by the Kenya Wildlife Service than at sites managed by the Forest Department. Logging was demonstrated to be a valuable quantitative indicator for human disturbance and thus an important tool for conservation managers. This information is valuable for the Kenya Wildlife Service as well as the Forest Department. The results support especially the strong law enforcement by the Kenya Wildlife Service that leads to a measurable decline in illegal tree logging. In addition, this work package demonstrated that by working on the 10 BIOTA study sites, it is possible to disentangle the effects of fragmentation and forest disturbance on the diversity of plant and animal communities as well as on ecosystem processes. For further information see Bleher et al. (2004).

Original work package 1: Fruit diversity and availability

In this work package we monitored fruit diversity and availability in different parts of the forest. The results demonstrated that *Ficus* appeared to act as a keystone genus for frugivores. This suggests that *Ficus* plays an over-proportional role in supporting the local frugivore community. This has important management implications. Managing for high *Ficus* diversity and abundance in the continuous forest as well as in the farmland surrounding the forest should increase the carrying capacity for frugivorous birds and, hence, species richness and abundance of frugivorous birds. Thus managing for high *Ficus* diversity might play a crucial role in counteracting negative effects of forest fragmentation and disturbance. This information is valuable for the Kenya Wildlife Service as well as the Forest Department.

Original work package 2: Frugivore and seed predator diversity

In this work package we tested the influence of forest fragmentation and disturbance on frugivore diversity. The results showed significantly fewer frugivorous species and individuals in fragments as compared to the main forest. Disturbance did not influence the frugivore community. These results demonstrate that especially forest fragmentation appears to have a negative impact on frugivore diversity and abundance. These results have important implications for forest conservation. If frugivore diversity is to be maintained in these rare Afro-montane forests, especially further fragmentation of forest should be prevented. In contrast, the small mammal community was much less influenced by forest fragmentation and disturbance. Again, this information is valuable for the Kenya Wildlife Service as well as the Forest Department.

Original work package 3: Seed dispersal, seed predation and regeneration

This work package showed the most interesting results. The work package was aimed to understand the influence of fragmentation and disturbance on ecosystem processes, i.e. seed dispersal, and seed predation, working with two selective tree species, *Prunus africana* and *Ficus thonningii*. The results showed that, for *P. africana*, more bird species and individuals visited trees in disturbed and fragmented sites and led to significantly higher seed dispersal in these sites. In contrast, for *F. thonningii* no differences between main forest and fragments nor between differently disturbed sites were found. In addition, seed predation on *P. africana* seeds hardly differed between the different sites. These results are interesting because they demonstrate that in spite of an impoverished frugivore community, seed dispersal (*in P. africana*) was enhanced in fragmented and disturbed sites. If this enhanced seed dispersal leads to enhanced seedling establishment these results demonstrate that ecosystems might contain processes that counteract the negative effects of forest fragmentation and disturbances at least for some time. These results are most interesting for ecosystem conservation in general, and have to be followed up in more detail to understand how an impoverished bird diversity can lead to improved ecosystem services.

2.4 Publications resulting from the project

Scientific publications

Bleher, B., and K. Böhning-Gaese: The role of birds in seed dispersal and its consequences for forest ecosystems. Acta Zoologica Sinica (accepted).

Bleher, B., and K. Böhning-Gaese: Consequences of forest fragmentation and disturbance on seedling establishment in Kakamega Forest, Kenya (in preparation).

Bleher, B., D. Uster, and T. Bergsdorf (2004): Assessment of threat status and management effectiveness in Kakamega Forest, Kenya. Biodiversity and Conservation (in press).

Böhning-Gaese, K., and G. Gauthier: Influence of birds on ecosystem structure and function. Acta Zoologica Sinica (accepted).

Farwig, N., K. Böhning-Gaese, and B. Bleher (a): Enhanced seed dispersal of *Prunus africana* in fragmented and disturbed forests (submitted to Oecologia).

Farwig, N., K. Böhning-Gaese, and B. Bleher (b): Does fragmentation and disturbance affect seed predator abundance and seed predation rates of *Prunus africana* in Kakamega Forest, Kenya (in preparation).

Kirika, J. M., R. M. Chira, K. Böhning-Gaese, and B. Bleher: Consequences of forest fragmentation and disturbance on avian frugivores of *Ficus thonningii* and implications for seed dispersal and recruitment (in preparation).

Mitchell, N. (2004) The exploitation and disturbance history of Kakamega Forest, Western Kenya. Bielefelder Ökologische Beiträge 20, edited by B. Bleher und H. Dalitz.

Theses

Farwig, Nina: Influence of forest fragmentation and disturbance on seed dispersal, seed predation, and genetic structure of *Prunus africana* in Kakamega Forest. PhD thesis, University of Mainz (in preparation).

Kirika, Jasper, M.: Consequences of forest fragmentation and disturbance for frugivore assemblages in *Ficus thonningii* and implications for regeneration processes. Master’s thesis, University of Nairobi: (submitted).

Melcher, Monika. Einfluss von Fragmentierung und Walddegradation auf Samenprädation von Prunus africana im Kakamega Forest, Kenia. Master’s thesis, University of Mainz (finished).

Abstracts of oral or poster presentations at scientific meetings

Bleher, B., and K. Böhning-Gaese (2001): Fragmentation and ecosystem processes: dispersal and regeneration. BIOLOG Statusseminar, BMBF, Bonn.

Bleher, B., and K. Böhning-Gaese (2002): The role of birds in seed dispersal and its consequences for forest ecosystems. 23rd International Ornithological Congress, Beijing, China.

Bleher, B., K. Böhning-Gaese, and G. Schaab (2003): Human impact on seedling establishment of animal-dispersed trees. BIOLOG Statusseminar, BMBF, Berlin.

Bleher, B., K. Böhning-Gaese, and G. Schaab (2003): Human impact on seedling establishment of animal-dispersed trees. Annual Meeting of the Association for Tropical Biology and Conservation, Aberdeen, Schottland.

Bleher, B., K. Böhning-Gaese, and G. Schaab (2004): Human impact on seedling establishment of animal-dispersed trees. 17. Jahrestagung der Gesellschaft für Tropenökologie, Bayreuth.

Bleher, B., J. Kirika, N. Sajita, and K. Böhning-Gaese (2002): Influence of fragmentation for seed dispersal and regeneration dynamics. BIOTA-Workshop, National Museums of Kenya, Nairobi.

Bleher, B., G. Schaab, and K. Böhning-Gaese (2003). Man, birds and berries – Human impact on forests and plant-animal-interactions. 16. Jahrestagung der Deutschen Gesellschaft für Tropenökologie, Rostock.

Bleher, B., F. Voigt, and K. Böhning-Gaese (2001): Diversity of frugivores and consequences for forest ecosystems. I. Seed dispersal and seedling establishment. 31. Jahrestagung der Gesellschaft für Ökologie, Basel.

Böhning-Gaese, K. (2002): Influence of bird diversity on the structure and function of ecosystems. 95. Jahresversammlung der Deutschen Zoologischen Gesellschaft, Halle.

Böhning-Gaese, K. (2002): Influence of birds on ecosystem structure and function. 23rd International Ornithological Congress, Beijing, China.

Böhning-Gaese, K. (2003): Impact of frugivores on plant populations and communities. Workshop: Birds and berries and plant secondary metabolites: frugivory, detoxification and utilisation. Internationales Wissenschaftsforum, Heidelberg.

Böhning-Gaese, K. (2004): Die Bedeutung früchtefressender Vogelarten für die Funktion tropischer Ökosysteme. 25. Tagung der Gesellschaft für Tropenornithologie, Berlin.

Farwig, N., K. Böhning-Gaese, and B. Bleher (2003): Consequences of forest disturbance on seed predator abundance and predation rates of *Prunus africana* (Rosaceae). BIOLOG Statusseminar, BMBF, Berlin.

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Kraemer, M., B. Bleher, T. Bergsdorf, and K. Böhning-Gaese (2001): Threatened mutualisms: pollination, seed dispersal and regeneration in forest remnants. BIOLOG Statusseminar, BMBF, Bonn.

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3. Capacity building

3.1 Technical capacity building

- Purchase of computer system for Department of Ornithology, National Museums of Kenya.
- Purchase of computer software (Paradox, JMP, Sigma Plot) for Department of Ornithology, National Museums of Kenya, instruction of J. Kirika how to use relational data bases and statistical work packages during his stay at the University of Mainz in 05/06 2004.

3.2 Students and scientific staff trained

- Akwanda, Bernard: Master's student. Collaboration on determination of small mammals.
- Analo, Caleb: Field assistant, collection of data on forest disturbance.
- Berens, Dana: Student, University of Mainz, independent project on seedling establishment.
- Chituy, Benson B.: Field assistant, collection of data on small mammals.
- Danner, Andreas: Student, University of Mainz, independent project on seed dispersal.
- Eshiamwata, George, W.: Intern, Department of Ornithology, collection of data on frugivorous birds.
- Farwig, Nina: PhD student, University of Mainz, thesis: Influence of forest fragmentation and disturbance on seed dispersal, seed predation, and genetic structure of *Prunus africana* in Kakamega Forest.
- Guhmann, Patrick: Student, University of Mainz, independent project on seed dispersal.
- Hutter, Sabrina: Student, University of Mainz, independent project on small mammals.
- Kirika, Jasper M.: Master's student, University of Nairobi, thesis: Consequences of forest fragmentation and disturbance for frugivore assemblages in *Ficus thonningii* and implications for regeneration processes.
- Maier, Annette: Student, University of Mainz, independent project on seedling establishment.
- Melcher, Monika: Student, University of Mainz, independent project on seedling establishment; Master's student, University of Mainz, thesis: Einfluss von Fragmentierung und Walddegradation auf Samenprädation von *Prunus africana* im Kakamega Forest, Kenia.
- Mitchell, Nick: Intern, collection of data and report on historical forest disturbance in the Kakamega area.
- Munyekenye, Fred B.: Intern, Department of Ornithology, collection of data on bird visitors of *P. africana* and on small mammals.

- Okalo, Benjamin: Field assistant, collection of data on seeds and seedlings.
- Rösner, Sascha: Intern, University of Marburg, collection of data on bird visitors on *P. africana*.
- Sajita, Nixon: Field assistant, collection of data on trees, fruit availability, seedlings, birds, and mammals
- v. Ewijk, Karin: Intern, University of Mainz, GIS support.
- Zink, Manuela: Student, University of Mainz, independent project on small mammals.

Subproject E12

Diversity and use potential of montane forest ecosystems in Kenya

Subproject leader: Dr. R. Bussmann, University of Bayreuth	
Short title: BIOTA E12	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

Kikuyu ethnobotany

Having established the key role of indigenous knowledge in natural resources management and biodiversity conservation the project aimed at documenting the traditional knowledge of the Kikuyu people in Central Kenya. The major objective was to provide quantitative ethnobotanical data of this region, which can be used in managing and restoring the degraded Mt. Kenya and Aberdares ecosystems of Central Kenya.

Analyses of regeneration strategies

The regeneration strategies of different stages of development should be investigated by monitoring tree offspring surrounding key tree species and quantification of seedlings in certain disturbance stages. Structural data of the tree composition and dispersion compared with the regeneration patterns lead to the linkage of stages of development.

Investigating the use potential of forest ecosystems

The establishment of a socioeconomic database concerning energy demand and economical background of 201 households was supposed to give information about the requirement of forest resources. Spot checks of forest resource use gave some information about the actual use of the forest and support the estimation of the potential pressure on the forest resources. A further parameter was provided by monitoring the degree of education of the local population.

Establishment of Maseno Botanical Garden

A major aim of this project was the establishment of a botanical garden at the university of Maseno. Botanical gardens around the world keep local plants and knowledge as well as from foreign regions. A botanical garden does not only preserve plants and knowledge but also supports the education of academics as well as of any interested person. With a particular design the Maseno Botanical Garden combines research, education and information. Not only the individual presentation of local plants, moreover the exposition of certain plants in their ethno botanically context shall keep the more and more decreasing knowledge of former generations. At the same time experimental fields show not only useful plants for information but also serve for research to develop more resistant plants for local use. To round off the picture an ornamental walkway invites also non-professionals in the vegetation field for interest in their natural environment and brings the nature also to local people who have not the advantage to experience a forest or other natural vegetation systems. In the framework of the garden particular research work concentrates on useful plants and their active agents. A germplams/seed collection will be established to conserve particularly rare plant species and make them available for further generations and plant species enrichment projects.

Planning and conduction

Kikuyu ethnobotany

The fieldwork was carried out using semi structure questionnaires in all the districts of Central Kenya. This was from 2001-2004. Reports were made every four months on the progress of the field data collected and dissemination.

Analyses of regeneration strategies

The study was carried out using methods gaining frequency data of both seedlings and trees. Other structural results like dominance and dispersion indices besides diversity indices were collected. In addition the seed intake for the area of the seedling survey was measured. The fieldwork was carried out between January 2001 and May 2004 in different time windows to gain seasonal data. A pure regeneration survey was carried out only in Kakamega Forest. But with the intention of expanding this survey for a comparison with the central of Kenya we also collected data from the Mt. Kenya area.

Investigating the use potential of forest ecosystems

The establishment of the socioeconomic database was carried out with a survey of private households surrounding Kakamega forest with questionnaires. The households did report their amounts and kind of energy demand as well as the energy supply. Additional demographic and economic data were inquired as well as information about livestock and fodder supply. Spot checks of wood collecting activities completed the survey. The socioeconomic survey was carried out in July and August 2002. The spot checks took place in February 2004. As a further parameter for quantifying the awareness of the population for consequences of the actual activities in the forest the degree of education was monitored. This was carried out on the one hand by the socioeconomic survey and on the other hand by monitoring the activities of a local environmental education initiative called Kakamega Environmental Education Program from 2001 to early 2004.

Establishment of Maseno Botanical Garden

With the provision of a 15-ha-compound from the Maseno University, Maseno, Kenya, in 2000 the foundation of the garden was laid in 2001 after the development of the ground and the construction of a fence. While creating the trails and clearing the area the establishment of the tree nursery and the creation of the experimental fields was conducted. At all times trees were added to the garden after an initial planting of over 100 tree species from the BIOTA research area in Kakamega. After the research activities already started with the establishment of the experimental fields its expansion was induced with the completion of the greenhouse and the office building with the herbarium where also the germplasm/seed collection was located.

Cooperations with other institutions

Kikuyu ethnobotany

The Jomo Kenyatta University, Kenya collaborated closely in this work. Part of the collaboration involved paying tuition fee for the PHD studies of Grace Njery Njoroge.

Analyses of regeneration strategies

In close cooperation with the herbarium of the University of Nairobi all vegetation surveys were conducted. In the framework of the survey a special collection of Kakamega plants was established in the herbarium. As a project partner the Botanical Garden of Maseno University was also highly involved in the project by providing infrastructure e.g. workspace and matters of transportation. The Botanical Garden was provided with tree seedlings of Kakamega forest and a drawing of a map of the Garden. The herbarium of the University of Nairobi was provided with stationary as well as 4 new herbarium cabinets and a database for herbarium specimens.

Investigating the use potential of forest ecosystems

The Botanical Garden of Maseno University supported this survey with matters of transportation. For the socioeconomic survey the chief of Kimbiri Location was very helpful. Besides the efforts to organize general BIOTA-meetings to inform the community, he also acted as a facilitator to enhance the acceptance of our work by the community. E12 supported these efforts with the provision of roof-building materials for the local church. The monitoring of the degree of education was conducted with support of the Kakamega Environmental Education Program (KEEP) and based on the membership in this association.

Establishment of Maseno Botanical Garden

There are close co-operations with Maseno University and related departments particularly concerning agriculture and horticulture and botany. In the field of *ex situ* propagation, particularly of endangered species the Maseno Botanical Garden has close relationships with KEEP to receive seed material and seedlings. The garden keeps the germplasm/seed material, improves it and makes it available for KEEP for further rare plant species enrichment programs.

2. Results

2.1 Scientific results

Kikuyu ethnobotany

So far ethnobotanical data has been collected in all the districts of central Kenya regarding plant usage and plant-bee interactions. With regard to ethnoanthecological investigations. 49 species in 30 plant families were documented as important food resources for honeybees. The most important families included Asteraceae 12.2% (6 species), Rosaceae, 6.1% (3 species) and Myrtaceae 6.1% (3 species). The traditional knowledge about the honey bee interaction with the plants was consistent and area specific. Among those interviewed in parts of Kirinyaga district 50% (14/28) agreed that *Musa paradisciaca* (Musaceae) is a important honey bee attractant plant while in case of *Caylusea abyssinica* (mȈ ra njȈ ki), 46% (13/28) indicated its importance. 61.5% respondents from Nyandarua district regarded *Eucalyptus*

(Myrtaceae) species as an important honey bee flora while 53.8% regarded *Dombeya burgessiae* (Sterculiaceae) as such. On the other hand *Croton megalocarpus* (Euphorbiaceae) was known by the majority (53.8%) as an important honey bee plant.

In response to the question on what the honey bees gain by visiting the various flowers, 85.5% agreed that the bees obtain food resources while 14.5% did not know. With regard to the question on the benefit of plant when they are visited by honey bees 41.9% affirmed that such plants benefit by increased fertility/production, while 58.1% did not know if the plants gained at all.

Concerning indigenous knowledge about medicinal plants about 34 families of weedy species were reported to be medicinal. Among these species the informant consensus was usually 0.5 and above. In discovery of new drugs from plants ethnobotanical investigations have been found useful. By using indigenous knowledge it is possible to increase chances for drug discovery by 400 times. In cases where random sampling is used in screening plants for drug discovery only one molecule in about 10, 000 samples has any hope of commercialisation.

Analyses of regeneration strategies

The seedling compositions of four key tree species (*Polyschias fulva*, *Funtumia africana*, *Croton megalocarpus, Olea capensis ssp. welwitschii*) as well as of the surroundings of the former tree stand on gaps have been reported. If we assume that certain trees occur in certain disturbance or succession stages, we can further assume that certain tree species can act as key species to characterize the disturbance state of their surrounding. *P. fulva* is a typical tree of very large openings or heavy disturbances, *F. africana* occurs in slightly disturbed forests or very small gaps, *C. megalocarpus* characterizes late secondary stages to natural forest, while *O. capensis ssp. weltwitschii* is a typical tree of the primary forest. 57 seedling composition plots have been reported for *C. megalocarpus*, 40 for *F. africana*, 41 for *P. fulva*, 29 for *O. capensis ssp. welwitschii* and 26 for Gaps. Structural data of the tree composition are reported from 8 random point quarter sampling transects with a total length of 1564 m for Kakamega forest and from 7 transects with a total length of 1208 m for Ngaia forest. The structural data are completed for the undergrowth by sampling 4 transects with a total of 197 subplots for recording the absolute number of individuals. One transect with 50 subplots is reported for Ngaia forest. To gain succession data the survey was completed by relevés after Braun-Blanquet on 30 Plots in Kakamega Forest, 39 Plots in Ngaia forest and 28 Plots from the Naro Moru area of Mt. Kenya.

From the history of the forest it is known that the southern parts of Kakamega forest have been much more influenced than the northern parts. In the present the threat on the southern forest parts is still high while the northern parts are quite good protected by the Kenya Wildlife Service. Only in the northern parts and particularly in remote areas, not accessible by trucks, some parts of natural forests can be assumed. Nonetheless the pristine natural forest can be assumed as completely vanished. The results of the survey reflect very well the assumption that the structural and species composition under a certain (key) tree species are related to the degree of disturbance. Under the assumption that the light conditions under the single key trees reflect the conditions in the certain disturbance stages we can expect that, first, the closer we are to the tree the more the light conditions are homogeneous and, second, the further we go away from a tree the light conditions become heterogeneous (Liebermann & Liebermann, 1992). Because of the design of the survey on circles around the key trees this hypothesis can be proofed and the relation of plots of different distances can be analyzed. By ignoring allelopathic effects the effect of the more heterogeneous light conditions appears to be likely but still has to be proofed. But the comparison of the patterns of all circles, as well as particularly the inner circles, fits very well with the assumptions of the disturbance states of the forest.

The approach for an assessment of the succession stages after disturbances with the structural data results in some clear distinguished stages while some stages in between can be assumed. For the assessment it is necessary to distinguish between heavy disturbances and slight disturbances or, to consider an indicator condition for succession, between dark gaps and light gaps. After an opening and an increase of light availability herbaceous plants are the first settlers. While representatives of the Acanthaceae- and Leguminosae-family are typical pioneers under less light conditions these families are marginal on big gaps where they occur actually on the shady margins. Light gaps are invaded very soon by creepers, mainly from the Curcubataceae- and Convolvulaceae-family followed immediately by shrubby and light wooded plants and woody plants with representatives from the Acanthaceae- and Solanaceae-family (for Kakamega forest mainly representatives of the Solanaceae-family, particularly *S. mauretianum* or *S. incarnum* and others). In the shade of these shrubs Leguminosae and light demanding tree seedlings can establish and form together with simultaneous growing woody shrubs the pioneer forest stage. It appears that in smaller openings also first secondary forest species can establish while in large openings they seem to grow only after the appearance of pioneer trees and the availability of descent shadow conditions. There might be a bias because of the inability of pioneer species to establish in smaller openings respectively lower light availability. It appears that only secondary species occur immediately after the herbaceous or low shrubby stages. It might be, that the herbaceous stage just endures longer and the secondary forest species appear temporary equal as on bigger openings. Only for large openings secondary species have to wait for the establishment of the pioneer stage. After the creation of suitable shadow conditions trees from the late secondary stages as well as primary forest trees can start growing either from waiting saplings or from fresh seedlings.

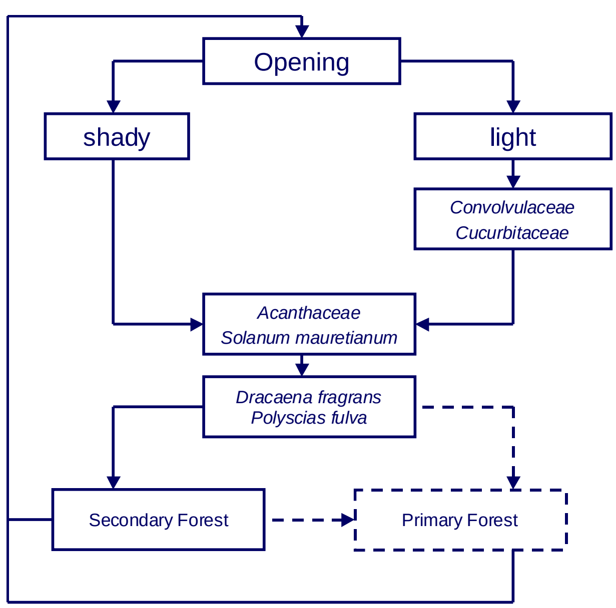

Fig. 1. Assessment of the regeneration cycle.

Investigating the use potential of forest ecosystems

For the socioeconomic survey respectively energy demand survey 201 households have been reported for their socioeconomic situation, demographic information and energy or potential forest resources demand. Let alone the fact that modern energy resources like electricity is hardly available for most of the people in rural areas the economic situation does not allow to use high price energy sources. About 46 % of the households rely only on the income from the farm while 41 per cent have additional income sources to support the household. About 11 % run a business as their main means of income. This is reflected also in the house construction and degree of education. While 82 % of the house constructions are based on wood and clay only 10 % can afford bricks for construction. Only 8.5 % of the 1406 persons in 201 households have visited school for more than 4 years. On average 7 persons live in a household. While all households use wood as their main energy source 10 % of the households also mentioned to use charcoal. 96 % of the households mentioned to use kerosene (paraffin). While kerosene is mainly used for lamps, wood and charcoal is mainly used for cooking and heating (Fig. 2).

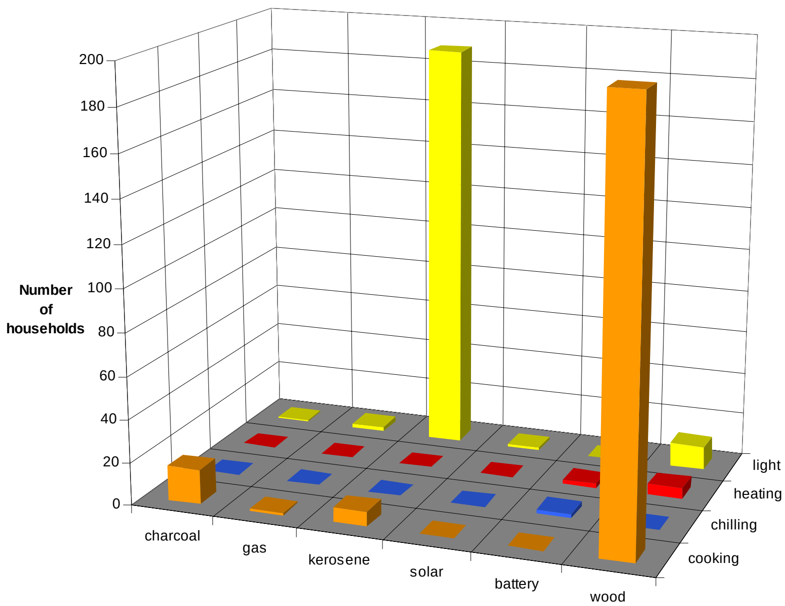

Fig. 2. Sources and usage of energy among households.

Even if the forest is protected by governmental organizations and the use of the forest is restricted respectively prohibited it is obvious that actually every household in the villages rely on forest products respectively wood. Regarding the area where almost all remaining trees belong to Kakamega forest and the fact that the households cannot afford high priced energy resources the origin of the wood can be easy assumed. With spot checks at every time in the day it is possible to watch people carrying wood out of the forest even where the forest is strictly protected. Even the people who have to protect the forest use the wood. Actually the rangers seem to be allowed to use the wood, which does not increase the appreciation of their service, by the population. Data from spot checks show, that 66 persons carried out 1978 kg of wood. That is on average 30 kg per person. Women are mainly observed carrying wood out (Fig.3), particularly the group of 18 to 40 year old women with 36 % and an average load of 44 kg (Fig. 4), followed by the group of 10 to 18 year group with 29 % and an average load of 24 kg.

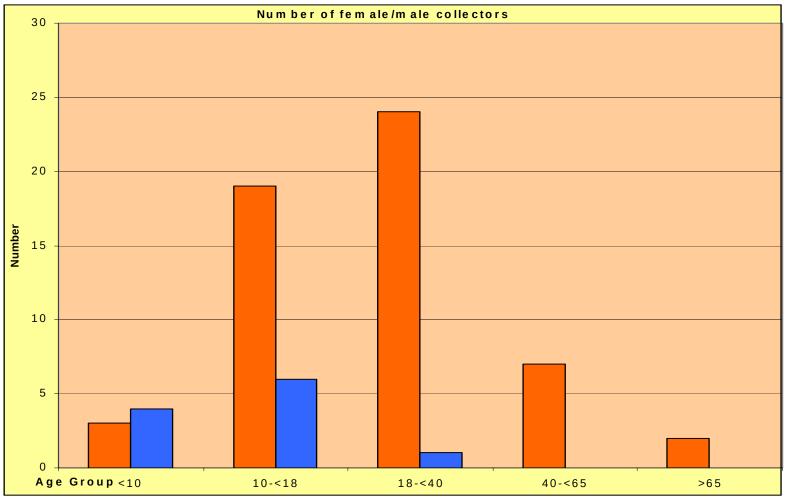

Fig. 3. Number of collectors by gender. orange: females; blue: males.

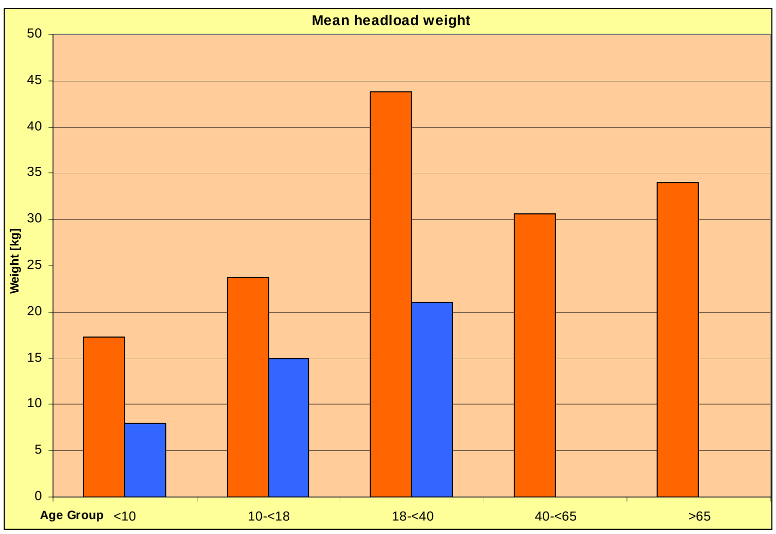

Fig. 4. Mean headload weight by gender (orange: females, blue: males).

Establishment of Maseno Botanical Garden

While the trees will need their time to grow the garden already shows its structures when the trails are finished. Benches invite people to stay at certain points and many labeled plants give not only information on scientific names but also tell the local names of plants to students and other visitors. While the tree walk around the garden needs its time other units can be seen in further stages, like the pond and the meadow or the vegetable fields. A herb garden welcomes the visitor at the entrance with important spices, local as well as exotic, and some ornamental plants. The tree nursery is producing steadily seedlings to plant in the garden but also supports the local community with surplus plants.

The experimental fields already yields drought-resistant vegetables used by the local people. The seed are distributed to the farmers to promote their use and help farmers to cultivate fields, which had been abandoned for use, particularly in dry years. Furthermore with the promotion of former used vegetables which had been hardly used in recent times because of the difficulties to grow them experience a revival. This does not only preserve this cultural treasure but also improves the diet of the local communities because of the better nourishment characteristics.

2.2 Interdisciplinary components

Together with Subproject E11 an experimental greenhouse has been established for germination and seed bank experiments. Further results from seedling survey will come out from cooperation with Subproject E03. A very close cooperation is conducted with the Maseno Botanical Garden. Here not only E12-related projects are conducted but also other projects use the greenhouse for experiments and are invited to use the infrastructure of the garden. A recent survey was conducted by E03 in cooperation with E12 to investigate germination of *Prunus africana* in different soil types. The garden received a digital and printed map of the garden from E12.

2.3 Likely benefit and applicability of results

Kikuyu ethnobotany

The ethnomedicinal data from this study will be of high significance for bio-prospecting programs. In addition the data provides a set of plants whose conservation status need to be given priority in future Kenyan conservation agenda. In regard to ethnoanthecological data, it is useful in restoration of honeybee and other pollinators habitats in the study area. Today pollinator decline is identified as a major threat to future food security. One of the causes of the decline has been identified as ignorance in pollinator management and protection among farming communities. Field information from this study has revealed the gap which need to be filled by raising awareness in pollinator conservation.

Analyses of regeneration strategies

The identification of basic regeneration strategies will help understanding the regeneration and succession processes. This knowledge leads to improved management strategies and can be useful for forest cultivation. Especially for conservation management the results give important information for planning and carrying out.

Investigating the use potential of forest ecosystems

With the knowledge about the energy demand and the likely pressure on the forest a better resource management is possible. The community as well as decision makers can profit from the recent inquiry to estimate the availability of resources and to answer the resources demand with alternative opportunities to secure future demands and for protection of the ecosystem. Compared with earlier inquiries more data for management tasks can be gained.

Establishment of Maseno Botanical Garden

The Maseno Botanical Garden gives the best opportunities for students and scientists from various institutes to learn and conduct research. But also non-academic people benefit from the garden where they learn more about useful plants and get information about the old knowledge about almost forgotten and still used medicinal and food plants. The surplus of the tree nursery and the seed bank is always available for the local community. The seed bank guaranties the conservation of genetic material and can help one day to reintroduce vanished plants and to increase biological diversity. The research activities in the garden lead to more robust plants and support the community with a higher variety in their diet which results in a better health and further in the conservation of traditional used plants. Apart from pure knowledge botanical gardens are also a fountain of recreation and support the approach of urban, but also rural, people towards nature.

2.4 Publications resulting from the project

Bussmann, R.W, Kiefer, S., Njeri, R., Njoroge, G., Mathenge, S., Mutiso, P. & Onyango, J. (2001). Montane forest ecosystems in Kenya – Diversity and potential for use. German Program on Biodiversity and Global Change, Report 2001, 170-171

Kikuyu ethnobotany

Njoroge, G.N; Gemmill, B.,Bussmann, R; Newton, L.E, Ngumi, V.W. (2000). Pollination ecology of the cucurbitaceae /cucurbits (case study at yatta, Kenya). National pollination initiative workshop. 14th Sept. 2000 National Museums of Kenya, Nairobi, Kenya.

Njoroge, G.N;.Bussmann, R; Gemmill, B; Newton, L.E, Ngumi, V.W. (2002). Pollination Ecology of Citrullus lanatus and way forward in African initiative. International pollinators initiative conference. ICIPE.

Njoroge, G.N; Gemmill, B.Bussmann, R; Newton, L.E, Ngumi, V.W. (2002). Using plants for health :indigenous knowledge of contemporary Kikuyu people (Kenya). Proceedings of the 8th International Ethnobiology congress. Addis Ababa, Ethiopia (16th-20th September, 2002).Abstract book pp. 54

Njoroge, G.N; Bussmann, R; Gemmill, B; Newton, L.E, Ngumi, V.W. (2003). Utillisation of weed species as sources of traditional medicine in Central Kenya: Optimising resource use efficiency in Agroecosystems. In Fernander et al (eds.) abstract book pp 229 Biodiversity Conservation Congress for the Andes and Amazonia, iv Ecuadorean Congress of Botany, August 25-30, 2003.

Njoroge, G.N; Bussmann, R; Gemmill, B; Newton, L.E, Ngumi, V.W. (2004). Phtotherapeutice resources in Central Kenya: an important component for homegardens and agroforestry systems in a changing society. In abstracts to the 9th international congress of ethnobiology. 13th – 17th June 2004, Kent University, Britain. Pg 88.

Njoroge, G.N; Bussmann, R (2004). Community education in thnophytotherapeutic resources conservation: An essential role of ethnopharmacology research for development of traditional communities in the 21st century. In abstracts to the 9th international congress of ethnobiology. 13th – 17th June 2004, Kent University, Britain. Pg 89.

G. N. Njoroge; B. Gemmill, R. Bussmann, L.E, Newton, V.W. Ngumi (2004). Pollination Ecology of Citrullus lanatus at yatta, Kenya. International journal of tropical Insect Science Vol. (24 No. 1): 73-77.

Analyses of regeneration strategies

Kiefer, S. & Bussmann, R.W. (in press). The meaning of regeneration strategies and anthropogenic influence for the forest expansion in East African montane forest ecosystems – a modeling approach. Lyonia.

Kiefer, S. & Bussmann, R.W. (2004). Using seedling distribution in different disturbance stages in Kakamega Forest, West Kenya as means for the characterization of regeneration strategies. Abstract, 47th IAVS Congress, Kailua-Kona, July 18-23, 2004, p. 98.

Kiefer, S. & Bussmann, R.W. (2003). The meaning of regeneration strategies and anthropogenic influence for the forest expansion in East African montane forest ecosystems – a modeling approach. Abstract in: Romero Fernández, L.M., Lucero Mosquera, H., Aguirre Mendoza, Z., Torracchi Carrasco, S., Suárez Calderon, J.P. & Bussmann, R.W. (Eds.) (2003). II. Congreso de la conservación de la biodiversidad en los Andes y en la Amazonia – IV. Congreso ecuatoriano de botánica, 25-30 de agosto de 2003, Loja, Ecuador. Volumen de resumenes, p. 212, Loja, UTPL

In prep.:

Kiefer, S. & Bussmann, R.W. : Characterization of regeneration strategies by using seedling distribution – a case study from Kakamega forest, W-Kenya.

Kiefer, S. & Bussmann, R.W. : The succession Cycle of Kakamega Forest, W-Kenya.

Kiefer, S. & Bussmann, R.W. : Comparison of vegetation and structure of Kakamega Forest, W-Kenya and Ngaia Forest, Central-Kenya.

Kiefer, S. & Bussmann, R.W. : Vegetation description of Ngaia Forest, Central Kenya.

Kiefer, S. & Bussmann, R.W. : The potential energy demand and challenges for forest management in the Kakamega area, W-Kenya.

Kiefer, S. & Bussmann, R.W. : The linkage of education and sustainable use of forest resources in Kakamega Forest, W-Kenya.

Establishment of Maseno Botanical Garden

Onyango, J.C., Bussmann, R.W. & Onyango, M.O.A. (2002). The university botanic garden, Maseno: a teaching centre for biodiversity management and germplasm conservation. Proceedings of African Botanic Gardens Congress: “Partnerships and linkages” Durban Botanic Gardens, South Africa. 24th to 30th November 2002.

Onyango, J.C., Nyunja, R.A.O. & Bussmann, R.W. (in press). Conservation of biodiversity in the East African Tropical Forest. Lyonia.

Onyango, J.C., Bussmann, R.W. & Abukutsa Onyango M.O., (2004). The Role of University Botanic Gardens in Environmental and Ethnobotanical Issues in Conservation in Kenya. Abstract 2nd International Botanic Garden Congress, Barcelona, April 16-22, 2004.

Onyango, J.C. & Bussmann, R.W. (2004). Ethnobotanical Issues in Biodiversity Conservation in the Tropics. Posterabstract, GTOE2004, Bayreuth, Germany, February 18-20.

Onyango, J.C., Bussmann, R.W. & Onyango, M.O.A. (2002). The university botanic garden, Maseno: a teaching centre for biodiversity management and germplasm conservation. Abstract, Proceedings of African Botanic Gardens Congress: “Partnerships and linkages” Durban Botanic Gardens, South Africa. 24th to 30th November 2002.

Onyango, J.C., Bussmann, R.W. & Abukutsa Onyango M.O. (2004). University Botanical Garden, Maseno. Conserving Biodiversity in the Tropics for Future Biotechnology Needs. Abstract, GTOE2004, Bayreuth, Germany, February 18-20.

Onyango, J.C., Nyunja, R.A.O. & Bussmann, R.W. (2003). Conservation of biodiversity in the East African Tropical Forest. Abstract in: Romero Fernández, L.M., Lucero Mosquera, H., Aguirre Mendoza, Z., Torracchi Carrasco, S., Suárez Calderon, J.P. & Bussmann, R.W. (Eds.) (2003). II. Congreso de la conservación de la biodiversidad en los Andes y en la Amazonia – IV. Congreso ecuatoriano de botánica, 25-30 de agosto de 2003, Loja, Ecuador. Volumen de resumenes, p. 266, Loja, UTPL.

3. Capacity building

3.1 Technical capacity building

Establishment of a herbarium for plants of Kakamega forest and Ngaia forest and programming and setting up of a database for the herbarium of the University of Nairobi.

Establishment of a botanical garden at Maseno University, Maseno, Kenya, with a greenhouse and a laboratory building. Provision of a herbarium, a germplasm/seed bank and a tree nursery.

3.2 Students and scientific staff trained

PhD Thesis: Grace Njery Njoroge, Jomo Kenyatta University, Botany Department, Kenya; Pollination ecology of watermelon and associated ethnobotany of the main pollinator.

PhD Thesis: Regina Nyunja, Maseno University, Botany Department, Kenya.

PhD Thesis: Stefan Kiefer, University of Bayreuth, Germany; Kakamega and Ngaia Forest, Kenya – Vegetation, regeneration and management under anthropogenic influences.

Field Assitant: Benson Bwibo Chituy, Buyangu, Kenya; Identification of seedlings and assisting seedling survey, interviewing of households for socioeconomic data.

Technical Assistant: Simon Gichuky Mathenge, Botanist, Herbarium University of Nairobi, Kenya; Identification of plants, assisting vegetation surveys and establishment of a herbarium.

Technical Assistant: Patrick Chalo Mutiso, Botanist, Herbarium University of Nairobi, Kenya; assisting vegetation surveys and establishment of a herbarium.

Technical Assistant: Peter Oweno, Technician, University Botanical Garden of Maseno, Kenya; coordination of planning and planting activities, support of research activities, coordination of the germplasm/seed bank.

Internship: Anna Konstanze Brecke, Technical University of Eberswalde, assisting vegetation survey, establishment of GIS data and drawing of a map for the Maseno Botanical Garden.

Biodiversity and ecology of palaeo-African refugia of the southern Arabian Peninsula

Subprojects E13-E16

The research of the Yemen Project Group focussed on relics of palaeo-African woodland ecosystems in the southern coastal mountains of the Arabian Peninsula and on the Yemeni island of Socotra. In contrast to the western mountains of the Arabian Peninsula little was known so far about these regions and their woodland ecosystems.

For their greatest part the southern mountains are desert-like, inhospitable, and consequently, sparsely inhabited, mainly by nomadic people. Only where higher mountain masses are directly exposed to the moisture-loaded winds from the Indian Ocean and where the topography is suitable, sea-facing escarpments receive – apart from erratic rains – fog precipitation throughout most of the year. Such fog oases have become refugia for relics of the more moist-demanding palaeo-African woodland ecosystems. Here they have survived heavy fragmentation during the post-Tertiary aridisation of the peninsula.

Such refugia are found only in the scattered coast-near promontories and have never been transformed by agriculture. Use of the woodland and forest resources by nomadic pastoral economies including extensive gathering of wood, forage and other natural products has been regulated by tribal law up to the most recent past. Far-reaching socio-economical changes have led since, however, to increasing overexploitation and conspicuous destruction.

Focusing on selected refugia along transect across the southern coastal mountains and also including Socotra island, the research of the four subprojects of the Yemen Project Group was dedicated to two main topics: (1) the assessment of the existing phytodiversity of the refugia – also in respect of conservation issues – and their environmental conditions; (2) the analysis of the biodiversity changes related to the fragmentation and including both a few selected examples of plants and animal species.

(1) *Assessment of the existing phytodiversity of the refugia and their environmental conditions*

Floristic and phytosociological analyses of the woodland and forest relics in the selected refugia along the transect [by E13], supplemented by ecological studies [by E14], allowed:

(a) The synsystematic classification (and thus the identification of phytogeographic affinities) of the different woodland and forest communities both on the mainland and along an altitudinal transect on the island of Socotra. This confirmed close affinities to the physiognomically similar communities of the Horn of Africa but revealed also peculiarities of the monsoon forest in the centre of the south coast and of all woodland types of the altitudinal transect on Socotra, which characterise them as unique communities with a particular demand for protection against overexploitation. Noteworthy are closer relationships of a single colline woodland type on Socotra with a corresponding mainland community.

(b) The reconstruction of the former principal woodland zonation in the southern coastal mountains of the Arabian Peninsula, which was less different than presumed earlier to that of the western mountains, since all principal woodland zones are or were also present, including the juniper zone. The relic of the former monsoon forest belt ranging from E tropical Asia to W tropical Africa, is however, unique to the southern mountains.

(2) *Analysis of the biodiversity changes related to post-Tertiary fragmentation*

On the basis of the phytodiversity assessment along the transect, it was a core aim of the Yemen Project Group to get access to an understanding of fragmentation processes. Therefore three levels of analysis were combined:

* *Phytogeography* [by E13] addresses biodiversity at the species (and vegetation) level. Distribution data of species from herbarium collections, field records and reliable literature data were processed in a GIS project.

* *Phylogeography* [by E15 + E16] addresses biodiversity at the population level in comparing the phylogeny of molecular markers (sequences, genetic fingerprints) with their spatial distribution in and among populations.

* *Population genetics* [by E15 + E16] also addresses biodiversity at the population level but concentrates on the consequences of fragmentation processes on the genetic diversity within and among populations by AFLP fingerprinting and microsatellite techniques.

Phytogeographic analysis revealed in particular two significant species distribution patterns: a western distribution pattern and an eastern distribution pattern in the southern mountain chain. They well correspond to the bifocal precipitation regime in the southern coastal mountains, with one maximum in the far west and another at the eastern end of the chain in the centre of the south coast. The corresponding pattern may be explained by a draw-back of species during arid phases to the eastern and western maximum of the precipitation.

On population level *phylogeographic analysis* obtained surprisingly similar results to those of the phytogeographic analyses in both examples of plant species (*Justicia areysiana, Maytenus senegalensis*, E 15) completed (and which seem to be paralleled by the single animal species having a comparable distribution range, *Reissita simonyi*, E 16). In both cases a distinct bipartition of the populations into a western and eastern group is observed, with non-overlapping chloroplast haplotype groups in the two subpopulations of the two species. It seems thus obvious that after that pronounced fragmentation, the populations of the two subareals never came into genetic contact again. On the contrary, both subpopulations eventually were further subdivided into smaller populations, presumably due to a further aridisation circle. On the other side, however, the joint occurrence of chloroplast haplotypes in most of the populations and population groups in the two subareals demonstrates that these populations were able to exchange individuals at certain (presumably more humid) periods. This interpretation is backed by palaeoclimatic data for the southern Arabian Peninsula: During the Pleistocene, periods of maximum glaciations in the northern hemisphere were tightly correlated with periods of a southward shift of the SW-monsoon and, consequently, with corresponding arid periods, while interglacial periods were characterised by monsoon positions comparable to the present.

First results from the *population genetic analyses* of the plant species *Justicia* and *Maytenus* demonstrate that the fragmentation did not necessarily reduce genetic diversity in small populations, since significantly lower values of genetic diversity were not observed in smaller populations when compared to larger ones. This is in contrast to findings in the flora of central Europe where fragmented populations are often found to have reduced diversity values caused by inbreeding effects. A possible explanation for this observation may be that the recurrent oscillations of population sizes in the southern Arabian Peninsula may have caused the species concerned to adapt to these fluctuations. A second interpretation may be that these climatic oscillations may have occurred on longer timer scales leaving the shrinking populations more time to adapt to the changed environment than central Europe plant populations. Results for the animal species *Reissita simonyi* and *Hyla savigny* are somewhat different and demonstrate high inbreeding effects in the highly fragmented populations, between which considerable genetic isolation exists, which increases also with the geographical distance between the populations.

Also regarding conservation issues, the phylogeographic analyses corroborate results of the phytogeographic investigations. Both reveal that the refugia of Kor Seiban and of Jabal Gedu exhibit the character of stepping stones or bridgeheads between the eastern (Hawf Mts, Dhofar) and western populations (Jabal Urays, western Yemeni mountains). Private genotypes only found in these areas point to the long isolation and independence of these populations. Therefore, in terms of conservation of this genetic and floristic diversity, implementation of a conservation management for these refugia should get high priority.

Subproject E13

Phytodiversity and vegetation of representative palaeo-African refugia in the southern coastal mountains and on Socotra, Yemen

Subproject leaders: PD Dr. H. Kürschner, Dr. N. Kilian, Freie Universität Berlin	
Short title: BIOTA E13	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

1.1. Aims

For the most time, the Arabian Peninsula and Africa had a common tropical flora and vegetation, since the Arabian Peninsula was separated from the African continent not earlier than in the Oligocene, 10-15 Mio years BP., and migration and exchange of the palaeo-African, Indo-Malayan and Mesogean floras had taken their course across Arabia. Due to the aridisation of the whole region in the late Tertiary, the tropical vegetation was forced into the south of the peninsula and into the climatically favoured mountains, fragmented and delimited to scattered refugia. These refugia today inhabit relics of woodlands and even forests and show strong affinities to the Somalia-Masai phytochorion of Africa, harbour mesic tropical elements and several endemic species.

The dominating palaeo-African element has been subject to a pronounced differentiation and speciation. Apart from isolation due to the continental drift, also isolation of taxa caused by fragmentation of the vegetation seems to play a considerable role with respect to the evolution of biodiversity. The palaeo-African refugia in southern Arabia and on Socotra are therefore perfectly qualified for investigating the significance of island-like vegetation complexes for the genesis and development of biological diversity.

In contrast to the fairly well-explored western mountains of the Arabian Peninsula, little so far was known about the refugia in the southern coastal mountains of Yemen and on the Yemeni island of Socotra (Fig. 1). The research of the Yemen Project Group therefore focused on these latter regions. Their xerotropical relict woodland vegetation has never been affected by agriculture but used by nomadic pastoral economies including extensive gathering of wood, forage and other natural products. Its use has been regulated by tribal law up to the most recent past. Far-reaching socio-economical changes have led since, however, to increasing overexploitation and conspicuous destruction.

The refugia in the southern coastal mountains and on Socotra largely depend on precipitation caused by condensation of moist air from the sea and thus constitute what have been termed fog oases by Troll (1935: "Nebeloasen"). Their vegetation and flora have never been subject of a more detailed study, habitat conditions and ecology were largely unknown. The distribution areas of most species were documented in a very fragmentary manner only and it had to be assumed that even a number of species were not yet described.

It was the aim of this subproject (1) to analyse and make and inventory of the phytodiversity (spermatophytes, pteridophytes and bryophytes) of these palaeo-African refugia, (2) identify and analyse their woodland vegetation phytosociologically, and (3) in combining the data from (1) and (2) to achieve a phytogeographic subdivisions of the southern coastal mountains. Combining these phytogeographical data with the data of the phylogeographic and population genetic analyses of the subprojects E15 and E16, we aimed at a better understanding of the fragmentation processes caused by aridisation, and a more profound assessment of the biodiversity along the transect with respect to conservation issues.

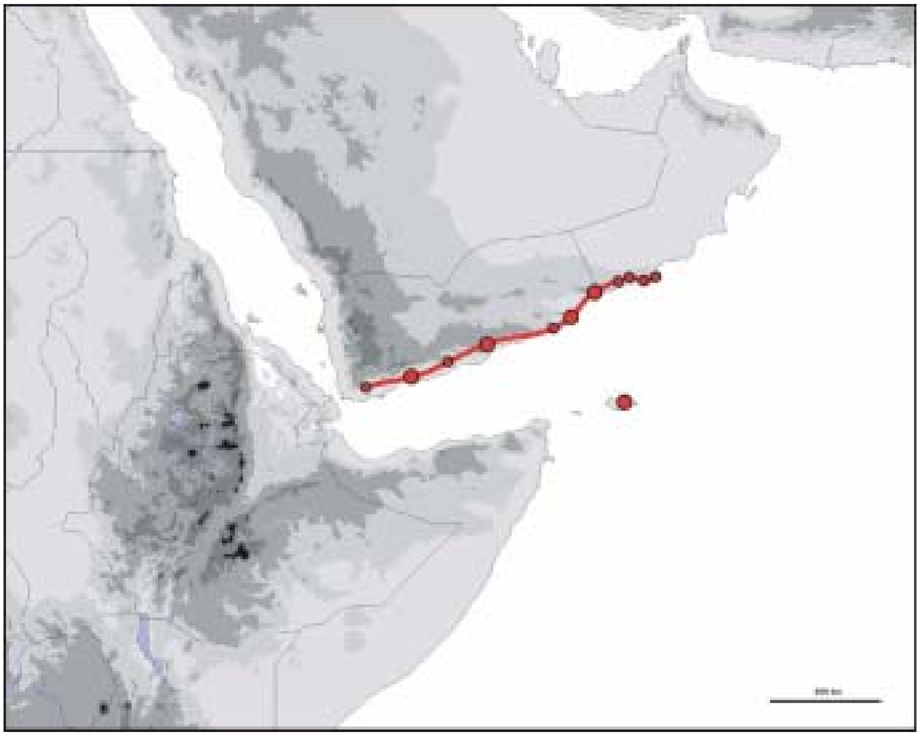

Fig. 1. Research transect of the Yemen Project Group across the southern coastal mountains of the Arabian Peninsula and also including the Yemeni island of Socotra. The five larger dots indicate the fog oases that were the main research areas; the smaller dots those that were studied to supplement the data from the former five.

Considering the threat posed by socio-economical changes to the biodiversity of the fog oases, the German-Yemeni project aims to provide an essential prerequisite to protect these unique xerotropical woodland ecosystems from irretrievable loss and conserve them also as an important natural resource for the local people.

1.2. Planning and conduction

To achieve these aims, the research of the Yemen Project Group has been conducted mainly along a transect across the southern coastal mountains and on Socotra (Fig. 1). The original plan was to survey altogether five refugia (shown by larger dots), which have been selected prior to the first project phase (see also Fig. 2). Later, two further fog oases were added for a better coverage of the southern mountain chain, but studied in less detail. Other additional sites have been studied in the Omani province of Dhofar, at the easternmost end of the southern mountains.

As had been planned originally, four field campaigns were conducted by subproject E13 between September 2001 and April 2003, partly in combination with other subprojects of the Yemen Project Group, so that each of the five main research areas was visited twice. Compared to the original plan the duration of the field work of four times four weeks was, however, increased by more than 25 % to a total of 152 days to compensate for the additional research sites and for unexpected time consume caused by logistic problems in areas of partly difficult access. Supplementary studies in the mountains of Dhofar were conducted during a one-week excursion in December 2002 by N. Kilian. The fieldwork of subproject 13 included:

- Vegetation surveys of woodlands and forest in the selected fog oases by using the phytosociological approach. Some 90 relevés were surveyed.

- Floristic investigation focusing on the selected fog oases but also including surrounding areas. About 5500 collection numbers (usually each with duplicates) of herbarium vouchers (vascular plants, bryophytes and lichens) were gathered, recorded and processed to document the phytodiversity and distribution of the taxa.

- Collection of the leaf material for the phylogeographic and population genetic analyses of subproject E15, altogether some 1140 samples.

According to the aims of the subproject, evaluation of the data gathered through the field campaigns concentrated (1) on the phytosociological classification of the woodland and forest vegetation in the investigated fog oases, and (2) on floristic, taxonomic and – for selected taxa – systematic analyses of the plant cover. Some results have been published as planned, others are in press or submitted, and some are still in preparation (see 2.4., below).

Fig. 2. Administrative division of Yemen (governorates) and the position (black marks) and names of the Yemeni fog oases studied.

1.3. Cooperations with other institutions

The main cooperation partner of subproject E13 has been the Agricultural Research and Extension Authority (AREA) of the Ministry of Agriculture and Irrigation of the Republic of Yemen. Research cooperation with this partner dates back to 1998 and, consequently, the subproject E13 and BIOTA Yemen Project in general was initiated and proposed in close consultation with AREA. The entire field work and part of the data evaluation has been done jointly with AREA, involving in particular: (a) the AREA Head Office in Dhamar (Dr. Ismael Muharram; Plant Genetic Resource Unit, GIS Unit), (b) the AREA research station in Mukalla (Dr. Mohamed A. Hubaishan; general project coordination in Yemen, transport logistics, field work in Hadhramout (including Socotra island), Shabwa and Al-Mahra, (c) the AREA research Station in El Kod (Dr. Ahmed S. Al-Zarri; field work in Abyan, Jabal Urays).

Further selective cooperation took place with following other Yemeni partners:

- Environmental Protection Authority (EPA) of the Ministry of Environment and Tourism, Head of in Sanaa (Dr. Mohmed El-Mashjary), Hadibu Office (Ahmed S. Sulaiman)

- The local department of the Ministry of Agriculture and Irrigation on Socotra (Said Masood Awad Al-Gereiri).

- Faculty of Natural Sciences, Aden University (Abdul N. Al-Gifri).

Cooperation has been established with Dr. Mike Thiv, University of Zürich with Prof. Linder, on the phylogeny and biogeography of south Arabian-Socotran endemics with molecular methods, in the frame of his project funded by the German Research Society (DFG), including joint field work, exchange of data and material, partly joint evaluation and publication of results (see 2.4., Thiv et al., submitted).

Cooperation regarding flora and taxonomy of the southern Arabian Peninsula and Socotra also exists with the Royal Botanic Garden Edinburgh, UK (Anthony G. Miller) and the Botanical Institute of the University of Uppsala, Sweden (Prof. Dr. Mats Thulin).

2. Results

2.1. Scientific results

Workpackage 1 – Woodland and forest communities in the southern coastal mountains of the Arabian Peninsula

A unique feature of the monsoon-affected central south coast is the existence, in the humid sites, of an *Anogeissus* forest or woodland in addition to the *Acacia-Commiphora* woodland. This drought deciduous, monsoon forest community in the fog oasis spanning Dhofar/Oman and eastern Al-Mahra/Yemen, had never been analysed in more detail. It has been described as the new association *Hybantho durae-Anogeissetum dhofaricae* (Kürschner et al., in press), and is characterized by the endemic Combretaceae tree *Anogeissus dhofarica* and can be classified in the East African Commiphoretea abyssinicae. Beside the typical variant that is restricted to the most humid sites, a broad-leaved variant with *Blepharispermum hirtum*, stocking on dryer sites can be distinguished. A phytogeographical-chorological analysis of the *Anogeissus* association corroborates its significance as a species-rich (up to 90 vascular plant species per 1000 m^2), unique, palaeo-African relict of a former continuous belt of xerotropical forests and woodlands, ranging in the late Tertiary from mainland Asia across the southern Arabian Peninsula to Africa (Kürschner et al., in press).

Additionally, an altitudinal form occurs, confined to the upper altitudinal range of the *Anogeissus* association. It lacks most of the broad-leaved, drought deciduous character species of the typical association and contains numerous evergreen Afromontane taxa, such as *Acokanthera schimperi*, *Euclea schimperi*, *Dodonea angustifolia*, *Tarenna graveolens* subsp. *arabica*, *Pyrostria phyllanthoidea*, *Pavetta longiflora*, which are character species of the Pistacio-Eucleetalia schimperi. In the north-western Fartak Mts. additionally *Olea europaea* subsp. *cuspidata*, *Jasminum grandiflorum* subsp. *floribundum*, *Rhamnus staddo*, which are character species of the Juniperion procerae are frequent between 780-950 m. This altitudinal form can thus be interpreted as relics of the Afromontane evergreen to semi-evergreen woodland zone, which mediate in the East African and West Arabian mountains between the drought deciduous thorny *Acacia / Acacia-Commiphora* woodlands at the lower elevations and the uppermost montane *Juniperus-Olea* forest or woodland zone (Kürschner et al., in press).

To the west of the monsoon fog oases in the central south coast, this Afromontane evergreen to semi-evergreen woodland zone has been found to occur in fragments across the transect to the west, but usually in a very contracted form. Outstanding in their rich species composition (with remarkable strong affinity to the corresponding woodlands of the North Somali mountains on the other side of the Gulf of Aden) are the evergreen woodland fragments on the Kor Seiban in Hadhramout (see Fig. 2), being with an altitude of 2100 m the highest of the southern coastal mountains. Worth to mention are such peculiarities as *Ceratonia oreothauma*, *Pappea capensis*, *Bauhinia ellenbeckii*, *Rhus glutinosa* subsp. *neoglutinosa*, *R. natalensis*, *Sideroxylon mascatense*, *Periploca somalensis*, *Celtis africana* (Kilian et al. 2002b, Kilian et al. 2004, Kürschner et al. in prep. 2). Outstanding in their extension – in spite of dramatic destruction during the most recent past – are the evergreen to semi-evergreen woodlands in the Jabal Urays range (see Fig. 2) at Maderan, which have not been known to science so far and have been studied by us for the first time in more detail (Kilian et al. 2004, Kürschner et al. in prep. 2).

A *Juniperus* zone, which is strongly fragmented (mostly by human activities) but present in the West Arabian mountains as far south as Jabal Eraf (see Fig. 2; Kilian et al. 2002b, Kürschner 2003c), was thought to be completely missing in the southern coastal mountains. However, fragments of an evergreen *Olea - Juniperus procera* woodland, which have been discovered by us in a fog oasis in Shabwa, 350 km east of the next population in the western mountains and starting at the spectacular low altitude of 750-800 m (Kilian & al. 2004), indicate a former (prehistoric?) occurrence of a fragmented *Juniperus* zone also in the southern coastal mountains (Kürschner et al. in prep. 2).

Other woodland types studied are species poor fragments of tropical riverine woodlands, which have for the first time been reported from the southern coastal mountains (Kilian et al. 2004) and the *Sterculia arabica* woodland, which occurs on lower sea facing escarpment slopes if some fog precipitation is available, and which shows a remarkably close relationship to the corresponding zone on Socotra island (Kürschner et al. in prep. 1+2).

Workpackage 2 – Mountainous woodland and forests communities of northern Socotra island

Following consultations with both the Head Office in Sanaa and the local office in Hadibu of the Environment Protection Authority (EPA), and also considering the most recently published "Final Report: Target Areas" of the EU project "Conservation and sustainable use of the Biodiversity of the Soqotra Archipelago", a transect across the northern escarpment of the Haggier Mts., ranging from the lower Wadi Ayhaft up to the Skant area and from the colline to the highest montane zone of the island, from 200-1500 m altitude, was selected. The area includes the richest, best preserved but hardly investigated woodlands of the island. The woodlands in the lower montane and colline zone are endangered due to their proximity to Hadibu, the main settlement and economic centre of the island. As we realised, when comparing the woodlands of this research transect with the other woodlands on the island, they provide the key to the understanding of the entire woodland vegetation of Socotra.

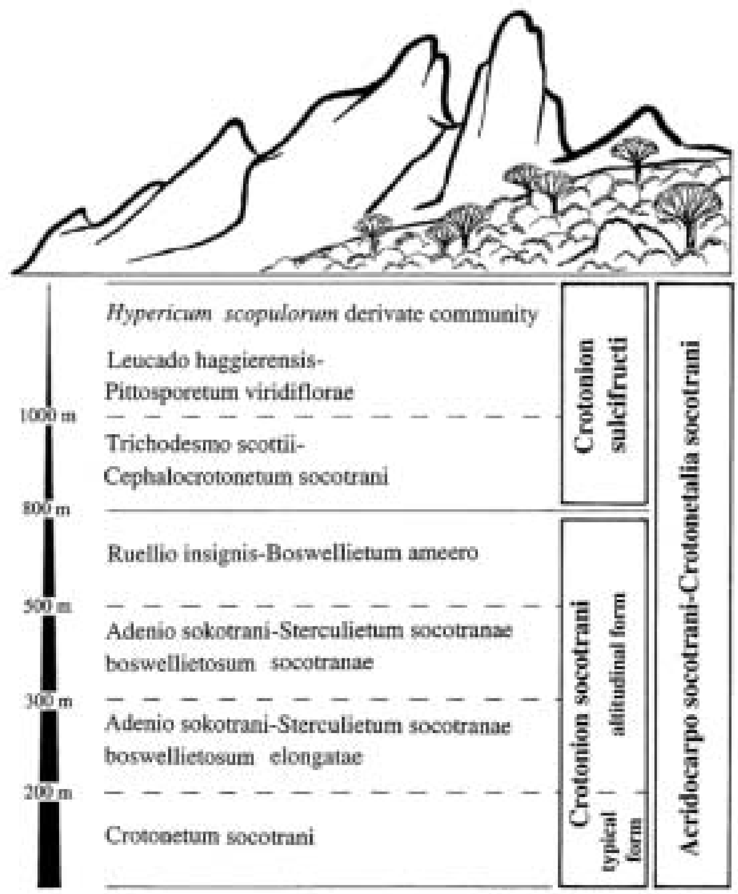

Fig. 3. Idealized altitudinal zonation of the woodlands in northern Socotra along a transect from the colline zone to the highest mountains.

An overview over the altitudinal zonation (Kürschner et al. in prep.1) gives Fig. 3. The most xeric and lowest north facing altitudes are covered by drought-deciduous *Croton* shrubland (*Crotonetum socotrani*) lower than 2 m in high. On rocky limestone slopes it is replaced by the open succulent woodland (Adenietum sokotrani), which is well known for its caudex succulents *Adenium obesum* subsp. *sokotranum* and *Dendrosicyos socotrana*. Above an elevation of 200 m, these communities are replaced by floristically very rich semi-deciduous woodland of the Adenio sokotrani-Sterculietum socotranae, characterised by the emergents of *Sterculia africana* var. *socotrana*, and which physiologically is nearly identical and floristically closely related to the *Adenio obesi-Sterculietum arabicae* of the more humid escarpments in the southern coastal mountains (Kürschner et al. in prep.2). At about (450-) 600-700 m, the altitudinal zonation exhibits a major change, which is supported by a change from calcareous to granitic substrate, by a change in the floristic composition and by physiognomic changes from drought-deciduous to mesic/humid semi-evergreen to evergreen woodlands and forests. Synsystematically this change is reflected by a classification of the woodlands into to different alliances, the *Crotonion socotrani* below and the *Crotonion sulcifructi* above this border. Immediately above this border the slopes are covered with a species-rich semi-evergreen forest (*Ruellio insignis-Boswellietum ameero*), which is remarkable in appearance for its many attractively flowering tree species (among them the *Dirachma socotrana*, one of the two species of a family *Dirachmaceae* restricted to the Horn of Africa and Socotra, and only occurring in this forest type). The highest altitudes (above 800-900 m) are naturally covered by almost impenetrable evergreen woodland, which is today frequently opened or replaced by anthropogenous dwarf shrubland or grassland. Two zones can be distinguished: a lower one ((800-) 900-1350 m) with the *Trichodesmo scottii-Cephalocroton socotrani* association, a higher one (1350-1520 m) with the *Leucado haggirensis-Pittosporetum viridiflorae* association. The latter one is remarkably rich in epiphytic bryophyte communities (Kürschner 2003a, 2004b), obviously because of strong fog precipitation.

Workpackage 3 – Diversity and phytogeography of vascular plants in the palaeo-African refugia of the southern coastal mountains of the Arabian Peninsula and on Socotra

(1) The *vascular plant flora* of the southern coastal mountains of Yemen was very incompletely known until the end of the 20th century. The floristic work and the intensive collecting activities along the research transect across the southern coastal mountains has considerably improved our knowledge of its flora. In four papers (Kilian & Hubaishan 2002, Kilian et al. 2002a, Kilian et al. 2002b, Kilian et al. 2004) one new species and 167 new and noteworthy records have been published from the southern coastal mountains, among them 12 records new to and two confirmed for the Arabian Peninsula. Other putatively new species of *Euphorbia* and *Ledebouria* await description. The emphasis of our work on Socotra was put on the analysis of the woodland vegetation (see workpackage 2), whereas floristic investigation was mainly limited to the needs of the phytosociological surveys. Our research on Socotra nevertheless also revealed a number of phytogeographically significant range extension of species, including single new records for the island (Kilian et al. in prep.).

(2) On the basis of an improved floristic knowledge and ample material, *taxonomic and systematic investigations* of a few selected taxa have been undertaken, either in the frame of diploma or doctoral theses (see 3.2.), or in cooperation with other scientists beyond the Yemen Project Group (see 1.3.). The taxa were chosen for the reason that they are in need of revision and/or clarifying their systematics helps to understand the phytogeography and fragmentation history in the region:

(a) The (micro)morphological study in the frame of a diploma thesis of the taxonomy and phylogeny of *Anogeissus*, a genus of eight species that are important components of palaeotropical monsoon forests, and with two species present on the Arabian Peninsula, revealed – as a preliminary result – that the genus originated in South Asia, its species are very closely related indicating a fairly young speciation, and that the dominating monsoon woodland species on the Arabian Peninsula has its closest affinities to South Asia rather than to Africa, providing additional evidence for the mediating position of the Arabian monsoonal forests between South Asia and tropical Africa (Hohlstein 2004). Morphological data are being supplemented by nr DNA sequences (ITS).

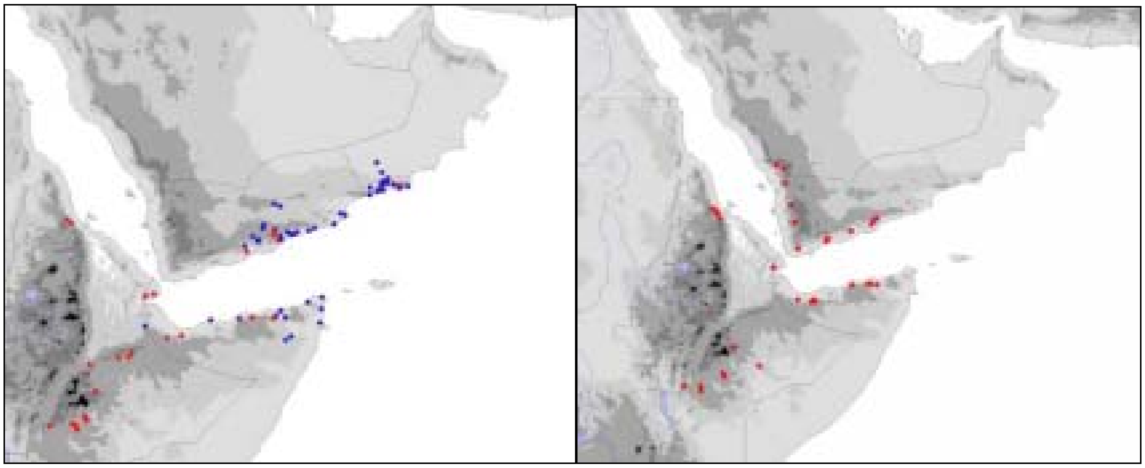

Fig. 4. Common distribution pattern of species in the southern coastal mountains – left: eastern elements, *Boswellia sacra* and *Pappea capensis*; right: *Tarchonanthus camphoratus*.

(b) The taxonomic revision and (micro)morphological phylogeny in the frame of a diploma thesis on the tiny succulent herbs of the palaeotropical *Portulaca* sect. *Neossia* revealed range extensions of East African species to the Arabian Peninsula (Kilian et al. 2004), new diagnostic micromorphological characters and also the monophyly of but not the relationships within this section (Kipka 2004). An additional molecular analysis (ITS) under way is expected to clarify these.

(c) Initially focusing on the relationships of the enigmatic south Arabian endemic genus *Dhofaria* (Capparaceae), a doctoral thesis on the Old World Capparoideae using morphological, anatomical and molecular data is elucidating the Arabian-African relationships within this subfamily (Rabe in prep) .

(d) A taxonomic revision of the genus *Helichrysum (Compositae)* with several new species in cooperation with the Royal Botanic Garden Edinburgh is under way (Kilian & Miller in prep).

(e) A molecular phylogeny of the palaeotropical genus *Aerva* Forssk. (Amaranthaceae), to which was contributed by subproject E13, revealed further evidence for the dominating Eritreo-Arabian affinities of the Socotran flora (Thiv & al. submitted).

(3) Phytogeography, addressing *distribution patterns and geographic affinities*, in the southern coastal mountains plus Socotra, at the species and vegetation level, forms part of a joint approach of the subprojects E13 and E15 to get a better understanding of fragmentation processes, by combining three levels of analysis (a) phytogeography [E13], (b) phylogeography [E15] and (c) population genetics [E15]. Processing the distribution data of species from herbarium collections, field records and reliable literature data in a GIS project, using the software DIVA-GIS, we revealed a few characteristic distribution patterns. Two frequent patterns, one of a western distribution in the southern mountain chain (Fig. 4 right), and one of an eastern distribution in this mountain chain (Fig. 4 left), exactly parallel the patterns found by E15 (and by E16 on the single comparable example) on the population level, where eastern and western populations show different genotypes and different

quantities of genetic diversity. The combined data thus strongly indicate a bifocal distribution of biodiversity both on genetic and species level as a result of a principle fragmentation in a western and eastern sector, with events of re-migration towards west or east, respectively. The Kor Seiban, as the highest mountain of the chain and being situated roughly in its centre, apparently plays the role of a bridgehead for several taxa and populations.

Workpackage 4 – Diversity, phytogeography and phytosociology of bryophytes in the palaeo-African refugia of the southern coastal mountains of the Arabian Peninsula and on Socotra

Our knowledge of the bryophyte flora of mainland Yemen and Socotra island is still very incomplete and despite various collecting activities, the country appears to be bryologically undercollected. As a first step towards a better understanding of this neglected group of plants and to act as a stimulus for future bryological research, the Bryophyte Flora of the Arabian Peninsula and Socotra (Kürschner 2000) was published, listing 103 taxa (one hornwort, 31 liverworts, 71 mosses) for the Yemeni mainland. The bryophyte collecting activities within the subproject E13 has resulted in a new species (Bruggemann-Nannenga & Kürschner 2004) and a number of new records (Kürschner et al. 2001, Kürschner 2003a-d, Kürschner & Ochyra 2003, 2004, Kürschner & Sollman 2004), which increased the bryophyte flora of mainland Yemen for 31 to 134 species (one hornwort, 39 liverworts, 94 mosses). To the hitherto known bryophyte flora of Socotra 26 species could be added after two field campaigns in 2002 and 2003 (Kürschner 2003a,d), increasing the hitherto known number of species to 74 (one hornwort, 30 liverworts, 43 mosses). Many of the new species are tropical elements, emphasising the tropical nature of the mountainous refugia along the south coast and on Socotra, and for many bryophyte species the new records constitute a considerable range extension.

Even poorer than our knowledge about the bryophyte flora is that about bryophyte communities. Such bryophyte communities have been studied phytosociologically both in the mainland and on Socotra. The epiphytic bryophyte community in the southernmost *Juniperus* stand in the western mountains could be shown to be the same as in the northern stand in Saudi Arabia, supporting their common origin (Kürschner 2003c). A remarkable bryophyte community of liverworts has been described from one blank soil in the Jabal Ureys mountains (Kürschner 2003b). The phytosociological survey of the woodland zonation on Socotra has been supplemented by surveys of the epilithic and epiphytic bryophyte communities, and it could be shown that the bryophyte communities parallel the woodland zonation (Kürschner 2004b and in prep).

2.2. Interdisciplinary components

Subproject E13 has chosen the fog oases along the transect to serve as common research sites for all four subprojects of the Yemen Project Group and opened them up logistically for the parts of the field work of subprojects E14 and E16 to be done there.

A particular close cooperation was established already during the planning period with subproject E15. This cooperation ranged from the selection of species to be analysed phylogeographically and population genetically, which was done jointly in the planning phase, over the sampling work in the field, which was done partly by E13 itself, partly by the scientists of E15 on the budget of E13 and jointly with scientists of E13, to the comparison and discussion of the data on geographical patterns of genetic diversity on population level as revealed in the analyses of E15 with the data of E 13 on the geographical distribution pattern of the species in the mountain system studied. Joint publications of results of both subprojects reflect this cooperation (Meister et al., submitted, and Meister et al. 2002, Oberprieler et al. 2003).

A population genetic analysis of the core tree species of the monsoon forest in the fog oasis of Al-Mahra and Dhofar, *Anogeissus dhofarica*, has been developed during this phase as a joined project between E13 and E15, to answer the crucial questions on the age of the fragmentation of this monsoon forest and the genetic diversity and fitness of the occurring small forest and woodland fragments. This joint project was funded independently of the BIOTA project.

The close cooperation with the Yemeni partner of AREA linked the research of subproject E13 tidily to the concerns of the local economies, which essentially are based on livestock. The Yemeni partners of AREA investigated the quality and intensity of the use of the biodiversity by the local communities in the fog oases studied, and made first evaluations of potentials, required measurements and problems to be solved for a limitation of the use of the natural resources to sustainability. This has enabled us to provide recommendations (in preparation) to the regional authorities for the development of the rural economy in the areas of concern, under consideration of nature conservation issues.

2.3. Likely benefit and applicability of results

The studied moist-demanding woodland and forest resources in the southern coastal mountains and on Socotra are all threatened by the economic pressure of a growing local population and their livestock. During the last decade, the formerly rather moderate use of the natural resources governed by tribal laws has changed into an increasing overexploitation. Destruction and devastation of woodlands and forests is immense. Our research activities, about which we have informed the local, regional and national administrations by several reports, have already led to increased awareness among the decision makers, and our results provide essential prerequisites for measurements towards a protection and sustainable use of these resources. Regarding the unique monsoon forest in the central south coast, we are initiating a subsequent, interdisciplinary project aiming at establishing a protected nature reserve. Regarding the northern woodland transect on Socotra, its analysis was done in agreement with the administration of the biosphere reserve on the island, to scientifically evaluate their value and to support the existing protection efforts.

The herbarium collections from the southern governorates of Yemen brought together prior to and during the project belong to the most important ones worldwide, and provide a sound base for various research purposes, from floristic or taxonomic to systematic and applied ones, as e.g., a most recent chemical investigation of *Boswellia* resin (frankincense) acids by J. H. Bergmann (Dep. Chemie, TU München), which was based to an important part on our documented collections.

2.4. Publications resulting from the project

Publications in refereed journals

Bruggemann-Nannenga, M. A. & H. Kürschner (2004): *Fissidens ellipticoides* spec. nov. (Fissidentaceae, Bryopsida), and three new Fissidens records for the Arabian Peninsula. – Additions to the bryophyte flora of the Arabian Peninsula and Socotra 7. – J. Bryol. 26: 107-111.

Kilian, N. & Hubaishan, M. A. (2002): *Tephrosia dura*, Leguminosae. – Curtis's Bot. Mag. 19: 241-246.

Kilian, N. & Miller, A. (in prep.): Studies in the Compositae of the Arabian Peninsula and Socotra – 6. Helichrysum (Gnaphalieae) on Socotra, Yemen.

Kilian, N., Hein, P. & Bahah, S. O. (2002a): A new species of *Campylanthus* (Scrophulariaceae) from Ras Fartak, Al-Mahra, and notes on other species of the genus in Yemen. – Willdenowia 32: 271-279.

Kilian, N., Hein, P. & Hubaishan, M. A. (2002b): New and noteworthy records for the flora of Yemen, chiefly of Hadhramout and Al-Mahra. – Willdenowia 32: 239-269.

Kilian, N., Hein, P. & Hubaishan, M. A. (ed.) (2004): Further notes on the flora of the southern coastal mountains of Yemen. – Willdenowia 34: 159-182.

Kilian, N., Hein, P. & Hubaishan, M. A. (in prep.): On the chorology and phytogeography of the vascular plant flora of Socotra.

Kürschner, H. (2003a): Further new bryophytes from Socotra and the Yemen mainland, including *Papillaria crocea* (Hampe) A. Jaeger (Meteoriaceae, Bryopsida), a palaeotropical Asian species. – Additions to the bryophyte flora of the Arabian Peninsula and Socotra 3. – Nova Hedwigia 76: 257-267.

Kürschner, H. (2003b): The *Riccietum jovet-astii – argenteolimbatae* ass. nov. of the Jabal Arays area, Yemen – life strategies of a remarkable xerotropical African bryophyte community. – Nova Hedwigia 76: 399-413.

Kürschner, H. (2003c): Epiphytic bryophyte communities of southwestern Arabia – phytosociology, ecology and life strategies. – Nova Hedwigia 77: 55-71.

Kürschner, H. (2003d): Nineteen new records to the bryophyte flora of Socotra island. – Willdenowia 33: 445-458.

Kürschner, H. (2004a): Intracapsular spore germination in *Brachymenium leptophyllum* (Müll. Hal.) A. Jaeger (Bryaceae, Bryopsida) – an achorous dispersal phenomen. – Nova Hedwigia 78: 447-451.

Kürschner, H. (2004b): Phytosociology, ecology and life strategies of a remarkable epiphytic bryophyte community of Socotra Island, Yemen. – Bot. Jahrb. Syst. 125: 377-395.

Kürschner, H. (in prep.): Syntaxonomy, synecology and life strategies of a saxicolous bryophyte community on Socotra Island, Yemen. – Englera

Kürschner, H. (in prep.): The bryophyte flora of the Socotra arquipelago. – Englera.

Kürschner, H. & Ochyra, R. (2003): *Erpodium glaziovii* (Erpodiaceae, Bryopsida) and further novelties from the Arabian Peninsula. Additions to the bryophyte flora of the Arabian Peninsula and Socotra 4. – Willdenowia 33: 205-210.

Kürschner, H. & Ochyra, R. (2004): Remarkable new records to the bryophyte flora of Yemen (al-Mahra and Socotra Island). Additions to the bryophyte flora of the Arabian Peninsula and Socotra 6. – Cryptogamie, Bryol. 25: 69-81.

Kürschner, H. & Sollman, P. (2004): New and noteworthy bryophyte records for the flora of Yemen. Additions to the bryophyte flora of the Arabian Peninsula and Socotra 8. – Willdenowia 34: 301-308.

Kürschner, H., Hein, P., Kilian, N. & Hubaishan, M. A (in press): The *Hybantho durae-Anogeissetum dhofaricae* ass. nova – phytosociology, structure and ecology of an endemic South Arabian forest community. – Phytocoenologica

Kürschner, H., Hein, P., Kilian, N. & Hubaishan, M. A (in prep.1): A phytosociological study of the mountainous woodlands and forests of northern Socotra. – Englera.

Kürschner, H., Hein, P., Kilian, N. & Hubaishan, M. A (in prep.2): A phytosociological study of the fragments of evergreen and semi-evergreen woodland in the southern coastal mountains of the Arabian Peninsula.

Meister, J., Hubaishan, J. A., Kilian, N. & Oberprieler, C. (submitted): Chloroplast DNA variation in the shrub *Justicia areysiana* Deflers (Acanthaceae) endemic to the monsoon affected coastal mountains of the Southern Arabian Peninsula. – Molecular Ecology.

Sipmann, H. J. M. 2002: Lichens of mainland Yemen. – Willdenowia 32: 127-135.

Thiv, M., Thulin, M., Kilian, N. & Linder, H. P. (submitted): Eritreo-Arabian affinities of the Socotran flora as revealed from the molecular phylogeny of Aerva Forssk. (Amaranthaceae). – American Journal of Botany.

Publications in non-refereed journals, Posters, Abstracts, Status reports, etc.

Kilian, N. & Fischer, K. (2004): Ein Feuerquirl aus Sokotra. – Museums-Journal Berlin 18(3): 88.

Kilian, N., Hein, P. Hubaishan, M. A. & Kürschner, H. (2001): Aridisation and habitat fragmentation in South Arabia, 1. Biodiversity of paleo-African refugia in southern Yemen (BIOTA E13). – BIOLOG Status Seminar 2001, Bonn, 4.-7. Dezember 2001, Poster.

Kilian, N., Hein, P. Hubaishan, M. A. & Kürschner, H. (2001): Phytodiversity and vegetation types of representative paleo-African refugia in the coastal mountains of southern Yemen and on Socotra (Republic of Yemen). Project BIOTA East Africa, Yemen E13. – Pp. 174-175 in.: Anonymous (ed.), BIOLOG, German Programme on Biodiversity and Global Change (Phase 1, 2000-2004), Funded by BMBF. Status Report 2001. – o.Ort.

Kilian, N., Hein, P. Hubaishan, M. A. & Kürschner, H. (2002): Phytodiversity and ecology of palaeo-African refugia in southern Arabia: *Anogeissus dhofarica* woodland in Yemen. – Sixth Plant Life of Southwest Asia Symposium, Van, 10.-14. Juni 2002, Poster.

Kilian, N., Hein, P. & Kürschner, H. (2002): Abstract: Phytodiversity and ecology of palaeo-African refuge areas in southern Arabia: *Anogeissus dhofarica* woodlands. – P. 83 in: Anonymus, Sixth Plant Life of Southwest Asia Symposium, 10-14 June 2002, Van, Turkey; Programm & Abstracts. – Van.

Kilian, N., Hein, P., Hubaishan, M. A. & Kürschner, H. (2003): Biodiversity and ecology of plaeo-African refugia in southern Arabia and on Socotra (Republic of Yemen) – Phytodiversity and vegetation types. BIOTA East Africa (E13) [Status Report]. – Pp. 124-125 in: Anonymous, Sustainable use and conservation of biological diversity. A challenge for society, International Symposium 1-4 December 2003, Berlin. Symposium Report, Part A. – o.O.

Kilian, N., Hubaishan, M. A., Hein, P. & Bahah, S. A. (in prep., invited contribution): Status of the endangered Indo-Malayan relic fan palm *Livistona carinensis* in Yemen. – Palms. Journal of the International Palm Society.

Meister, J., Kilian, N., Hubaishan, M. A. & Oberprieler, C. (2002): Phylogeographical studies in monsoonal woodland refugia of the coastal mountains in the Southern Arabian Peninsula. – Symposium of the Nationaal Herbarium Nederlands, 13.-15.11.2002, Leiden, Poster.

Meister, J., Kilian, N., Hubaishan, M. A. & Oberprieler, C. (2002): Phylogeographical studies in monsoonal woodland refugia of the coastal mountains in the Southern Arabian Peninsula. - In:

Anonymous (ed.), Plant species-level systematics - patterns processes and new applications, Symposium of the Nationaal Herbarium Nederlands, 13.-15.11.2002, Leiden.

Oberprieler, C., Kilian, N., Kürschner, H., Mies, B., Naumann, C. M., Hubaishan, M. A., Nashr, A. K., Hein, P., Klütsch, C., Meister, J., Rabe, K. (2003): Habitat fragmentation in Southern Arabia: Xerotropical ecosystems at their outer limits; Abstract. – P. 56 in: Anonymous (ed.), Gesellschaft für Tropenökologie e.V., Tagungsband, 16. Jahrestagung in Rostock, Tropische Biodiversität im globalen Wandel, 19.- 22. Februar 2003. – [Rostock]. Abstract.

Rabe, K. (Konzeption) (2004): Inseln in der Wüste – Botanische Forschung im Jemen. – Ausstellung in der Galerie des Botanischen Museums Berlin-Dahlem vom 16. September bis 14. November.

Diploma and doctoral theses

Hohlstein, G. (Abschluss 2004): Revision und phylogenetische Analyse der Gattung *Anogeissus* (Combretaceae, Myrtales, Rosidae) mittels morphologisch-anatomischer Daten

Kipka, S. (Abschluss 2004): Phylogenie von *Portulaca* sect. *Neossia* (Portulacaceae). – Diplomarbeit FU Berlin.

Rabe, K. (laufend): Phylogenie der altweltlichen Capparoideae auf der Basis morphologischer, anatomischer und molekularer Merkmale – Dissertation FU Berlin.

Reisch, M. (Abschluss 2002): Untersuchungen zur Gliederung und floristischen Struktur der südarabischen *Anogeissus dhofarica* Wälder.

3. Capacity building

3.1. Technical capacity building

The two 4-W-drive cars, which were bought second hand for the project in 2001, were left to the main cooperation partner, the Research Station in Mukalla of the Agricultural Research and Extension Authority (AREA) – Eastern Coastal Branch.

3.2. Students and scientific staff trained

Training and assistance have been provided to Omar Saleh Bahah and Nadja G. Mohamed of the scientific staff of the Research Station in Mukalla of the Agricultural Research and Extension Authority (AREA) – Eastern Coastal Branch to build up a local reference herbarium for the work of the various applied projects dealing with farming and rangeland management. The training has also been supported by providing basic literature.

The following German students and postgraduates, all of the Freie Universität Berlin, have been trained, both in the field and indoors, in either floristic, taxonomic and systematic research or in phytosociological research:

- Markus Reisch, diploma thesis, phytosociological research.
- Gesche Hohlstein, diploma thesis, floristic, taxonomic and systematic research.
- Simone Kipka, diploma thesis, floristic, taxonomic and systematic research.
- Katharina Rabe, doctoral thesis, floristic, taxonomic and systematic research.

Subproject E14

Ecological causes of biodiversity in the coastal mountain ranges of southern Yemen and Socotra

Subproject leader: PD. Dr. B. A. Mies, Prof. Dr. G.B. Feige, Universität Duisburg Essen	
Short title: BIOTA E14	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

Due to the aridisation of the Arabian-North-East African region during the late Tertiary, the palaeo-African vegetation was forced into the southern part of the Arabian Peninsula where it became isolated from that of the African continent. With increasing aridity of the region, the vegetation gradually became fragmented and restricted to refuge areas. In the monsoon-affected mountainous areas on the south coast of the Arabian Peninsula and on the island of Socotra, such island-like relict vegetation complexes, rich in endemics and with close floristic affinities to NE tropical Africa, have survived up to the present day. They are bioclimatically and ecologically conspicuously differentiated, and comprise shrub formations, as well as various deciduous and semi-deciduous woodlands.

A detailed examination of the vegetation of these important refuge areas was lacking, and neither was there an adequate description of the habitats and ecology. According to our observations, the study areas at Al Mahra (eastern Yemen) and on Socotra comprise an outstandingly rich and well-conserved xerotropic relic vegetation (Fig. 1).

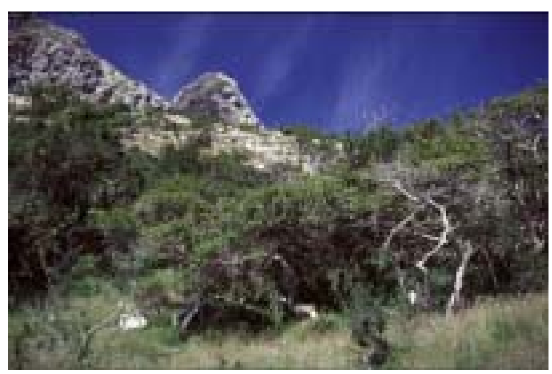

Fig. 1. (a) Dense indigenous forests at Dixam on the Northern Hajhir Range, Soqotra (no.8329), **(b)** Patchy *Rhus thyrsiflora* stands on a cow meadow at Adho Demalu, Hajhir, Soqotra (no.9335)

The main aim of the vegetational studies was to examine general patterns of xerotropical plant cover in these areas, and also to investigate morpho-functional adaptations of individual species. These studies allowed an assessment of water economy, phytomass and specific productivity of the different vegetation types. In addition, pedological examinations gave more insight into the relationship between edaphic factors and vegetation development. The overall results of these studies should allow a proper assessment of habitat destruction and loss of biodiversity in the areas, and thus elucidated current desertification trends.

Furthermore, the studies provided a sound scientific basis for introducing an ecologically sustainable development. The evaluation of the landscape should help to assess the ecological potential of the natural resources and their sensitivity in response to the intensity of human use or exploitation (Fig. 1b). This evaluation also showed in cooperation with South Arabian projects within BIOTA which vegetation types are important or potentially important to the indigenous economy, the precise effects of anthropogenic degradation and currents threats to the ecosystems.

Planning and conduction

Field data surveys were conducted during six field trips, mostly in areas and localities common to all South Arabian sub-projects. Data on time-courses of the micro- and mesoclimate were obtained at Ras Fartaq, Hauf, Damqaut and in various localities in Soqotra Island. Dense stands of the dominant species *Anogeissus dhofarica* were examined at Hauf and Damquaut. At these two areas, field research focused on the comparisons of parameters inside and outside of the tree canopy. Ras Fartaq represents localities with very patchy, island like tree vegetation cover (Fig. 2). On the other hand, the mountains of Soqotra are still preserved with dense indigenous forests and shrubby thickets. Nocturnal dewfall was especially measured at all locations, in order to enable the quantification and to allow a modelling of water input into the vegetation. Studies in the micro- and mesoclimate within and outside of vegetation patches showed the valuable ambient conditions for seedling establishment and re-growth. Our Yemeni colleagues supplied with long-term climate data of a station in the foothills of the Djaul plateau at Ghayl ba Wazier and Seyun.

Fig. 2. Patchiness of vegetation on the Ras Fartaq promontory (no.10488)

Due to the even more minimized research budget at the starting point in March 2001, it was not possible at least to conduct the invaluable autecological measurements on the potentials of the dominating species in the laboratory glasshouses. Nevertheless, seeds and plant material were collected on each field trip, to be cultivated in the greenhouses of the Universities of Essen, Cologne and Bonn to conduct subsequent studies. The examination of physical and chemical soil characteristics is currently underway in the soil laboratory at the University of Essen, preliminary results on soil compression and denudative erosion as part of the desertification are mentioned later on. Photosynthetic studies by chlorophyll fluorescence on *A. dhofarica* and other dominant species were studied at Hauf and Damqaut with respect to sun and shade leaves and also at various stages of senescence. The interpretation of these data is not yet complete and has to be continued.

A number of difficulties had to be resolved: (a) Funds for manpower were very limited, and the Yemeni counterparts of the subprojects could not be maintained after 2004, losing invaluable expertise and field experience. (b) A second difficulty was that the ecological studies have focused on specific areas, and these involve continual measurements, often over several weeks in order to obtain worthwhile results. This means that the equipment required constant supervision, and this method of working (i.e. remaining in one location for a substantial period of time), was in contrast to that of other subprojects, whose concerns operated over a much wider area. (c) We found many of the administrative procedures rather laborious and time consuming instead of unburden the researchers. We would like to suggest that in future projects, fieldwork and the evaluation and publication of results in scientific journals should be given top priority, rather than constantly having to respond to "urgent" requests for statements for reports that have little scientific impact.

Cooperations with other institutions

Project E14 cooperated within the union of the subprojects E13 to E16. In Yemen, the Agricultural Research Department of the referring Ministry of Agriculture and especially its Branch Mukallah were counterparts evolving manpower, skills and training. Moreover, the individual researchers mentioned in 2001 took part in the fieldwork and in publishing the results.

2. Results

The general climate of the region depends on the NE monsoon - together with trade-winds in the winter half year and the SE monsoon in the summer period. The most remarkable climate change bringing cloud, fog and aerosol precipitation to the coastal mountain ranges depends on the local upwellings of cold deep-water and special currents and whirls in the Arabian Sea from May to October (see Klaus, R. & J.R. Turner, 2004: The marine biotopes of the Socotra Archipelago. Fauna of Arabia 20, 45-115). The authors cited confirmed our results in graphing the results of the Yemeni long-term surface observations on the cycling of temperatures and torrent precipitation events following ENSO or El-Nino years (Fig. 3). Moreover, there is a trend to detect global warming influence on the coasts and islands of Southern Arabia (Fig. 4). In continuing the data evaluation, preliminary results especially from Soqotra Island will be figured herein.

Vegetation degradation and desertification in general are a menace in many parts of the world with serious implications for sustainable use of the natural environment. According to Warren & al. (1996) and Agnew & Warren (1996), it is particularly the semi-arid regions of the world that are most susceptible. At the same time, these regions, both rich and poor, are experiencing some of the highest population growth rates (Warren & al. 1996). Le Houérou (1996) states that the direct causes of land degradation in arid areas stem from a drastic reduction of the perennial plant cover and simplification of the plant structure with a number of serious consequences for productivity, soil structure, water relations and microclimate. The same author is of the opinion that the indirect causes of land degradation are the same the world over, namely the ever-increasing pressure on the land from an expanding human and livestock population. Particularly in poorer regions, the collecting of wood for fuel and construction purposes can also have a significant impact on the vegetation (Warren & al. 1996) and a restoration of the natural or indigenous vegetation remains almost very difficult because of environmental or socio-economic reasons (Le Houérou 1998).

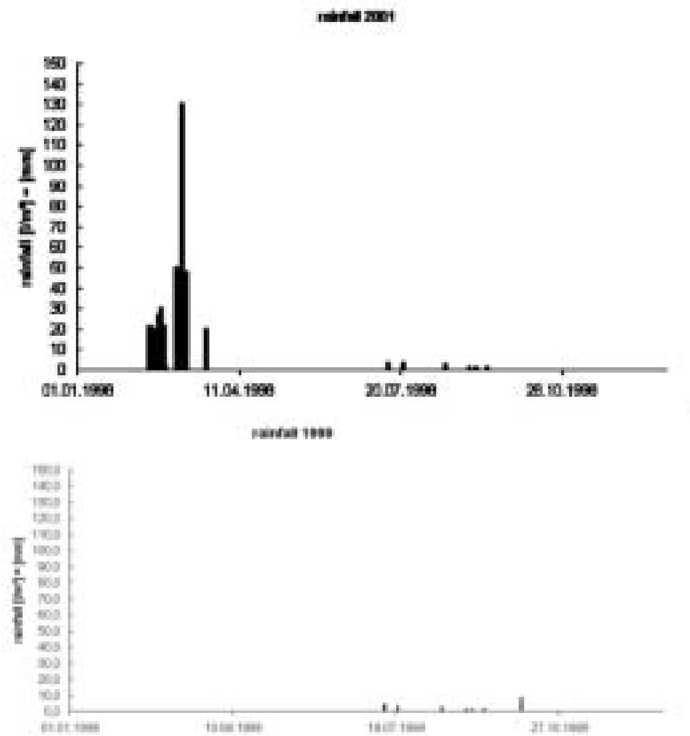

Fig. 3. Precipitation in post-El-Nino year 1998 and in the subsequent dry 1999 (Station Ghayl ba Wazier)

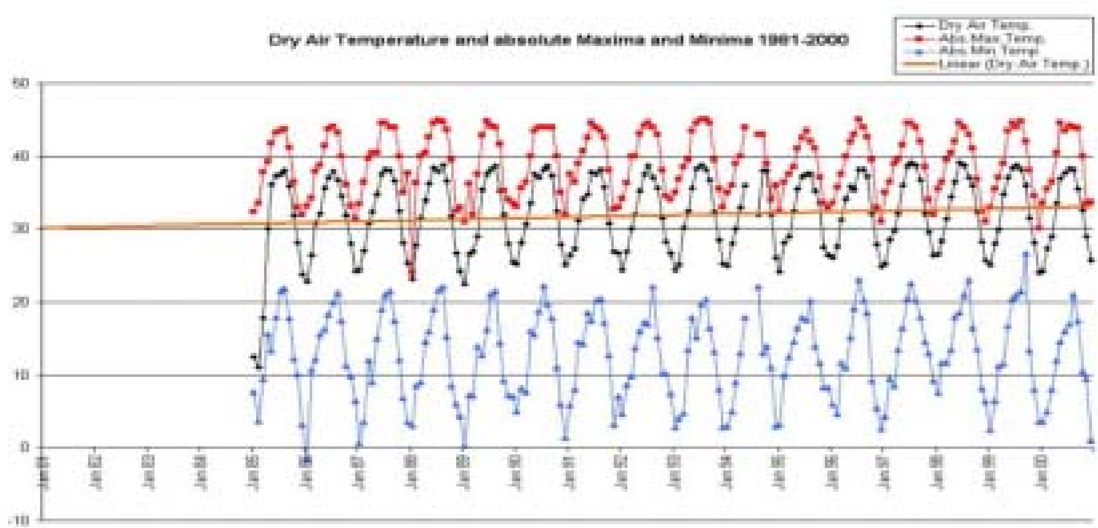

Fig. 4. Trendline indicating global warming in Southern Arabia (Station Seyun)

Why are ’desertification’ and ’phytodiversity’ interconnected? In regions, which are subject to aridisation, habitats are fragmented and populations decrease to island-like areas of occurrences. The isolation of taxa and genetical drift may increase the biodiversity as a higher pressure to adaptation can be seen as an evolutionary factor (Stebbins 1952). On the other hand, the loss of habitats and the isolation of populations may cause a decrease of biodiversity as the genetical drift may cause a loss of genetical diversity in isolated populations. The latter communities start to adapt into changing ambient conditions by a reduced potential (Boyce 1992, Menges 1992, Ellstrand & Elam 1993). Concluding both, the dose prevails in that an anthropogenous desertification effects or depletes biodiversity and the ecosystem.

2.1 Scientific results

Valley of Qalansiyah

In 1999, the potential yield of wood crop out of the Qalansiyah Valley has been assumed to be 2494.8 t per year. Compared to results obtained in the years before, within two decades it will decrease to 623.7 t per annum due to the depletion of vegetation foreseen following increasing population pressure (comp Mies & Beyhl 1999). Random sampling of *Croton socotranus* counted to more than 30 individuals (averaging 47 ±10). Those authors beforehand and during the project increasingly, we encountered more and more heaps of cut wood with surrounding spots having a density of less than 30. According to our counts until 2002, the damaged area was estimated to be even less than 2 % of the total valley and we modelled the actual gross standing phytomass at 173.388 t after Walter (1977). Today, the loss of *Croton socotranus* bush becomes obvious inside the valley.

Different intensities in using the wood resource inside Qalansiyah Valley are based on the opinion of the indigenous land owners who - if one remembers a long tradition in sustainable use of pasture and the sophisticated structures of private and public ownerships between the tribes (Naumkin 1993) - will probably not change their basic land needs. Among the rural population, number of inhabitants will be maintained in the near future but the urban population will increase following immigration. Thus, the increased number of logged *Croton socotranus* entirely points to the development of the few main villages. Regarding a stagnation of the urban head number of today as well as a living standard maintained, a monthly yield of wood - indicated by renewing those heaps of wood once a month along the road - results in a total cut of 518.4 t per annum. 2,264.4 t would be cut down per year if the rural people would sell their wood heaps weekly. The former of which can be calculated as a decrease of 0.2 % and the latter as 1.2 % of the total standing phytomass, respectively means an adequate loss of vegetation cover (see Mies & Beyhl 1999).

It would be realistic to take into account a further migration from the Yemeni mainland first and a migration from the interior into the villages of Soqotra. A continuous rate as observed in the past years would increase Qalansiyah's population number to the fourfold. A fourfold increase results in a prognosis of 0.8 resp. 4.8 % loss of total wood mass inside the Valley. Regarding the maintained conditions of today, the actual wood supply would be exhausted within 77 years. Using a progressive equation a worst case scenario predicts a decreases of 89,856 t standing phytomass or 52 % of the total bushland within a 10 year period. The total resource in mainly *Croton* wood will be finished in 19.3 years already! Both prognosticated scenarios in their extremes even neglected the down-modulating effects of a steadily retarded re-growth after severe overbrowsing.

The population of *Boswellia socotrana* had counted to 640 individuals in 1994. Revisited in 1999 and 2002, the number was maintained at 624 individuals and 620 respectively. In 1994, there were already no smaller trees than of 4 m height, indicating a senescing population structure. The trees had been and still are cut for their frankincense resins.

Population densities on the Hadibu plain

The *Croton socotranus-Jatropha unicostata* shrub community on the Hadibu Plain is physiognomically very similar to that of other vegetation types found elsewhere in northern and north-eastern Africa as well as the Middle East that experience similar climatic conditions. Thalen (1979) reviewed the literature on potential forage supply from desert scrub vegetation and compared it with the situation in semi-arid and arid regions of Iraq. For areas receiving rainfall in the region of 125 to 250 mm, annual production of aerial dry matter was estimated to be about 375 kg ha^{-1} . However, Thalen's figure if anything, overestimates forage production, as it is based on homogenous intact areas. A similar amount was found over a three-year period for a number of sites protected from grazing in Kuwait, although considerable inter-site and annual variability was a pronounced feature (Omar & al. 1990). Various authors including Noy-Meir (1973), Le Houérou & Hoste (1977) and Fisser (1990) have shown that in general, aerial productivity in arid zones can be directly related to precipitation. For the Mediterranean Basin, Le Houérou & Hoste (1977) estimated that each millimetre of precipitation produced about 4 kg of aboveground phytomass. A high proportion of the latter does not consist of herbs and grasses but of edible parts of wooden chamaephytes and nanophanerophytes. These gross amounts equate to about 2 kg ha^{-1} a^{-1} of consumable dry matter. On this assumption, 100 mm of precipitation can be expected to produce c. 200 kg of forage ha^{-1} a^{-1}. Again, this figure is applicable to high-productivity stands and is possibly biased towards the upper limits of forage production. For low-productivity degraded stands, i.e. such as in the vicinity of villages, forage production is likely to be much less, probably about 50 kg ha^{-1} a^{-1}, as indicated by Le Houérou & Hoste (1977).

In order to estimate productivity on the Hadibu Plain, we used the vegetation map presented in Mies (2001) who applied the following forage estimates: 50 kg ha^{-1} a^{-1} for low-productivity stands and 170 kg ha^{-1} a^{-1} for intact high productivity areas - as we have subjectively decided that this Soqotran vegetation type appears to be somewhat less dense and less productive than the Iraqui counterpart presented in Thalen (1979). Low-productivity stands such as those dominated by *Tephrosia apollinea*, *Ballochia amoena* and *Argemone mexicana* occupy about 34 % (30.4 km²) of the total study area (89.4 km²). Annual forage production here can therefore be estimated to be roughly 152 000 kg ha^{-1} a^{-1}. Intact *Croton* and *Jatropha* scrub covers about 38 % (= 33.7 km²), and a further 14.6 km² (16.3 %) is occupied by degraded *Croton* scrub. No differentiation was made between these two types when estimating forage production, which is in the region of 996 000 kg ha^{-1} a^{-1}. This figure was obtained by applying the minimum amount of forage for Semi-desert scrub, and does not include forage produced in date-palm groves as well as on the edges of montane thickets. For the entire Hadibu Plain, therefore, total annual forage production in a typical year was in the region of 1 118 000 kg or 125 kg ha^{-1}. The pictures (Fig. 5) show that the wooden vegetation nowadays is severely effected and they reflect the realistic degree or response of the former hypothetical modelling. In 2002, bushland had been degraded further (Fig. 5). In 2003, degraded *Croton* bushland - less than 30 stems per 100 m² - contributed with 24 % of the plain area (compared to 16.4% in 1999). The suburbs and vicinity of Hadibu as well as along the road tracts was nearly avoid of wooden plants nowadays.

Fig. 5. Vegetation degradation in the SE corner of the Hadibu plain in 1996 (left) and 2002 (right) (nos.7573 & 11237)

Microclimate and soils

Microclimatic variables were recorded in stands of *Croton socotranus* scrub as well as in deforested squares of the Hadibu Plain. Maximum temperatures (recorded at 1:00 p.m.) were distinctly lower (29 °C) amongst the *Croton* shrubs than in areas without shrubs (32 °C). Average photon flux densities of about 1700 µmol $m^{-2}s^{-1}$ between 10:00 a.m. until 3:00 p.m. were somewhat lower (by about 15 %) amongst the shrubs due to shading. Wind velocities here were on average 30 % lower than out in the open. On the mountain ranges, light flux density was lowered from appr. 2000 µmol $m^{-2}s^{-1}$ outside to 700 to 300 inside of the patchy canopies of *Rhus* dominated stands and Piché-evaporation was lowered to 35-48 %. Inside, there loosely structured soil particles could be encountered at surface and underneath. Litter accumulation, available plant nutrients and humification were significantly higher therein.

In the lower study areas, vegetation is highly dependent on rainfall as a source of water. Only locally, however, it has access to groundwater originating from the Hajhir Mountains. On the mountains, fog and dewfall precipitation seems to be considerable for plant growth (we assumed to contribute with up to 50 % of the whole precipitation available, see Mies & Beyhl 1999).

Soils over Soqotran limestone or granite range between 6.8 and 7.3 pH values. Conductivity and NaCl content of the soil is quite high on the coastal plains (> 5 000 ppm NaCl), but not as high as found in soils from inland saline flats (> 18 000 ppm NaCl). Water content of the soils fell on the Hadibu Plain from 92 (±5 g kg^{-1}, in respect of dry soil weight) in January 1998 to less than 20 g kg^{-1} (±3 g kg^{-1}) in March 1998 (Mies 1999c), below the measuring range of the tensiometer minus 800 cm water column (= > -2.8 pF). The apparent incipient wilting point for most herbaceous species was estimated to be less than 70 - 80 g kg^{-1}.

Considerable differences were found in the amount of gravel cover for the various plots on the plains. Samples taken from *Croton socotranus* scrub contained on average 3.12 (± 1.20) kg m^{-2} gravel, whereas in stands without nano-phanerophytes, gravel cover was 6.50 (± 2.17) kg m^{-2}. In the latter areas, finer material was generally lacking from the surface, probably due to the effects of wind erosion and water denudation. Such material was, however, present beneath the surface layer of coarse gravel and in flat ponds of the wadis.

Due to increasing pressure of browsing flocks, trampling and path erosion led to soil compression and erosive infiltration of flowing water through drought cracks. Especially on inclined surfaces, this is the serious starting point of denudation of the soil cover. We conducted studies concerning the subjects of path building, soil compression, primary (thickets) and secondary vegetation cover (*Helichrysum* meadows) and erosion leading to desertification. Fig. 6 depicts such a degraded soil situation at the Demalu ridge on the Hajhir Range.

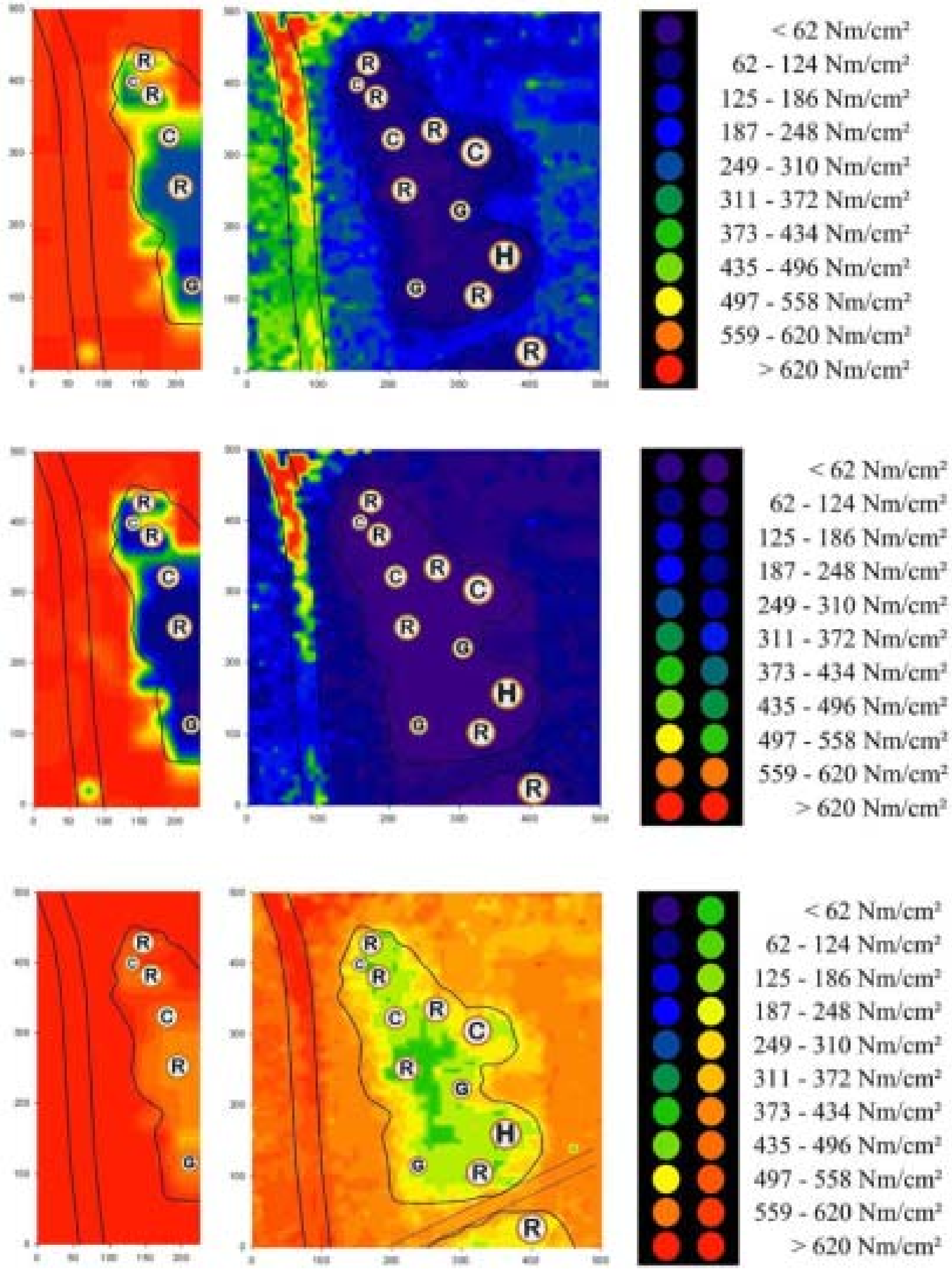

Fig. 6. Soil compression [right column: Nm classes] inside and outside a *Rhus thyrsiflora* thicket with a path indicating higher values outside with a path in the left and a higher erosion risk in the surrounding soils of the meadow. Left column: in May 2003, mid column: in December 2003

References to overgrazing

Own assessments revealed that the number of livestock dependent on forage was c. 4000 individuals on the Hadibu Plain (Mies 1999c). Thalen (1979) examined the amount of forage needed by sheep and goats in the desert scrub of Iraq and found that each animal had a daily requirement of about 1.2 to 3.3 kg when woody plants were the sole source of nutrition. Similar values (2.5 kg) were reported by Brown (1954) and USDA (1976) for sheep grazing on semi-desert vegetation. In years of plentiful rainfall, the requirements of animals may be largely met by the more luxuriant ephemeral vegetation, at least for a few months. This would relieve the pressure on perennials such as shrubs, because ephemeral plants are a much more attractive source of food for sheep and goats. However, according to the results of Thalen (1979), it is possible that the daily food intake by sheep and goats may actually rise when ephemeral vegetation is present, as he reported values of 6.6 kg per animal. Unfortunately, years of low rainfall are common on Soqotra (Mies & Beyhl 1998). As a consequence, the contribution of the ephemeral vegetation to total forage production is usually rather low. On the basis of a daily requirement of 2.5 kg per animal, 4000 sheep and goats can be expected to require approximately 3,650,000 kg of forage per year or 408 kg ha^{-1}. This outstrips production by over three-fold.

2.2 Interdisciplinary components

The Southern Arabian Project E14 has been intended to work closely with E13, E15 and E16 in the field. The plans of setting up observation plots throughout Africa and Arabia did not prove to be practicable in being coordinated and financed in Yemen. Projects of BIOTA-SOUTH, -EAST and -WEST had sufficient funding in conducting satellite remote sensing, to detect vegetation cover and area models from above as well as funding in paying field assistants. But this was not the case at all for Southern Arabia. In asking those remote sensing projects to be assisted, they claimed exorbitant funding to conduct an interdisciplinary cooperation. Interdisciplinary research should become possible and evident in providing funding of meetings and publication volumes.

2.3 Likely benefit an applicability of results

Example Soqotra: Stop desertification

The symptoms of desertification mentioned above are clearly visible in the vicinity of the main village of Hadibu. This village has experienced a surge in population in recent years, not only attributable to the influx of people from more remote areas of the island, but also more recently (since 1990) from mainland Yemen. As most inhabitants are dependent on grazing animals for their livelihood, this population increase has been accompanied by severe land deterioration. Although overgrazing can be regarded as the primary cause of this adverse situation, this has also been confounded by the cutting of shrubs for fuelwood, as typical of many other arid regions of the world experiencing similar problems (Warren & al. 1996). The degree of over-exploitation is so great that in the vicinity of Hadibu, there has also been a considerable decline in the occurrence of unpalatable species, such as *Caralluma socotrana* (used as a traditional medicine against fever, including malaria) and *Aerva* spp. (whose hairy inflorescences provide material for filling cushions). An analogous situation exists in the Arabian Gulf countries, where Box (1990) states that most people now live in large cities, and that heavy concentrations of livestock around them denude the landscape, increase dust and in general decrease the quality of life for the urban dweller. In contrast, the vicinity of Shiq, a village that has not been subjected to any significant increase in population, has not suffered land degradation to any great extent. Nevertheless, this village area might be subject of the same land degradation processes as growing to a suburb of Hadibu and easily reachable to motorcars.

It must be stated that although human impact particularly in the form of overgrazing is often recognised as possibly the major cause of desertification, most authors (e.g. Agnew & Warren 1996, Le Houérou 1996, Thomas 1997) emphasize that the phenomenon is highly complex in respect of the underlying socio-ecological causes. Clear examples of how direct human impact has led to severe desertification in a relatively short period of time (40 years) are available, for instance, from Kuwait (Khalaf 1989). Mies & Beyhl (1999) imagined that the bushland inside Qalansiyah Valley would vanish within 20 years at a steady population growth. In a study carried out in southern Africa, Skarpe (1991) has recently shown the destructive forces of overgrazing in a South African savannah in which *Acacia* spp. play an important role. In this case, degradation was strongly correlated with high grazing intensities, which occurred when a certain threshold of grazing was exceeded as it actually happened on Soqotra Island.

Disturbance of the desert soil surface may have serious consequences for desert scrub ecosystems that may not be visible immediately (Rundel & Gibson 1996). Huge stocking levels may affect soil properties leading to compaction of the surface and/or promoting soil erosion (Webb & Stielstra 1979). Pandey & Singh (1991) have shown that intensive grazing also leads to a higher loss of coarser particles (0.5 - 2.0 mm). The lack of fine soil material in combination with the less favourable microclimate is likely to be highly detrimental to plant growth, in particular seedling establishment. Furthermore, the highly detrimental effects of off-road vehicles on soil and vegetation properties in arid areas have been well documented (e.g. Wilshire & Nakata 1976; Webb 1982).

In natural semi-arid ecosystems, a number of authors, including Vetaas (1992) and Brown & Porembski (1997), have indicated the importance of microsites created by trees and bushes for plant establishment. Mies & Aschan (1996) showed a more favourable microclimate within the canopy of a semi-desert shrub and O'Connor (1991) demonstrated that improved ground cover in savannas was associated with a surface layer of litter. Our own analysis of soils from the Hadibu Plain showed that intact scrub samples had much more favourable characteristics than those from degraded sites. The studies from Hadibu Plain indicated likewise that grain sizes, nutrients and organic compounds are better represented underneath *Croton* scrub vegetation than on bare and subsequently denudated areas (see above, and partly still not published works). Subtropical arid zones as on the island express a high proportion of Leguminosae in biomass, which add nitrogen into the soil by bacterial fixation to proliferate plant growth. Tongway & Ludwig (1996) have described a successful procedure for restoring productive soil patches in semi-arid landscapes in Australia which involved laying piles of branches of native woody plants (i.e. by artificially creating microsites) in open patches and allowing soil, litter and water to accumulate there. The same technique also proved feasible in restoring vegetation patches in the same area (Ludwig & Tongway 1996). McConnaughay & Bazzaz (1987) nevertheless correlated a greater patch of land (acres to hectares) to be re-colonised with an accelerated succession than a small one of a square metre e.g. in size, as nor dense grass mats neither moribund material could casually repress germination and seedling establishment as in a small patch. Optimum soil conditions and maximum grazing capacity on the Hadibu Plain is vital to be conserved and, where necessary, to restore the natural scrub vegetation, as this is best adapted to the specific local environmental conditions. Furthermore, there is evidence that perennial shrubs provide a far better opportunity for utilising the edaphic and environmental resources of an arid region than either annual or perennial grasses, as they are usually both rich in protein and highly nutritious (Goodin 1990). Ecological restoration is defined as the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems (Jackson et al. 1995).

The use of wood and pastures and ongoing immigration should be controlled and restricted to a minimum that can be overseen. There is an increasing discrepancy between decreasing biomass to feed the husbandry and flocks and the increase in demand for meat. Most countries in the subtropics teach that less herbs and grasses grow in deforested areas and any tree regrowth is suspended not able to regenerate hardly forever (Higgins & al. 1999). Goats and sheep nibble all edible plant parts and even more until the soil potentials of regrowth and seeding reach critical points. The same processes succeed to the exhausted low pastures in higher altitudinal vegetation belts a few years later where the browsing animals have been moved. A subsequently removed highland forest or bushland does not contribute to an additional harvest of dewfall or droplet precipitation for the gross water supply any further (Mies & Beyhl 1998). Soqotran relic species are especially threatened from extinction on these formerly remote highland plateaus.

The desertification speeds up with the erosion of bare soils (Fig. 7a) which cannot be fixed by root systems and are denudated following excessive rains during the cyclones typical for the Southwest monsoon period (Fig. 7b). Hence, nature economy suffers from an irresistible spiral of deforestation and overgrazing.

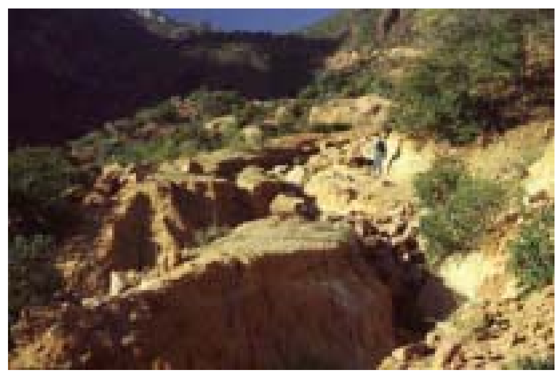

Fig. 7. (a) Building of new roads in December 2003 into the mountainous interior of Jebel Ma'alli area South of Qalansiyah (no.fb2003_12...5). **(b)** Infrastructural enhancement is leading to gullys and severe erosion damage (no.7582)

The number of grazing animals should equilibrate the production of biomass to enable or restore a sustainable grazing regime (Fig. 8). This points as well to the use of *Croton socotranus* and further trees for firewood. The need for wood exceeds the offer of that potentially regrowing resource. An increasing population number more and more degrades - by its increasing demand for meat - the natural vegetation cover. This should be told as a consequence especially to the Soqotrans and especially explained to the urban population parts. The desertification of Soqotra fits to a general tendency of wide parts of Africa facing overgrazing and deforestation - and overpopulation as well (Skarpe 1991 e.g.). A long-term use of regrowing resources such as wood and pastures is only possible in a sustainable and ecologically based and consequent economy. In order to speed up recovery of the natural vegetation, it may prove feasible to establish enclosures for a certain period of time. According to Le Houérou (1998), vegetation in desert regions usually responds favourably to permanent enclosure. Hayashi (1996) discussed the results of a five-year enclosure experiment involving drought-deciduous woodland in Kenya. The complete cessation of grazing during this period proved most successful, if it enabled trees to reach a height of about 3 to 4 m. Omar & al. (1990) and Zaman (1997) provide good examples of the desired response of the vegetation to permanent enclosure in the degraded Kuwait desert, although there were exceptions where no significant improvement was found. According to Le Houérou (1996), desertification is irreversible (i.e. will not recover to its pristine condition after 25 years of total protection) the drier the environment and the shallower the soil. In addition, recovery of the vegetation is presumably dependent on the extent of degradation when remediating measures were invoked.

Fig. 8. Flocks of goats and sheep are maintained over the drought season even by local water pipe installations (no.5216)

Endemic wooden species are optimally adapted to the local ambient conditions and the Soqotran ones can be regarded as moderately fast growing compared to other hot semi-arid regions of the world. Introduced woody species have the risk to invade uncontrolled natural vegetation and to erase the unique biodiversity of Soqotran ecosystems. The agroforestry of drought-resistant *Parkinsonia aculeata*, *Casuarina equisetifolia*, *Acacia*- nor *Eucalyptus*-species should be avoided although common and anyhow productive elsewhere in the subtropics. At least, a potential natural vegetation cannot be reconstructed but one, of which the economical interests and the visions of nature conservation should be jointly satisfied with selected indigenous wood and tree species (Zerbe 1998).

Phytodiversity and the quantitative use of phytomass could be maintained conserving the present *Commiphora* and *Croton socotranus* stands as well as promoting traditional land use practices the latter of which proved to be successful over centuries. McConnaughay & Bazzaz (1987) stated that great continuously extending areas in the dry belts of East Africa regenerated more rapid and easier, expressing and having maintained a variety of ecological microniches. To facilitate the natural regeneration on Soqotra, local tree nurseries should distribute their treelets of dominating species free from costs or even by monetary benefits to local responsibilities. Even, the Hadibu plain is able to be regrown with semi-natural bushland near to the boomtown Hadibu, if a network of bushland areas were fenced for a period of years (8-10) and the natural seed banks in the soils and the immense grazing and cutting pressure would be avoided. An additional subsequent litter fall from a denser shrubland enriches the soil with nutrients and complexes it by the organic humus fraction. Setting up actions such as those of Tongway & Ludwig (1996, see above) should be executed to facilitate germination and young growth on depleted and crusted soils. Indigenous tree species of Soqotra proved to be able to be grown and proliferated by seeds in nurseries already to be planted (*Croton socotranus*, *Commiphora socotrana*, *Sterculia africana* ssp. *socotrana* e.g.). Other species can recover by cuttings or even by grafting them on related basis to obtain seeds in the natural environment in the following cycles (*Jatropha socotrana*, *Cissus subaphylla* and *Dendrosicyos socotrana, Euphorbia arbuscula*) or by planting stolones (*Corchorus erodioides* and some grasses). The cover of high-growing species and a canopy is in need to be reconstructed to protect a variety of more sensible herbs and others from insolation or exsiccation.

A careful and locally sensitive management strategy is required to restore the vegetation of the Hadibu plain and the Valley of Qalansiyah and to guarantee a sustainable and traditional pastoral economy. It must be balanced the interests of the grazing economy and the benefits from the wood yield and the interest of conservational intentions. According to Krueger (1990), the socio-ecological perspective seems more successful as programs of grazing regimes and the overall productivity of the livestock and the areas would have been maintained and increased, in order to promote indigenous tree species e.g. It should be practicable on Soqotra - if browsing and cutting is allowed – to sustain areas inside dense bushland in years of good or distinctively sufficient rainfall which remain otherwise under subsequent reduction. This biomass management should be undertaken until vegetation has recovered completely. It is evident that the number of flocks and herds should be down-regulated by the increase of drought periods and the decreasing fodder supply. The offer of subsidized domestic fuel makes not only ecological sense but also ends up in an economical benefit at least to satisfy the increasing demands of growing urban populations. An implementation can only be executed under the responsibility and under the own administration of the local population meaning social structures.

Future ecological studies and the interfering socio-economic questions are very much in need on Soqotra to stop thrilling desertification, and to secure a long-term sustainability of natural resources. Conserving biodiversity must include the protection of habitats at the whole and the maintenance of the local income. The ecological and conservation parties may contribute by proposing studies (1) of consequences of the intensities of grazing regimes and use of wood on species composition, (2) of specific fodder value of Soqotran species, (3) about social acceptance of an improved or enhanced grazing management, (4) about re-introducing indigenous tree and shrub species to stabilize the regional ecosystems and to secure the needs of tomorrow, (5) about germination and ambient seedling requirements including soil and nutrition of dominating species and (6) the infra- and interspecific concurrence or co-existence of species.

2.4 Publications resulting from the project

Scientific publications

Mies, B.A. (2004): Die Desertifikation der Insel Soqotra. - Results of Worldwide Ecological Studies. Proc. of the 2nd Symp. of the A.F.W.Schimper-Foundation (S.-W. Breckle, B. Schweizer & A. Fangmeier, eds.), 297-326, Verlag Günter Heimbach, Stuttgart.

Mies, B.A. & G. Orlando (2004): Vanishing forests and sustainable development of an arid island. Soqotra (Yemen): an example. - Insula, Int. J. Island Affairs (Spec. Issue: Island Biodiversity. Sustaining life in vulnerable ecosystems.), 13, 95-98.

Mies, B.A. & M. Schultz (2004): New and interesting lichen records from Soqotra Island (Yemen, Indian Ocean). - Bibl. Lichenol., Festschrift in Hon. of Hannes Hertel (P. Döbbeler & G. Rambold, eds), 88, 433-452.

Mies, B.A., F.E. Beyhl, G. Brown, M.A. Hubaishan, F. Bolz & J.J. Lavranos (2003): Facets of desertization on Soqotra Island. - Symposiumsband II. Soqotra Symposium held at Aden University (S. Ba-angood, ed.), 1-37, Aden.

Schultz, M. & B.A. Mies (2003): The saxicolous and terricolous, cyanobacterial lichens of Socotra (Yemen, Indian Ocean). - Nova Hedwigia, 77, 73-97.

Mies, B.A. & J.J. Lavranos (2002): *Kleinia deflersii* am Jebel Urays (Jemen). - Kakt. u. and. Sukk., 53, 105-110.

Mies, B.A. (2001): Flora und Vegetationsökologie der Insel Soqotra. - Essener Ökol. Schr. (2. überarb. Fass. d. Habil.schrift Univ. Essen), 15, 1-293.

Mies, B.A. & J.J. Lavranos (2001a): Die Pflanzenwelt am Ras Fartaq. - Kakt. u. and. Sukk., 52, 174-177.

Mies, B.A. & J.J. Lavranos (2001b): Auf Pflanzensuche am Ras Fartaq. - Kakt. u. and. Sukk., 52, 214-221.

Mies, B.A. & J.J. Lavranos (2001c): Die Verbreitung des Echten Weihrauchbaumes *Boswellia sacra* in Südarabien. - Kakt. u. and. Sukk., 52, 327-335.

Lavranos, J.J. & B.A. Mies (2001a): *Pseudolithos mccoyi* (Asclepiadaceae - Stapelieae) a significant new species from the Sultanate of Oman. - Asklepios, 82, 27-30.

Lavranos, J.J. & B.A. Mies (2001b): A noteworthy new Aloe from the Ra’s Fartaq Mountains, south-east Yemen. - Cact. Succ. J. U.S., 73, 146-151.

Lavranos, J.J. & B.A. Mies (2001c): A new species of Rhytidocaulon (Apocynaceae - Asclepiadaceae) from South Eastern Yemen. - Cact. Succ. J. U.S., 73, 299-303.

Lavranos, J.J., T. McCoy, B.A. Mies & G. Orlando (2001): The last corner of Yemen. - Cact. Advent., 53, 2-15. Villaricos (E).

Poster

5-9.12.01 Biodiversity and ecology of the palaeo-African refuge areas in Southern Arabia and on Socotra (Republic of Yemen). Ecological causes of biodiversity in the coastal mountains of Southern Yemen and on Socotra. - (zus. mit G.B. Feige), BIOTA-Ostafrika, BMBF Projekt ID: 01LC0025, Yemen E14)

13.12.2003 Path Building and Soil Erosion in the Northern Hajhir Mountains of Socotra (Republic of Yemen). - (zus. mit F. Bolz) II. Soqotra Symposium Aden University.

Abstracts

Mies, B.A. & G.B. Feige (2001): Ecological causes of biodiversity in the coastal mountains of Southern Yemen and on Socotra (Republic of Yemen). BIOTA-East Africa E 14. - BIOLOG, German Programme on Biodiversity and Global Change (Phase I, 2000-2004), Status Report 2001, Environmental Research Programme, Bonn 5.-10. Dec. 2001, pp.176-177.

Mies, B.A. (2002): Die Desertifikation der Insel Soqotra. - 2. Symposium der A.F.W. Schimper Stiftung von Heinrich und Erna Walter, Oktober 2002, Stuttgart-Hohenheim.

Mies, B.A., F.E. Beyhl, G. Brown, M.A. Hubaishan, F. Bolz & J.J. Lavranos (2003): Facets of desertization on Soqotra Island. - II. Soqotra Symposium Aden University.

Beyhl, F.E. & B.A. Mies (2003): Vernacular Names of Soqotran Plants. - II. Soqotra Symposium Aden University.

Bolz, F. & B.A. Mies (2003): Path Building and Soil Erosion in the Northern Hajhir Mountains of Socotra (Republic of Yemen). - II. Soqotra Symposium Aden University.

Lectures

12.1.2001 Reliktvegetation auf Sokotra und in Südarabien. Phytodiversität und Desertifikation (Univ. Greifswald)

10.1.2002 Die Wüste - Lebensraum für Pflanzen (Antrittsvorlesung Univ. Essen)

16.4.2002 Die Desertifikation der Insel Soqotra (Univ. Göttingen)

25.10.2002 Die Desertifikation der Insel Soqotra (2. Schimper-Symposium Stuttgart-Hohenheim)

17.7.2003 Adaptationen der Photosynthese (Univ. Bielefeld)

17.7.2003 Lebensgrundlage Wasser und Desertifikation (Univ. Bielefeld)

12.12.2003 Mies, B.A., F.E. Beyhl, G. Brown, M.A. Hubaishan, F. Bolz & J.J. Lavranos (2003): Facets of desertization on Soqotra Island. - II. Soqotra Symposium Aden University.

13.12.2003 Beyhl, F.E. & B.A. Mies (2003): Vernacular Names of Soqotran Plants. - II. Soqotra Symposium Aden University.

Publications in preparation

Mies, B.A., T. McCoy & J.J. Lavranos (in press): Taxonomical remarks on Commiphora planifrons from the Hajhir Range on Socotra Island. - Cact. Succ. J. US

Mies, B., G. Brown, F.E. Beyhl, A.N. Al-Gifri & S.A. Gabali (in press.): Vegetation and pasture degradation on the Hadibu plain, Island of Soqotra (Yemen, Arabia, Horn of Africa). - J. Environm. Managem.

Thiede, J., B.A. Mies, F.E. Beyhl, J.J. Bos & N. Jürgens (in prep.): Polyphyletic origin of the 'dragon trees' (Convallariaceae s.l.): evidence from trnL-trnF cpDNA sequences. - Biochem. Syst. Evol.

3. Capacity building

Officials of A.R.E.A. and the local staffs have been sensibilized for the support by ecological field studies and to argue about realistic counts and productive data. A range of methods have been carried out and the counterparts are ready to take responsability in using even purely descriptive methods as counts or describing indicating species (Fig. 9).

Fig. 9. Research groups AREA, E13, E14 and E16 at Qadifut, Ras Fartaq in 2001 (no.10957)

3.1 Technical capacity building

Project vehicles (E13) of the three-years period were left in the country. Unfortunately, technical equipments have not been part of project E14 which could have been necessary to collect long-term and sustainable results for our counterparts.

3.2 Students and scientific staff trained

Bolz, F. (2004): Bodenverdichtung, Wasserabfluß und Klimabedingungen in Pflanzenbeständen des Hajhirgebirges (Insel Sokotra). - Studienarb. Univ. Essen, Institut für Bodenkunde.

Bolz, F. (2005 vorauss.): Mikrohabitate in Pflanzenbeständen der südjemenitischen Küstengebirge anhand von Mikroklima- und Bodenuntersuchungen. - Diplomarb. Univ. Essen

Subproject E15

Phylogeographical and population genetic aspects of the phytodiversity in palaeo-African refugia of the coastal mountains in Southern Arabia and Socotra

Subproject leader: Prof. Dr. C. Oberprieler, University of Berlin	
Short title: BIOTA E15	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

Within the integrated BIOTA Yemen project which aims to portray, analyse and compare biodiversity and ecology of the palaeo-African refuge areas of the Southern Arabian Peninsula and Socotra, the primary goal of the subproject E15 is a phylogeographical and population genetic analysis of six species/species groups (e.g. *Justicia areysiana*, *Maytenus senegalensis*, *Gossypium stocksii/ G. incanum/ G. areysianum*, *Cadia purpurea*, *Euclea schimperi* and *Launaea crassifolia*) in the monsoonal affected coastal mountains of Southern Arabia. Phylogeographical studies, based on PCR-RFLP and chloroplast microsatellites, are aimed at a reconstruction of the sequential (chronological) fragmentation of the mentioned refuge areas and at a discussion of the present patterns of genetic diversity as a result of this spatial and temporal fragmentation process which was caused by aridisation and by habitat destruction during the Pleistocene and Holocene. Additionally, population genetic investigations based on AFLP-fingerprinting are focusing on the analysis of consequences of this historical habitat fragmentation for the genetic diversity within and among populations and population groups. Furthermore, by the selection of *Maytenus senegalensis* as one of the six study groups we are trying to contribute the botanical part to the study of a co-evolving system with its counterpart *Reissita simonyi* studied in phylogeographical and population genetic aspects by subproject E16.

Planning and conduction

The species or species groups under study were chosen in collaboration with E13 to satisfy the following demands: the taxa should be found in all refuge areas studied; they should represent a variety of different families of flowering plants, different life forms (annuals, perennials), and reproductive types (autogamous, xenogamous). Therefore, in the original approach five plant taxa were chosen to meet these demands, i.e. *Gossypium stocksii*/*G. incanum*/*G. areysianum* (Malvaceae), *Maytenus senegalensis*/*M. dhofarensis* (Celastraceae), *Launaea crassifolia* (Compositae), *Dracaena serrulata*/*D. cinnabari* (Dracaenaceae), and *Thamnosma hirschii*/*T. socotrana* (Rutaceae). Soon after the start of the project and as a consequence of the intensive floristic exploration of the Southern Arabian Peninsula by subproject E13, *Dracaena* and *Thamnosma* were replaced by *Euclea schimperi* (Ebenaceae), *Justicia areysiana* (Acanthaceae), and *Cadia purpurea* (Fabaceae) because the populations of *Dracaena* and *Thamnosma* were restricted to only a subgroup of the refuge areas under study.

After the commence of the subproject in spring 2001, field trips and plant collections were conducted in close co-operation with subproject E13 in the years 2001-2003. Additionally, in autumn 2002 an additional and privately financed collecting trip to the Omani Dhofar mountains was made aiming at a completion of the sampling for all species/species groups to allow a comprehensive analysis for the whole area. The phylogeographical and population genetic laboratory work lasted longer than considered. This is due to the large number of samples to analyse (app. 1600 samples in the PCR-RFLP analyses, 1500 samples in the AFLP analyses) and to the long phase of development, optimisation, and screening of genetic markers. As a consequence, the statistical analyses for the phylogeographical and population genetic studies in most of the species/species groups are under way at present. Most of the envisaged publications are presently in preparation and will be submitted for publication within the next 6-9 months.

Cooperations with other institutions

An intense co-operation was built up with subproject E13 (Dr. N. Kilian, Botanic Garden & Botanical Museum Berlin-Dahlem) and the Yemeni counterpart to the whole project, Dr. M. A. Hubaishan (AREA Mukalla), who organized the field trips in autumn 2001 and spring 2002. Other links were with all subprojects of the project, especially with subproject E16 (Prof. C. Naumann, C. Klütsch, University of Bonn) that collected plant material for the molecular genetic analysis from the Northern Yemen area.

2. Results

2.1 Scientific results

Workpackage 1: Justicia areysiana (Acanthaceae)

For a better understanding of the temporal and spatial differentiation processes of the palaeo-African vegetation elements in the monsoon affected coastal mountains of the Southern Arabian Peninsula, chloroplast DNA variation in 14 populations (242 individuals) of the endemic shrub *Justicia areysiana* (Acanthaceae) was studied using PCR-RFLP and chloroplast microsatellites (Fig. 1). This species occurs in the monsoon affected, climatically favoured coastal escarpments (*Commiphora* woodland, *Anogeissus dhofarica* woodland) between Abyan province (Yemen) in the west and the Dhofar region (Oman) in the east, spanning a distance of around 1000 km between its most distant populations. Where it occurs, the species is not rare but often strongly browsed by dromedary, goats, and cows. *J. areysiana* is a much-branched shrub which grows to a height of 1.5 meters and which is characterised by spikes of white, two-lipped flowers with a yellowish-brown throat and far exerted anthers and styles. Each flower produces shortly hairy capsules with four seeds, which are presumably ballochorously through a so-called jaculator formed by the hook-like funiculus.
Eleven haplotypes could be characterized and show a distinct geographical distribution pattern with a deep split between populations from the Yemeni and Omani fog oases in an eastern (Hawf Mts./ Dhofar) and western region (Jabal Urays/ Jabal Gedu/ Kor Seiban) (Fig. 2). In accordance with the geographical distribution pattern, a very limited haplotype diversity within populations (h_S = 0.153) and a high level of population differentiation (G_{ST} = 0.807) demonstrate the strong isolation of populations and refugia (Fig. 2). Past oscillations between humid and arid periods in the Pleistocene and Holocene are considered responsible for the observed pattern of genetic variation.

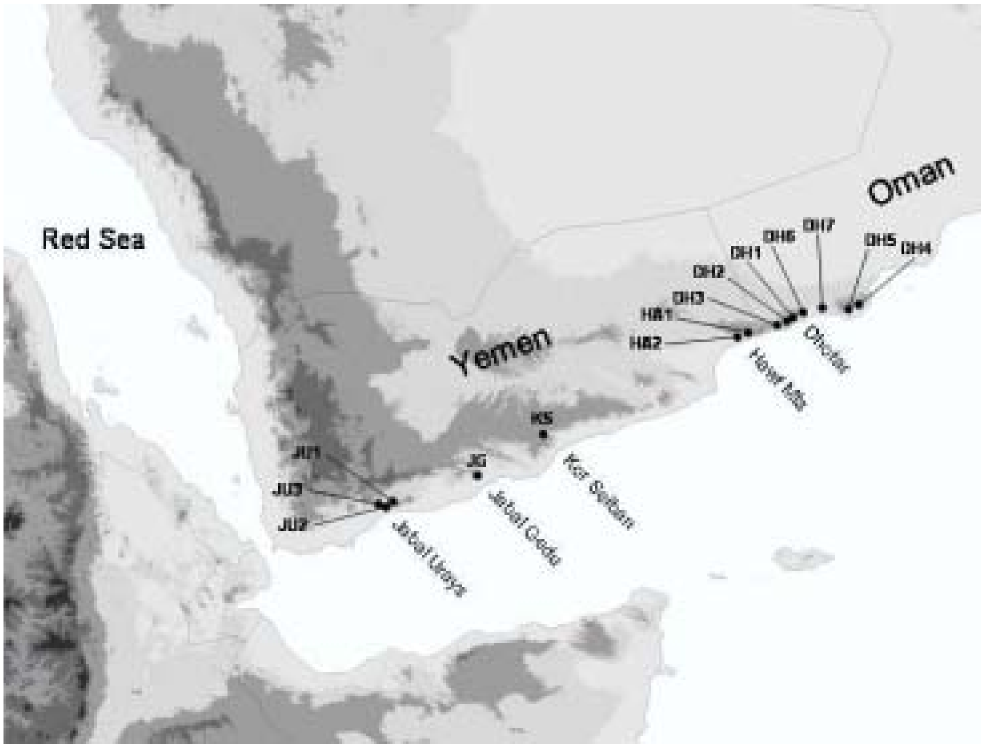

Fig. 1. Distribution of the sampled *Justicia areysiana* populations on the Southern Arabian Peninsula

It appears tempting to align the split between the two main haplotype groups in *Justicia areysiana* with arid conditions connected with the last (Weichselian) glacial period which severely influenced the climate of the southern Arabian Peninsula (e.g. traces of glaciation in the western Yemeni mountains, see El-Nakhal (1993). Following the scenarios mentioned above we then have to assume that as a consequence of aridity *J. areysiana* was restricted to two (scenario 1) or one refuge (scenario 2), respectively, from where it eventually migrated into its present areal (or even into a larger areal) during the following period of extreme humidity between 10,5-6 kyr before present (e.g. Holocene lakes from Ramlat as-Sab´atayn, E Yemen, see Lézine et al. 1997). Further cycles of aridity/humidity in the last 6000 years may then have contributed through periods of isolation of populations or contact between them to the fixation and exchange of novel haplotypes, respectively.
With our present data at hand it seems difficult to further corroborate the described hypothesis of population differentiation in *J. areysiana,* especially the timing of events and the decision between the two alternative scenarios for the first split into the two haplogroups. The fact that despite the intense screening for polymorphisms in the chloroplast genome (11 noncoding regions and five restriction enzymes for PCR-RFLPs; 7 microsatellite loci) only eleven haplotypes were found and that the two main haplotypes (like most of the other haplotypes in the network) are separated only by a single mutation argues for the quite recent differentiation of populations and/or the lack of extinction events leading to the loss of intermediate haplotypes. Higher values of total genetic diversity and stronger differentiation among populations observed in the eastern part (Hawf Mts, Dhofar) as compared to the western part of the distributional range may at first glance argue for a single refugium restricted to the eastern part and a secondary colonisation of the western parts with the side effect of fixation of HT8 via sampling effects during this colonisation process. However, observations that the actual monsoon activity is more pronounced in the Dhofar region than in the southern Yemeni mountains (presumably being due to the land masses of the Horn of Africa forming a barrier

for the humidity-loaded southwesterlies) may indicate that oscillations between arid and humid periods were more pronounced in the western part of the distributional range of *J. areysiana* than in the eastern part. As a consequence, this may have led to a more severe loss of genetic diversity via bottleneck effects and restricted gene flow in western populations than in the eastern ones where populations may have remained comparatively large and less isolated from each other.

The preliminary analysis of Amplified Fragment Length Polymorphism (AFLP) variation in *Justicia areysiana* where a total of 76 polymorphic bands were found with three different selective primer combinations (M-CAC/E-AAC, M-CAA/E-AAG, M-CAT/E-ACT) corroborates the above results from PCR-RFLPs of the chloroplast genome. The subdivision of populations into two main clusters (Hawf Mts + Dhofar vs. Jabal Urays + Jabal Gedu + Kor Seiban) emerges also from this data set, as does the strong evidence for the isolation and lack of genetic exchange among the populations of the different refugia.

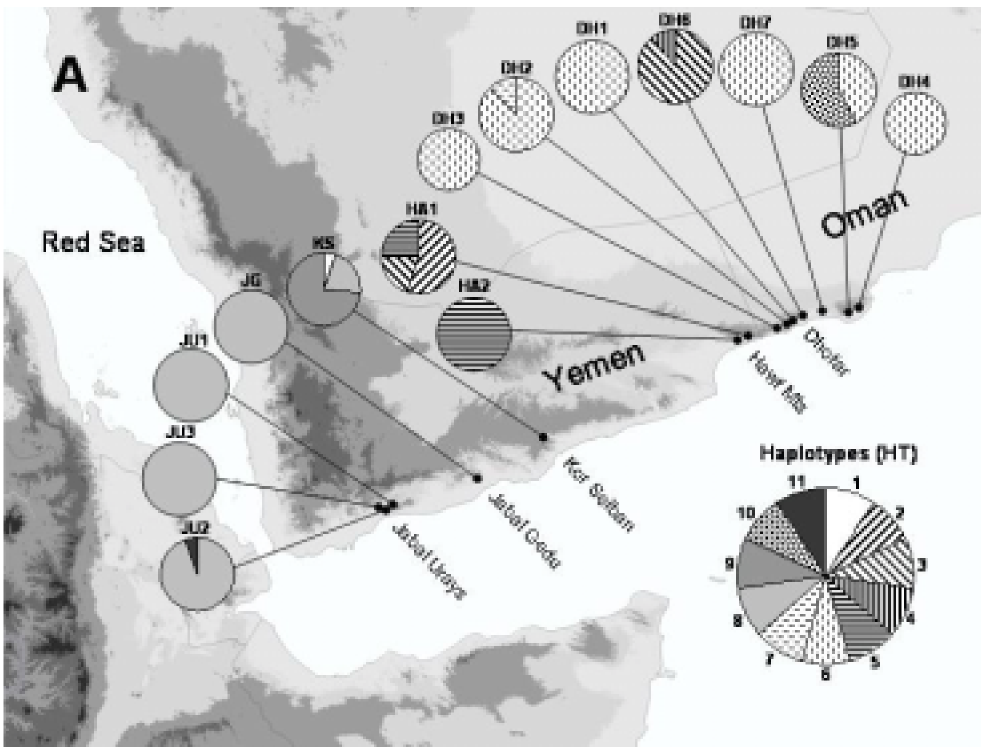

Fig. 2. Distribution and frequency of cpDNA haplotypes in *Justicia areysiana* populations

Workpackage 2: Maytenus senegalensis s.l. (Celastraceae)

For *Maytenus senegalensis*, chloroplast DNA variation in 35 populations (573 individuals) were studied from all monsoonal affected refuges, including the fog oasis of the Omani Dhofar mountains, by using PCR-RFLP (Fig. 3). Due to the collecting activities of subproject E16 in the western Yemeni mountains, a geographically comprehensive analysis for the Arabian Peninsula is possible for this species.

In the PCR-RFLP analysis, seven haplotypes could be characterized in *Maytenus* which show a distinct geographical distribution pattern that is comparable to the pattern found in *Justicia*. A very limited haplotype diversity within populations (h_S = 0.063) and a high level of population differentiation (G_{ST} = 0.903) demonstrate that the isolation among populations and refuge areas is strong. Though the haplotype distribution show a deep split of populations of the eastern and western region, three of four *Maytenus* populations from the Kor Seiban refuge show a higher genetic affinity to the eastern than to the western populations (Fig. 4). This is in contrast to the pattern found in *Justicia* where the Kor Seiban populations were members of the western haplogroup (Fig. 2). Therefore, it seems that despite the correspondence between the two species in the gross pattern (differentiation into a western and an eastern haplogroup) the geographical history of the two species is not completely congruent.

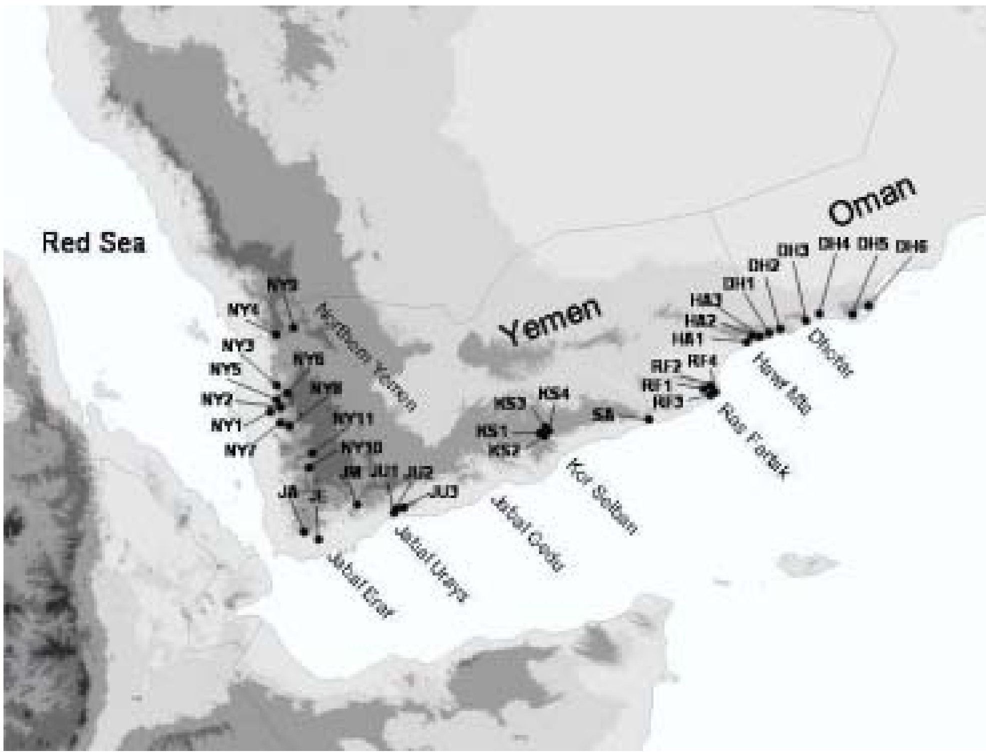

Fig. 3. Distribution of the sampled *Maytenus senegalensis* populations on the Southern Arabian Peninsula

Results of the Amplified Fragment Length Polymorphism (AFLP) variation within and among all populations of *Maytenus* are based on the 145 polymorphic bands from three different selective primer combinations (M-CAC/E-AAC, M-CTG/E-AAG, M-CAT/E-ACT). A total of 19 populations and 332 individuals were included in these analyses. In contrast to the cpDNA PCR-RFLP analysis, in the AFLP analysis populations of the Kor Seiban refuge are found genetically equally distinct both from the eastern and from the western populations.

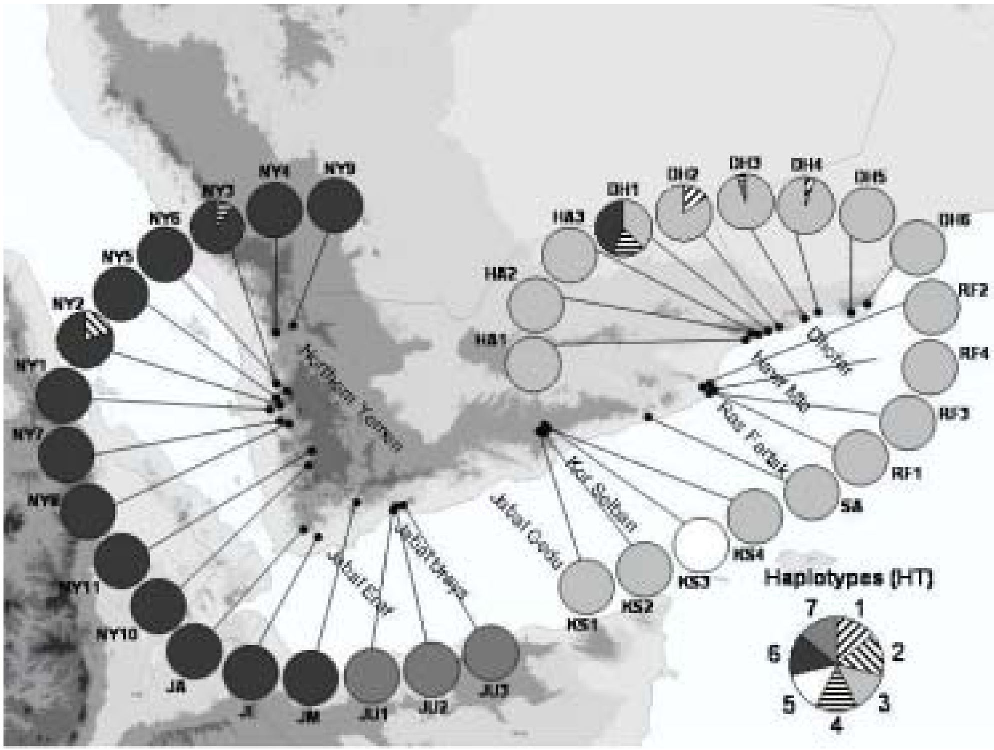

Fig. 4. Distribution and frequency of cpDNA haplotypes in *Maytenus senegalensis* populations

Workpackage 3: Gossypium stocksii, Gossypium incanum, Gossypium areysianum (Malvaceae)

For the species group of *Gossypium stocksii*, *G.incanum*, and *G. areysianum*, chloroplast variation in 12 populations (153 individuals) was studied using cpDNA PCR-RFLPs and chloroplast microsatellites (Fig. 5). This resulted in the detection of four distinct haplotypes. (Fig. 6) As in the above-discussed species, a strict chloroplast haplotype split between the eastern and western populations was detected. However, interpretation of this picture is not yet settled because in contrast to the other study groups three biologically isolated entities (species) are involved. The joint occurrence of haplotype HT3 in all three species may point to past or actual interbreeding of species. We hope that the results of the AFLP fingerprinting will further elucidate these results.

The AFLP analyses in *Gossypium* were carried out in 12 populations and used 230 individuals. It resulted in 91 polymorphic bands from three different selective primer combinations (M-CAC/E-AAC, M-CTG/E-AAG, M-CAT/E-ACT). As in *Justicia* and *Maytenus*, a strong population differentiation is observed (preliminary results). In addition to the analysis of genetic variation within and among the populations, regions, and species, the phenomenon of genetic introgression among the three species will be discussed.

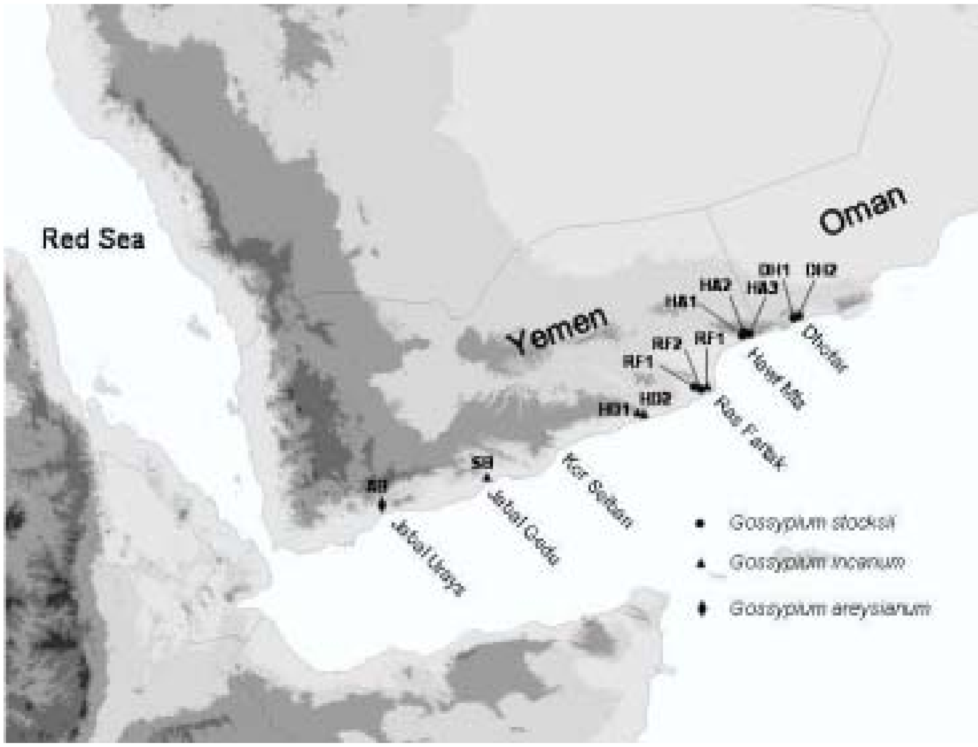

Fig. 5. Distribution of the sampled *Gossypium spp.* populations on the Southern Arabian Peninsula

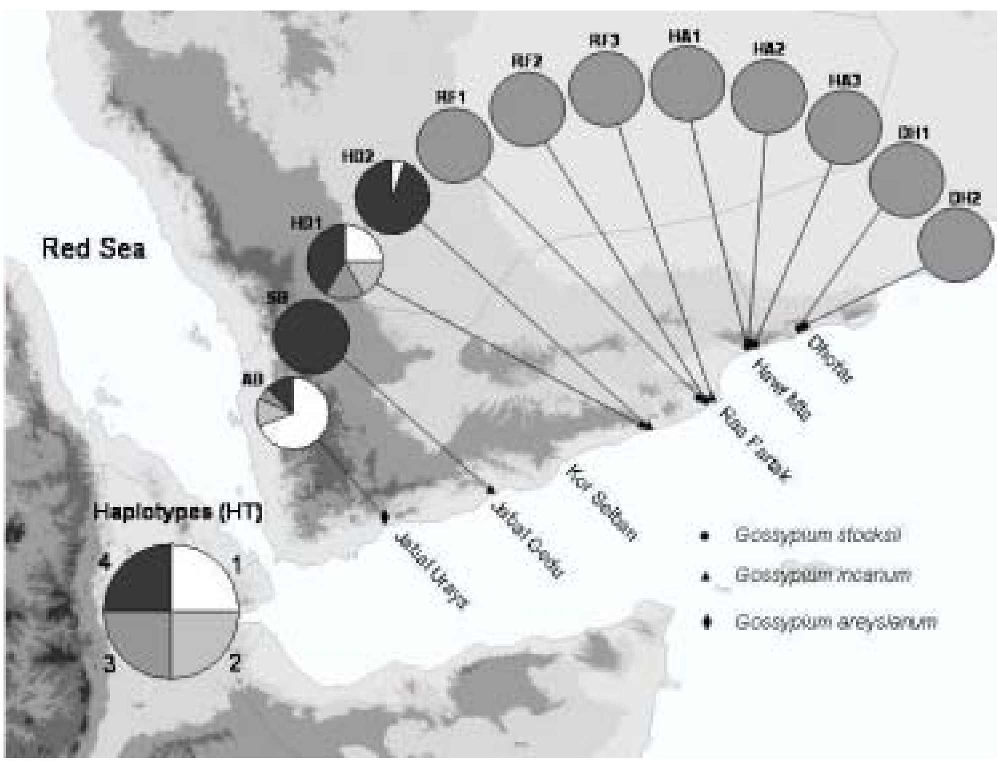

Fig. 6. Distribution and frequency of cpDNA haplotypes in *Gossypium spp.* populations

Workpackage 4: Launaea crassifolia (Compositae)

Chloroplast DNA variation of the annual *Launaea crassifolia* (Compositae) was studied in 13 populations (291 individuals) by using PCR-RFLP and chloroplast microsatellites (Fig. 7). In contrast to the above discussed species, the populations of *Launaea* show a low geographical differentiation among populations and refuge areas. This may be due to the more limited geographical sampling of this species but it may also be a consequence of the annual to short-lived perennial habit species and the pronounced dispersal abilities of the species caused by a pappus.

Additionally, preliminary results of the AFLP analysis (selective primer combinations M-CAC/E-ACC, M-CAG/E-AAG, M-CAT/E-ACT) show a lower genetic population differentiation than in *Justicia* and *Maytenus*. Only populations from Socotra are genetically strictly separated from the populations of the Al-Mahra/ Dhofar fog oases. This may corroborate results obtained from the cpDNA PCR-RFLP analysis.

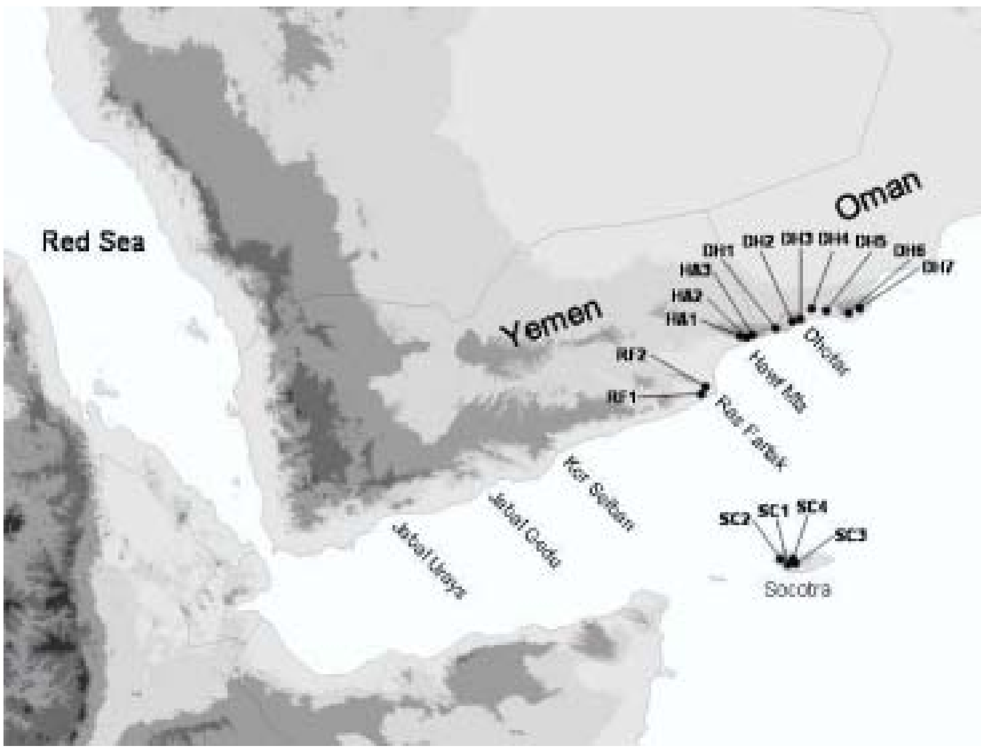

Fig. 7. Distribution of the sampled *Launaea crassifolia* populations on the Southern Arabian Peninsula

Workpackage 5: Euclea schimperi (Ebenaceae)

Chloroplast DNA variation of the shrub *Euclea schimperi* (Ebenaceae) was analysed in 12 populations (122 individuals) by using cpDNA PCR-RFLP and chloroplast microsatellites (Fig. 8). Eleven haplotypes were found in the data set and showing a lower population differentiation in contrast to *Justicia* and *Maytenus* in the eastern region. However, the isolation of the sole sampled population from the western part (Jabal Eraf) suggests also a geographical split between the eastern and western populations.

The AFLP analyses in this species are still not finished. At present, the initial screening phase for the evaluation of the selective primer combinations is in process and a completion of the analyses is envisaged for the end of 2004.

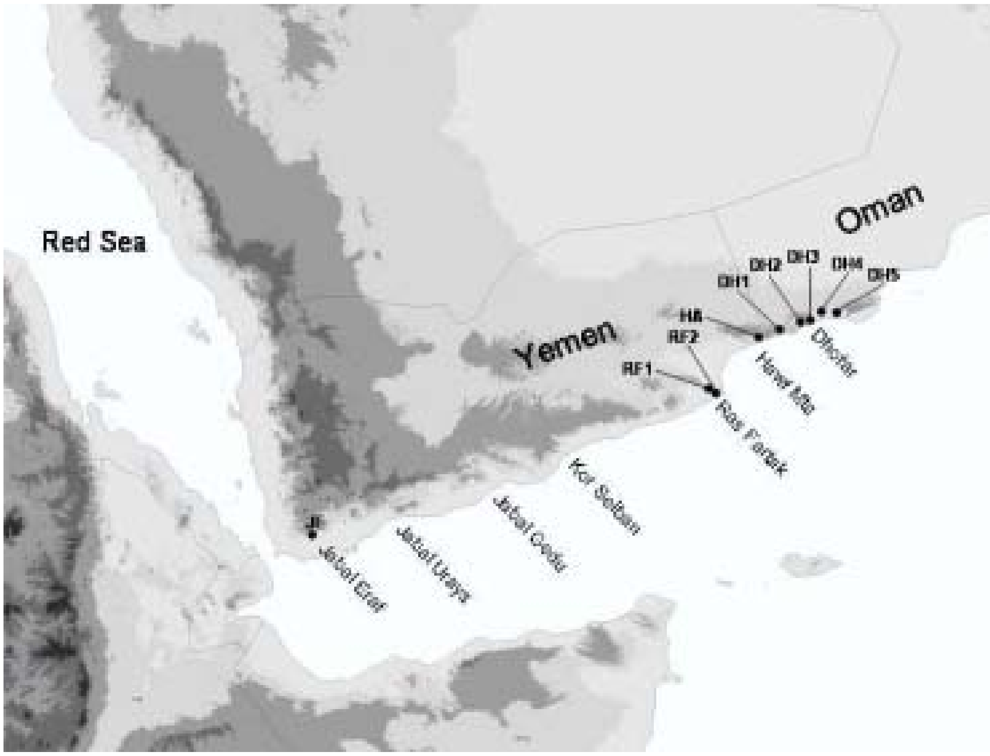

Fig. 8. Distribution of the sampled *Euclea schimperi* populations on the Southern Arabian Peninsula

Workpackage 6: *Cadia purpurea* (Fabaceae)

In *Cadia purpurea* (Fabaceae), no chloroplast DNA variation was observed using cpDNA PCR-RFLPs and chloroplast microsatellites in the 11 populations (190 individuals) sampled (Fig. 8). As a consequence, we tried to detect genetic variability of the chloroplast genome by sequencing non-coding, fast-evolving regions (introns, intergenic spacer regions). However, only a single polymorphism was detected (10 bp inversion in the intergenic spacer between the genes psbC and trnS). This polymorphism will be screened in all populations in the next weeks. Additionally, all individuals are included in an AFLP analysis using three selective primer combinations (M-CAC/-AAC, M-CAA/E-AGG, M-CAA/E-ACA). Genotyping and analysis of scored fragment data will be finished within the next three months.

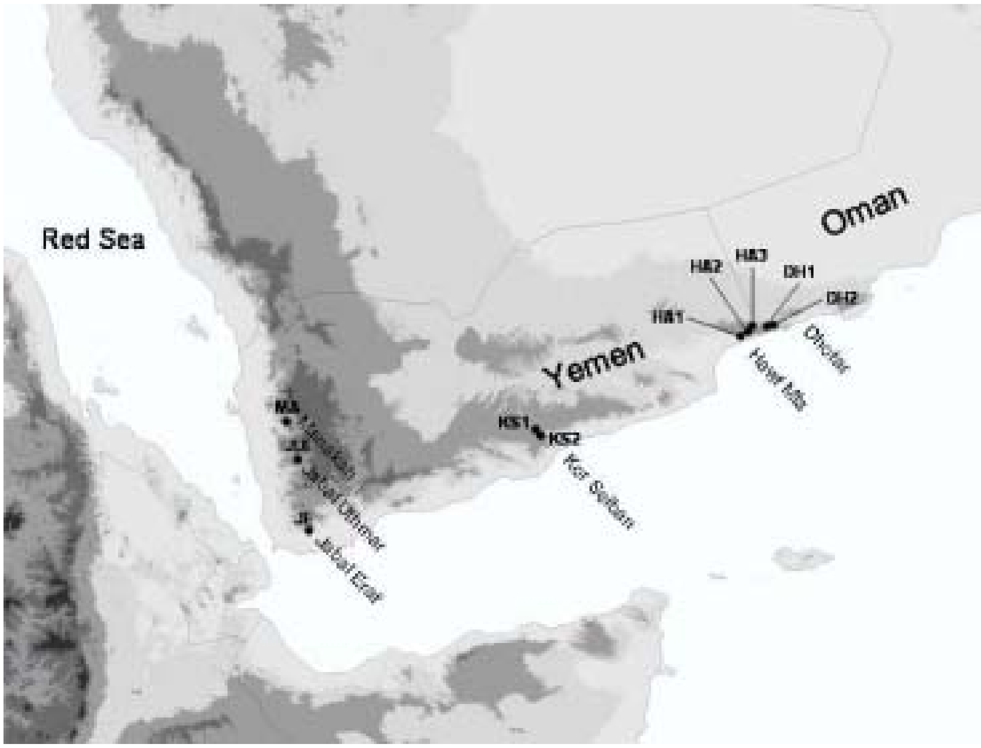

Fig. 8. Distribution of the sampled *Cadia purpurea* populations on the Southern Arabian Peninsula

Summary

Though only a small part of the final analyses are finished in the different groups, some first patterns of genetic differentiation of fragmented and isolated populations emerge:

- The monsoon affected palaeo-African refugia of the southern Arabian Peninsula show a complex floristic history. For the two species for which is presently possible to reconstruct their spatial and temporal pattern of differentiation *(Justicia areysiana, Maytenus senegalensis)* some surprisingly similar results were obtained. In both cases, we observe a distinct bipartition of the populations into a western and eastern group. This may indicate that in both species a once (under more humid conditions) continuous areal was subdivided into two parts as a consequence of aridisation. Since we observe non-overlapping chloroplast haplotype groups in the two subpopulations of the two species, respectively, it seems obvious that after that pronounced fragmentation process populations of the two subareals never came into genetic contact again. On the contrary, both subpopulations eventually were further subdivided into smaller populations, presumably due to a further aridisation circle. On the other side, however, the joint occurrence of chloroplast haplotypes in most of the populations and population groups in the two subareals demonstrates that these populations were able to exchange individuals at certain (presumably more humid) periods. This interpretation is backed by palaeoclimatic data for the southern Arabian Peninsula: During the Pleistocene, periods of maximum glaciations in the northern hemisphere were tightly correlated to periods of a southward shift of the SW-monsoon. As a consequence of these shifts the coast of the southern Arabian Peninsula were not reached by the monsoon and arid conditions prevailed. Conversely, interglacial periods were characterised by monsoon positions comparable to the present. Therefore, the oscillations between more arid and more humid conditions during the Pleistocene may have had a strong influence on the observed patterns of chloroplast haplotype distribution in *Justicia* and *Maytenus.*

- First results from the population genetic analyses carried out in the study groups using the AFLP fingerprint technique demonstrate that fragmentation caused by aridisation did not necessarily lead to a reduction of genetic diversity in small populations. At least in populations of *Justicia* and *Maytenus* we did not observe significant lower values of genetic diversity in smaller populations when compared to larger ones. This is in contrast to findings in the flora of central Europe where fragmented populations are often found to have reduced diversity values caused by inbreeding effects. A possible explanation for this observation may be that the recurrent oscillations of population sizes in the southern Arabian Peninsula may have caused the species concerned to adapt to these fluctuations. A second interpretation may be that these climatic oscillations may have occurred on longer timer scales leaving the shrinking populations more time to adapt to the changed environment than central Europe plant populations.

2.2 Interdisciplinary components

Between subprojects E13, E15 and E16 a close collaboration was built up. During the preparation of the Yemen project and throughout the project period a close cooperation with subproject E13 was established. This cooperation ranged from the selection of species to be analysed phylogeographically and population genetically over the sampling work in the field, which was done partly by E13, to the comparison and discussion of the data on geographical patterns of genetic diversity on population level as revealed in the analyses of E15 with the data of E13 on the geographical distribution pattern of the species in the mountain system studied. Joint publications of results of both subprojects reflect this cooperation (see 2.4.). A population genetic analysis of the core tree species of the monsoon forest in the fog oasis of Al-Mahra and Dhofar, *Anogeissus dhofarica*, has been developed during this phase as a joined project between E13 and E15, to answer the crucial questions after the age of the fragmentation of this monsoon forest and the genetic diversity and fitness of the occurring small forest and woodland fragments. For this joint project funds were raised independently of the BIOTA project.

Subprojects E15 and E16 will closely work together for a synthesis of the genetic analysis on the coevolutive system of *Maytenus senegalensis* and *Reissita simonyi*. Subproject E16 (Prof. C. Naumann, C. Klütsch) collected a large part of the *Maytenus senegalensis* samples and provided also information about localities from the Northern Yemeni region, whereas E15 provided *Reissita simonyi* samples from the Dhofar mountains (private field trip Prof. C. Oberprieler & J. Meister). In collaboration with E16, a joint publication is in preparation (Co-evolutionary relationships among *Reissita simonyi* and *Maytenus senegalensis*).

2.3 Likely benefit and applicability of results

For some of the relict areas under study the phylogeographical results correspond to results of the floristic inventory of the southern Arabian Peninsula carried out by subproject E13. Both surveys point to the observation that the refugia of Kor Seiban and of Jabal Gedu exhibit the character of stepping-stones or bridgeheads between the eastern (Hawf Mts, Dhofar) and western populations (Jabal Urays, western Yemeni mountains). Private genotypes only found in these areas point to the long isolation and independence of these populations. Therefore, in terms of conservation of this genetic and floristic diversity, implementation of a conservation management for the Kor Seiban refugium should get high priority.

2.4 Publications resulting from the project

Meister, J., Hubaishan, M.A., Kilian, N., Oberprieler, Ch.: Chloroplast DNA variation in the shrub *Justicia areysiana* Deflers (Acanthaceae) endemic to the monsoon affected coastal mountains of the Southern Arabian Peninsula (submitted).

Meister, J., Hubaishan, M.A., Kilian, N., Oberprieler, Ch.: Amplified Fragment Length Polymorphism (AFLP) variation within and among populations of the endemic *Justicia areysiana* (Acanthaceae) in the monsoonal affected coastal mountains of the Southern Arabian Peninsula (in prep.).

Meister, J., Hubaishan, M.A., Kilian, N., Oberprieler, Ch.: Spatial and temporal aspects of the genetic structure of *Maytenus senegalensis* s.l. (Celastraceae) in the monsoonal affected coastal mountains of the Southern Arabian Peninsula (in prep.).

In collaboration with E16, a publication is in preparation (Coevolutive relationships among *Reissita simonyi* and *Maytenus senegalensis*)

Abstracts

Meister, J., Kilian, N., Hubaishan, M.A., Oberprieler, Ch. 2002: Phylogeographical studies in monsoonal woodland refugia of the coastal mountains in the Southern Arabian Peninsula, Pp. 38. – In: Anonymus (eds.), Plant species-level systematics: patterns, processes and new applications, Symposium, Leiden.

Oberprieler, Ch., Kilian, N., Kürschner, H., Mies, B., Naumann, C.M., Hubaishan, M.A., Nashr, A.K., Hein, P., Klütsch, C., Meister, J., Rabe, K. 2003: Habitat fragmentation in Southern Arabia: Xerotropical ecosystems at their outer limits, Pp.56 – In: Anonymus (ed.), Gesellschaft für Tropenökologie e.V., Tagungsband, 16. Jahrestagung in Rostock, Tropische Biodiversität im globalen Wandel, Rostock.

Meister, J., Kilian, N., Hubaishan, M.A., Oberprieler, C. 2003: Phylogeographical patterns in monsoonal woodland refugia of the Southern Arabian Peninsula, Pp. 67. – In: Bayer, C., Dressler, S., Schneider, J. & Zizka, G. (eds.), 16th International Symposium Biodiversity and Evolutionary Biology of the German Botanical Society (DBG) – Palmarum Hort. Francofurtensis 7: 1-264.

Kilian, N., Oberprieler, C., Naumann, C., Meister, J., Klütsch, C., Hein, P., Hubaishan, M.A., Kürschner, H., Mies, B., Nashr, A.K., Rabe, K. 2003: Biodiversity and ecology of palaeo-African refugia in the southern Arabian Peninsula – Phyto- and phylogeographical patterns and population genetical aspects. – International symposium “Sustainable use and conservation of biological diversity. A challenge for society.” – Conference Proceedings, Berlin.

Meister, J. & Oberprieler, Ch. 2003: Phylogeographical patterns and population genetic aspects of the phytodiversity in monsoonal refugia of the Southern Arabian peninsula, Pp. 128-129. – In: Anonymus (ed.), Biodiversity – Sustainable use and conservation of biological diversity – A challenge for society, Symposium Report, Part A, Berlin.

Oberprieler, Ch., Meister, J., Kilian, N., Hubaishan, M.A., Hein, P., Rabe, K. 2004: Phylogeographical patterns and population genetic aspects of the phytodiversity in monsoonal refugia of the southern Arabian Peninsula, Pp. 55. - In: Jürgens, N., Thiede, J., Veste, M., Saphir, A., Metzing, D. (eds.), 28th IOS Congress – Sytematics, Ecology and Biological Interactions of Succulent Plants, Hamburg.

3. Capacity building

3.1 Students and scientific staff trained

Doctoral thesis: Jörg Meister, University of Regensburg – Phylogeographic and population genetic aspects of the phytodiversity in palaeo-African refugia of the monsoon affected coastal mountains of the Southern Arabian Peninsula

Undergraduate student project: Ronald Hößl, University of Regnsburg – Molecular genetic investigations on *Cadia purpurea* and *Euclea schimperi* with nuclear DNA markers

Undergraduate student project: Gregor Pachmann, University of Regensburg – Molecular genetic analysis on *Cadia purpurea* and *Anogeissus dhofarica* with chloroplast microsatellites

4. Literature cited

El-Nakhal, H. A., 1993 The pleistocene cold episode in the Republic of Yemen. Palaeogeography, Palaeoclimatology, Palaeoecoloy 100: 303-307.

Lézine, A.-M., J.-F. Saliege, C. Robert, F. Wertz and M.-L. Inizan, 1998 Holocene lakes from Ramlat as-Sab'atayn (Yemen) illustrate the impact of monsoon activity in southern Arabia. Quaternary Research 50: 290-299.

Subproject E16

Evolutionary history and phylogeography of South Arabian faunal elements

Subproject leader: Prof. Dr. C. M. Naumann, PD Dr. B. Misof, University of Bonn, ZFMK	
Short title: BIOTA E16	**FKZ:** 01LC0025
Duration of project: 01.03.2001 - 31.05.2004	**Period of report:** 01.03.2001 - 31.05.2004

1. Brief outline

Aims

The primary goal of this project was dedicated to the invention of first population genetic results in a geographically relatively inaccessible region. In this context, fundamental distribution pattern and genetic differentiation pattern were in the focus of our study as well as the consequences of habitat fragmentation and destruction. Special attention was put here on the linkage of a botanical and zoological coevolutive system (*Maytenus senegalensis* and *Reissita simonyi*), in order to set the population genetic investigations and hypothesis examination on a stable biological basis. Furthermore, the genetic investigations was extended to a number of other animal species (*Hyla savignyi*, *Varanus yemenensis, Lasiommata felix*), in order to include as many different systems as possible, which show differences in biogeographical origins, as well as different habitat requirements and migration abilities, in the project. This lead to an overview of the effects of habitat destruction and habitat fragmentation on different biological systems in Southern Arabia.

Planning and conduction

In the original approach four Arab faunal elements, in particular *Reissita simonyi*, *Hyla savignyi*, *Lasiommata felix* and *Varanus yemenensis*, were planned to be examined. One main reason for the selection of these animal species was the different biogeographical origin of these species. *Reissita simonyi* and *Varanus yemenensis* are assumed to have an Afrotropical; *Hyla savignyi* and *Lasiommata felix* a Palaearctic origin. Secondly, the selected species show different habitat requirements and migration abilities. Thirdly, vertebrates and invertebrates should be represented, in order to cover a broad range. *R. simonyi*, *L. felix* and *H. savignyi* could successfully be examined, but for *Lasiommata felix* the analysis was limited to the investigation of distribution patterns for time reasons. For *Varanus yemenensis* no research could take place, since unfortunately only one sample could be collected. The field trips could be completed in the years 2001 / 2002 like planned. The population genetic laboratory work lasted longer than considered. This was due to the large number of samples to analyse (app. 1200 samples) and to the long development and optimisation time of genetic markers. Thus the statistic analyses were retarded, which are under way at present. During the project time a part of the publications were successfully published. A further part of the publications is in preparation and will be published in the next 6-9 months. Altogether a large part of the objectives were reached, although with a delay of one year.

Cooperations with other institutions

An intensive co-operation was built up with Professor Dr. Abdul Karim Nasher and Dr. Masa'a Al-Jumaily (Sana'a University, Yemen), as well as Dr. Antonius van Haarten, who could give valuable faunistical references and helped intensively in field trips and meetings. Further co-operation partners were Dr. Mohamed A. Hubaishan (AREA Mukalla), as well as his co-workers, who extensively helped and organized field trips. Moreover, the subprojects E13-E16 permanently worked with one another. Additionally, we co-operated with Yemeni Science Research Foundation (YSRF) for Visa invitations and meetings.

2. Results

2.1 Scientific results

Workpackage 1: Distribution pattern (see Klütsch et al., 2003; Klütsch et al., submitted)

The distribution patterns of three faunal elements of Southern Arabia, *Lasiommata felix* (Warnecke, 1929), *Hyla savignyi* (Audouin, 1827) and *Reissita simonyi* (Rebel, 1899) are presented (Fig. 1-3). Two of them, *Lasiommata felix* and *Reissita simonyi*, are endemic to the Arabian Peninsula and information about distribution patterns is rather fragmentary for all three species. Both papers summarize the results of several field trips to Southern Arabia in 2001/ 2002 and review additional published evidence on the distribution patterns. Numerous new localities for all three studied species from Yemen are offered. According to found samples of the three species, *Lasiommata felix* and *Hyla savignyi* seem to be limited to the mountainous areas along the Red Sea (Fig. 1 + 2), where as *R. simonyi* shows a division into two subspecies: *R. simonyi yemenicola*, which also occurs along the mountainous areas along the Red Sea and *R. s. simonyi*, which is distributed along the Indian Ocean (Fig. 3).

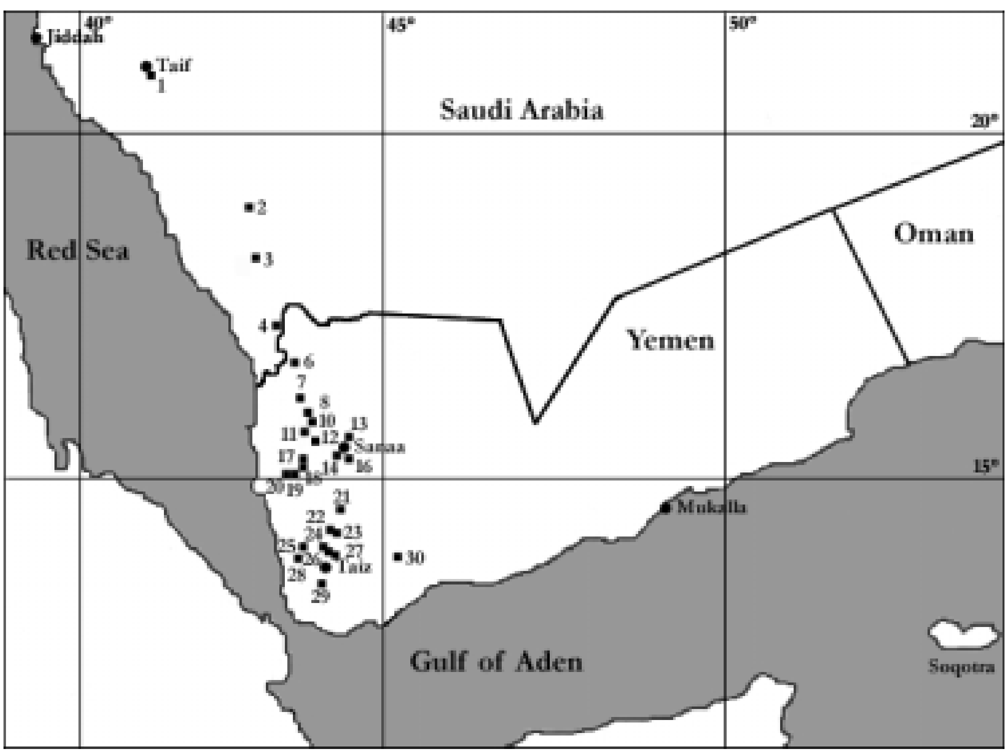

Fig. 1. Distribution of *Lasiommata felix*

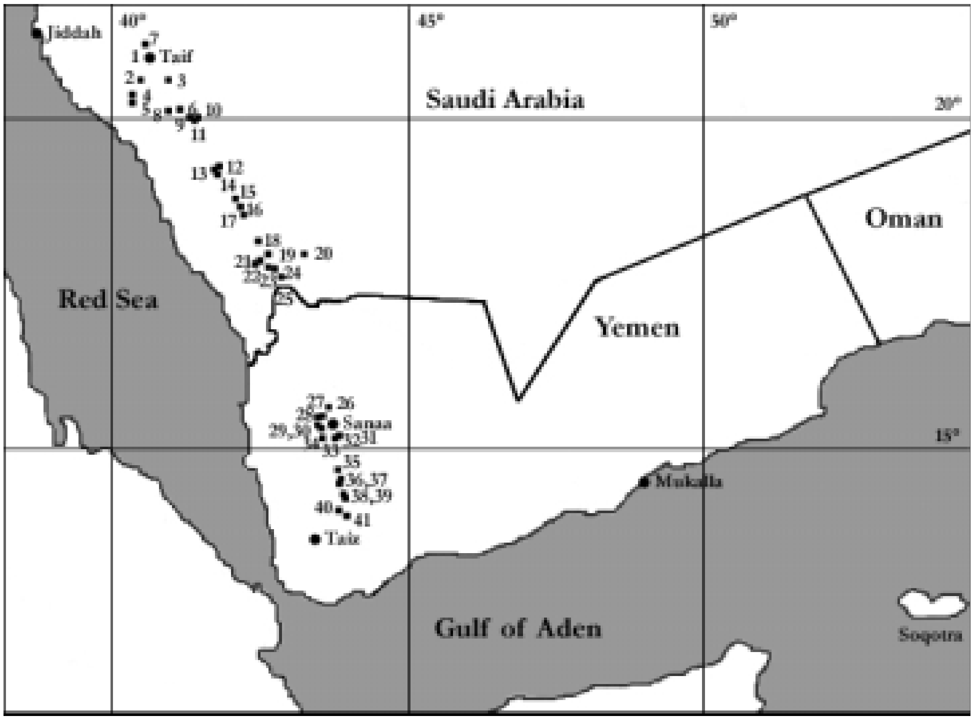

Fig. 2. Distribution of *Hyla savignyi*

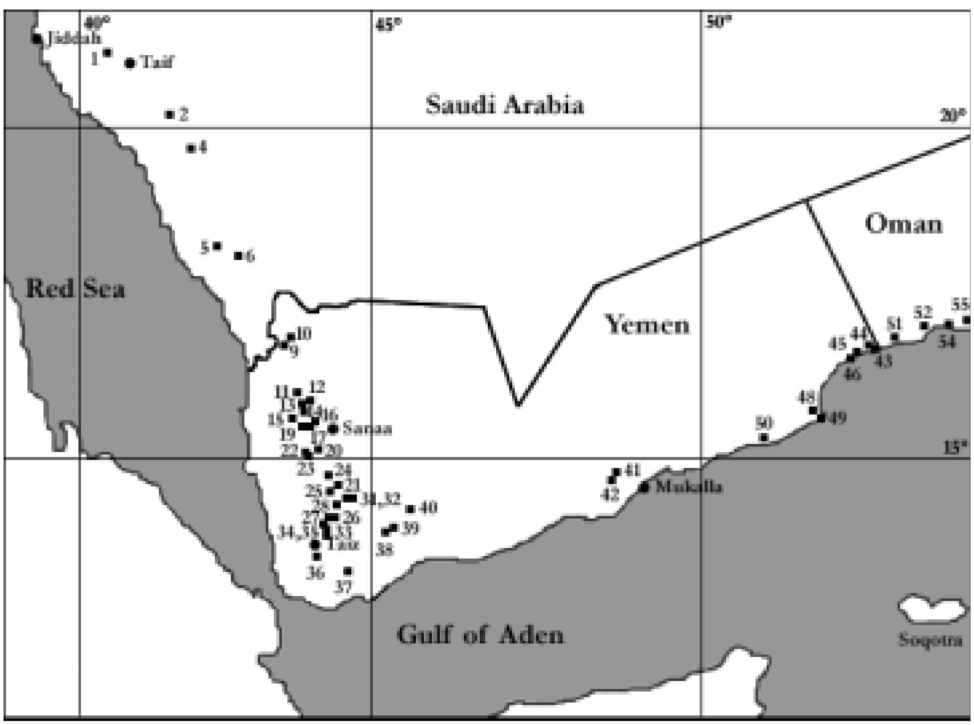

Fig. 2. Distribution of *Reissita simonyi simonyi* and *Reissita simonyi yemenicola*

Currently, *Reissita simonyi* is known from Al Hada, vic. Ta´if, Asir in Saudi Arabia to Province Dhofar, Jabal Samhan, N of Juffa (17°12´01´N 54°56`16´E) in Oman. *Lasiommata felix* is distributed from Taif, Saudi Arabia (21°16´N 40°24´E) to the Jaffah area, E of Taiz/ Yemen (13°47´N 45°11´E) in Southern Arabia (Klütsch et al., submitted). The northernmost occurrence of *Hyla savignyi* was found near to Taif in Saudi Arabia (21°16'N/ 40°25'E), the southernmost near to Mawah (14°13.266'N/ 44°23.614'E) in Yemen (Klütsch et al., 2004). For *Hyla savignyi*, all sites were found between 1.400 and 2.800 m; in this case there also seems to be a restriction in altitude.

Workpackage 2: Hyla savignyi

For *H. savignyi*, the ongoing statistical analysis reveals a strongly fragmented population structure. Moreover, one major factor for genetic differentiation seems to be isolation by distance (Fig. 4). This means that with growing geographical distance, the genetic differentiation between populations also increases.

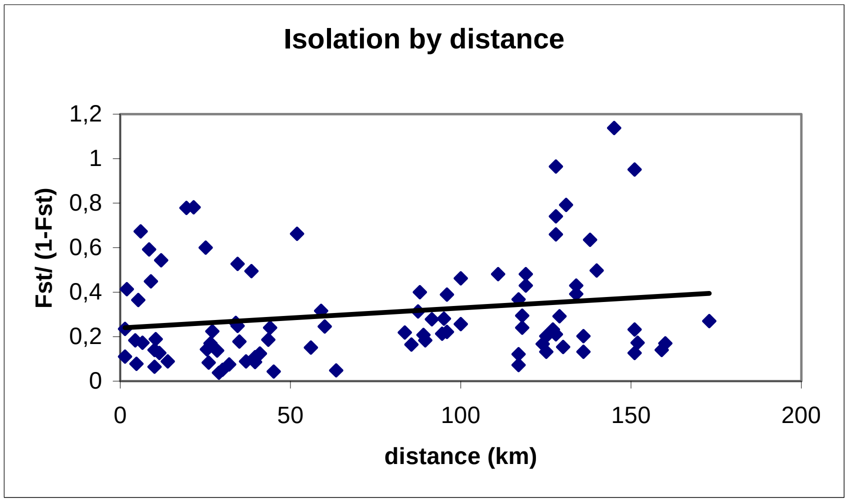

Fig. 4. Isolation by distance for *Hyla savignyi* (calculated with Genepop 3.4; see Klütsch et al., in prep.). There is a significant positive correlation between genetic differentiation and geographical distance.

Despite this fact, there seem to be additional mechanisms for genetic differentiation, for example a correlation of the proportion of heterozygotes and altitude level. This would indicate that the degree of inbreeding would rise or fall with height and could explain some of the great Fst and Fis values found. Generally, all population showed high Fst values indicating a great genetic differentiation. Moreover, all Fis values suggest a high inbreeding.

Workpackage 3: Reissita simonyi

For one species, *Reissita simonyi*, a microsatellite system was developed and published, which is the first set for this family. This microsatellite set enabled us to accomplish the population genetic analysis (Table 1; taken from Klütsch et al., 2003). Preliminary results show that also in this species high inbreeding effects and great genetic differentiation are found (Table 2). Furthermore, isolation by distance is one major factor in this species, too (Fig. 5).

Table 1. Characterization of *Reissita simonyi* microsatellite markers and their products (taken from Klütsch et al., 2003)

Microsatellite locus	Repeat	Predicted product length (bp)	Primer sequences (forward, reverse)	Annealing temperature	Number of alleles (bp)	Allelic range	Mean H_O/ H_E	Genbank Accesion numbers
RS-3	$(CA)_{11}$	107	5´-TCAGAAGTTCCAAACGAAGAG-3´ 5´-ATCATAGCAAGCTCGAAAAGC-3´	48°C	19	99-124	0.5357 0.9273	AY250755
RS-4	$(GT)_4(GC)_2$GTGC $(GT)_3$ATGTAT $(GT)_3$AT$(GT)_5$GCGTGC CT$(GT)_3$ATGT$(GCGT)_3$ GA $(GT)_9$	390	5´-AGCTGACTGCCAAACTA-3´ 5´-AGACTGCGACCACTATGA-3´	49°C	7	346-360	0.0769 0.7781	AY250744
RS-5	$(CA)_3$TA $(CA)_9$	286	5´-GAGCGGCCGCCAGTGTGA-3´ 5´-ATAAAGCATGCAAAAGTTCT-3´	50°C	6	244-254	0.0000 0.3189	AY250742
RS-17	$(CA)_6(TA)_2(CA)_3$	173	5´-GTATGGAAACTGCTAACAAAT-3´ 5´-TTCGTAACGTCACACTCACA-3´	52°C	5	138-155	0.2000 0.6136	AY250743
RS-19	$(CA)_8$CTAA $(CA)_9$	281	5´-ATGTAGAATTTTGTGATGTAGAG-3´ 5´-TAGCCTGATATAAAGAGTTCC-3´	49°C	13	233-284	0.1600 0.8098	AY250745
RS-24	$(CA)_2$CG$(CA)_8$CC$(CA)_7$ CC$(CA)_8$CGCATATG(C A$)_4$CGTAAA$(CA)_4$	213	5´-GGAAGCAGGAGTAAAAGCAAATAA-3´ 5´-CCGACTAAGGTGACAATGGTGATA-3´	51°C	7	189-205	0.4000 0.7467	AY250746
RS-28	$(GT)_{11}$	115	5´-TGAAGGAATTTTTAAAGTGACAAC-3´ 5´-ATTCCCCTTAGATTTATGATGATT-3´	48°C	9	106-119	0.4048 0.5306	AY250747
RS-31	$(GTTT)_{14}$	204	5´-GGTCCACCATTCCTTAGAGATA-3´ 5´-ACCAGTAGTTTCGGAGATTAG-3´	47°C	15	147-217	0.2273 0.8946	AY250748
RS-32	$(CA)_8$CTCG $(CA)_7$CGCG $(CA)_5$CTCGGCGG $(CA)_{18}$	225	5´-GGCAGGGAAAGAAGGAGAGGA-3´ 5´-CAAGTGTAAGTTCGGATGTG-3´	51°C	5	163-169	0.0000 0.6200	AY250749
RS-33	$(CA)_8$	329	5´-GACAACAGCCACATTCATACT-3´ 5´-CCCGAGGAAATCCCGAAAGTT-3´	50°C	22	312-347	0.3878 0.9325	AY250750
RS-37	$(GT)_9$	295	5´-TAGACTGCGTACCAATCGTG-3´ 5´-CTTAAGTCGGCTAGTCAAATC-3´	48°C	7	276-304	0.1316 0.6434	AY250751
RS-44A	$(GAAAT)_3$GAAT(GAA AT$)_5$	173	5´-TATTACCACCGTTTTTGTTTGTCA-3´ 5´-TATCCTCTTTGTTGCGGCTCAGTA-3´	48°C	9	163-177	0.2632 0.8601	AY250752
RS-47	$(CA)_2$CG$(CA)_8$CC $(CA)_7$CC$(CA)_6$	217	5´-GGAAGCAGGAGTAAAAGCAAATAA-3´ 5´-AAATCCGACTAAGGTGACAATGGT-3´	51°C	14	192-214	0.3810 0.8605	AY250753
RS-50	$(GT)_3$GC$(GT)_5$ AC$(GT)_4$GC$(GT)_3$AC(G T$)_4(GC)_4$GY$(GT)_{12}$	245	5´-GAGAGTGCGAAATCCATAAT-3´ 5´-ATACGCGCATAACAAACTAC-3´	50°C	9	210-229	0.1500 0.7725	AY250754

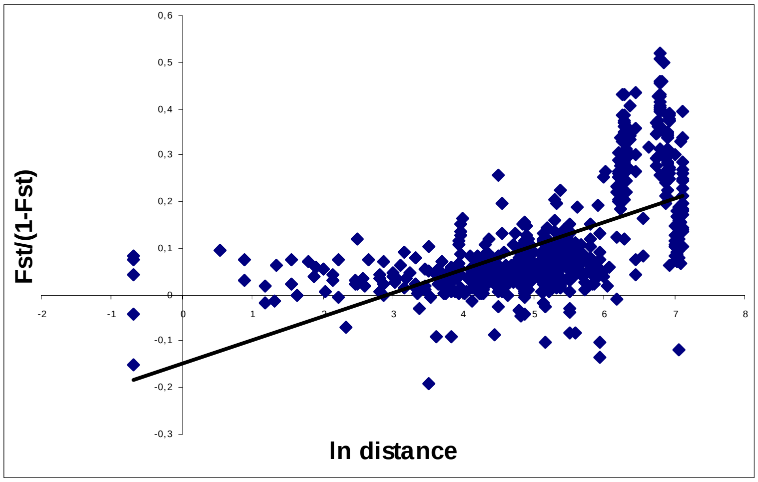

Fig. 5. Isolation by distance for *Reissita simonyi* (Klütsch et al., in prep.)

Table 2. F-Statistics for *Reissita simonyi*; average values for each of the seven loci are given

Locus	Fst	Fis
RS- 3	0.1128	0.3137
RS- 4	0.2470	0.2673
RS-5	0.1136	0.2561
RS-17	0.3043	0.3194
RS-37	0.261	0.6161
RS-44	0.1662	0.3656
RS-50	0.1138	0.3807
Mean	0.1887	0.3595

2.2 Interdisciplinary components

Between E15 and E16 a close collaboration was built up, since both projects worked on the same coevolutive system: *Maytenus senegalensis* and *Reissita simonyi*. For Project E15, Cornelya Klütsch collected a large part of the *Maytenus senegalensis* samples and provided supplemental information about localities (e. g. name, coordinates, height). E15 provided *R. simonyi simonyi* samples from Oman and both projects will closely work together for a synthesis of both genetic analyses to present a more detailed picture about the population genetic relationship between both species. Furthermore, especially project E13 offered logistical organisation for field trips and background information.

2.3 Likely benefit and applicability of results

According to results, both species seem to be highly disturbed. Fst values suggest highly fragmented populations with high inbreeding effects. To avoid extinction especially for *Hyla savignyi*, retaliatory actions could be the introduction of new water basins to reduce distances. Another aspect for conservation would be the improvement of water quality since *H. savignyi* was mainly found in clear water places with dense vegetation at the edges. For *Reissita simonyi*, an endemic to southern Arabia, conservation could effectively concentrate on the prevention of overgrazing.

2.4 Publications resulting from the project

Klütsch, C. F. C., Misof, B., Naumann, C. M. (2003): Characterization of microsatellite loci for *Reissita simonyi* (Rebel, 1899), (Lepidoptera, Zygaenidae), Molecular Ecology Notes 3 (4): 528-531.

Klütsch, C. F. C., Grosse, W.-R., Misof, B., Nasher, A.-K., Naumann, C. M. (2004): The distribution of the yellow-lemon tree frog *Hyla savignyi* (AUDOUIN, 1827): updates and extensions of previous records. Zoology in the Middle East 31: 47-52.

Grosse, W.- R. & Klütsch, C. F. C. 2004: Verbreitung des *Hyla arborea*- Komplex in Europa (in press).

Misof, B., Klütsch, C. F. C., Niehuis, O., Patt, A.: Of Phenotypes and genotypes: Two sides of one coin in taxonomy? (accepted Bonner Zoologische Beiträge).

Klütsch, C. F. C., Misof, B., Naumann, C. M. Distribution patterns of the Arabian burnet moth *Reissita simonyi* (Rebel, 1899) and the wall butterfly *Lasiommata felix* (Warnecke, 1929) in Yemen (submitted).

Klütsch, C. F. C., Misof, B.: DNA-Taxonomy: well-known science in a new dress? (in prep.).

Klütsch, C. F. C., Misof, B., Naumann, C. M.: Population genetic study of *Hyla savignyi* (Amphibia: Hylidae) suggests highly fragmented habitat structure (in prep.).

Klütsch, C. F. C., Misof, B., Naumann, C. M.: Population genetic analysis of the Arabian burnet moth *Reissita simonyi* (Lepidoptera: Zygaenidae) (in prep.).

Klütsch, C. F. C., Misof, B., Naumann, C. M.: Biogeographical pattern of *H. savignyi* (in prep.).

Darüber hinaus ist ein Artikel über die koevolutive Beziehung von *R. simonyi* und *Maytenus senegalensis* auf genetischer Basis geplant.

Abstracts

Grosse, W.- R. & Klütsch, C. F. C. 2003: Verbreitung des *Hyla arborea*- Komplex in Europa, Nordafrika und Kleinasien, Rundbrief zur Herpetofauna von NRW 24 – Dezember 2003.

Oberprieler, Ch., Kilian, N., Kürschner, H., Mies, B., Naumann, C. M., Hubaishan, M. A., Nashr, A. K., Hein, P., Klütsch, C., Meister, J., Rabe, K. 2003: Habitat fragmentation in Southern Arabia: Xerotropical ecosystems at their outer limits; Abstract. – P. 56 in: Anonymous (ed.), Gesellschaft für Tropenökologie e.V., Tagungsband, 16. Jahrestagung in Rostock, Tropische Biodiversität im globalen Wandel, 19.- 22. Februar 2003. – [Rostock]. Abstract.

Kilian, N., Oberprieler, C., Naumann, C., Meister, J., Klütsch, C., Hein, P., Hubaishan, M.A., Kürschner, H., Mies, B., Nashr, A. K., Rabe, K. 2003: Biodiversity and ecology of palaeo-African refugia in the southern Arabian Peninsula – Phyto- and phylogeographical patterns and population genetical aspects. – Talk and abstract in Conference Proceedings; International Symposium “Sustainable use and conservation of biological diversity. A challenge for society.” 1-4 December 2003, Berlin

Naumann, C., Klütsch, C. 2001: „A most remarkable insect: the Arabian Burnet moth (*Reissita simonyi*, Rebel, 1899) and its Ecology (Insecta: Lepidoptera, Zygaenidae)“ International Yemeni Science Conference. Talk and abstract in Conference Proceedings.

Klütsch, C., Misof, B, Naumann, C 2002: „Evolutionary history and biogeography of Southern Arabian faunal elements“, Talk and abstract in Conference Proceedings.

Klütsch, C. F. C., Misof, B., Naumann, C. 2003: A population genetic analysis of the tree frog *Hyla savignyi* (AUDOUIN, 1827) from Southern Arabia, - 9. Meeting of PhD students in Evolutionary Biology, Fiesch/ Schweiz, Talk and abstract in Conference Proceedings.

Klütsch, C., Misof, B., Naumann, C: Analysis of the population structure of *Reissita simonyi* Rebel, 1899 (Zyganidae, Lepidoptera) using microsatellites. 10th PhD meeting of Evolutionary biology, Shrewsbury, UK, 28.08.04-3.09, Talk and abstract in Conference Proceedings.

3. Capacity building

3.1 Technical capacity building

DAAD stipendium for Prof. Dr. Abdul Karim Nasher: Prof. Nasher was introduced in molecular techniques like DNA extraction, PCR, cycle-sequencing, alignment of sequences, statistical analysis. Furthermore, he and his wife, Dr. Massa´a Al-Jumaily were able to do literature research in the library for their scientific work.

Another project under way is a book donation for the biological library in Sana´a. Therefore, Prof. Dr. Clas Naumann, Prof. Dr. Abdul Karim Nasher and Cornelya Klütsch worked together to prepare a proposal for the DFG.

Moreover, Cornelya Klütsch prepared a donation (camping equipment) for the ecological investigation group of Sana´a University under guidance of Prof. Dr. A.-K. Nasher. This camping equipment will be of use for field trips for further investigations in Yemen.

3.2 Students and scientific staff trained

Doctoral thesis: Cornelya Klütsch, University of Bonn/ ZFMK – Evolutionary history and phylogeography of Southern Arabian faunal elements.

DAAD stipendium: Prof. Dr. Abdul Karim Nasher, University of Sana´a- Introduction in molecular techniques