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Distribution and Ecological Range of the Alien Plant Species *Mikania micrantha* Kunth (Asteraceae) in Taiwan

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ABSTRACT: In the past two decades *Mikania micrantha* Kunth, a climbing plant species originating from tropical America, has spread across Taiwan. It can now be found frequently in the lowlands and lower mountain areas up to 1,000 m a.s.l. in the centre and south of the island. *Mikania micrantha* is considered a problematic invasive alien plant species which is said to cause economical as well as environmental damage. This study investigated the ecological site characteristics of *M. micrantha* in Taiwan. 112 vegetation surveys were carried out in habitats where the alien plant was present. A comparison between sites with a high and a low abundance was carried out in order to assess which factors especially influence the extensive spread of the plant. Furthermore, the influence of disturbances was examined. Results showed that *Mikania micrantha* grows very dense in habitats which are characterized by good light conditions combined with vertical structures, such as trees. Results revealed that this invader occurs most frequently in agricultural fallows and wastelands, but it could hardly be found in the intensively managed plantations in the investigation area. Results provide great evidence that the plant is strongly influenced by disturbances, but only if impacts occur rarely.

Key words: Alien plant species, Biological invasions, Disturbance, Land abandonment, Land use

INTRODUCTION

The impacts of biological invasions by alien species are today recognized as serious environmental and socio-economic problems worldwide (Pyšek et al. 1995, Cronk and Fuller 1995, Drake et al. 1989, Mooney and Hobbs 2000, GISP 2003, Nentwig 2008). There is abundant evidence that plant invasions can cause serious damage to the environment and the human society (e.g. IUCN 2000, Pimentel et al. 2000, Perrings et al. 2002, GISP 2003), but in some cases it is questionable whether an alien species really poses problems in its introduced range. Since a lot of money can be spent on control measures against invasive alien species (Starfinger et al. 2003), it should be carefully examined what kind of consequences emanate from the occurrence and spread of introduced plants in reality before large scale management programs are initiated.

Mikania micrantha Kunth, an herbaceous perennial climber of the family Asteraceae, originating from subtropical and tropical America (Holm et al. 1977) is today widespread in many subtropical and tropical Asian countries. Its non-native range stretches from India, where the plant was introduced on purpose during the Second World War (Parker 1972), to Indonesia, across the Pacific Islands and to southern China (Waterhouse 1994, Zhang et al. 2004). The plant is reported to cause serious problems outside of its native geographic distribution, especially in agricultural and silvicultural systems of the moist tropics in Southeast Asia and the Pacific (Parker 1972, Waterhouse 1994). Today, it is considered one of the 100 worst invasive alien species in the world (GISD 2006).

Throughout its native range, *M. micrantha* is a common plant, but it is seldom considered a weed (Holm et al. 1977). It grows primarily in open and moist habitats, for example along streams or lake margins, on the edge of forests, in damp lowland clearings, and along roadsides (Holm et al. 1977, Holmes 1993). The plant occurs at elevations up to 2,000 m a.s.l. and it was even observed in high mountains growing at 3,000 m in Bolivia (Holm et al. 1977).

Mikania micrantha can reproduce generatively as well as vegetatively. It produces a large number of seeds (Kuo et al. 2002), which are easily dispersed by wind, but also in the hair of animals or in clothing (GISD 2006, PIER 2007). Seeds germinate especially well under light-intensive conditions and in disturbed areas (Kuo et al. 2003, Hsu and Chiang 2003, Hu and But 1994). Vegetative propagation can be considered at least as important as the reproduction by seeds (Holm et al. 1977, Hsu and Chiang 2003). Especially in

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areas with open soil, the American climber can develop stems across the ground which are similar to runners. Because of the plant's ability to regenerate from stem sections with only one node, control measures by cutting or mowing are problematic if the cut material is not removed properly (Holm et al. 1977). *Mikania micrantha* also has a strong ability to resprout from the base after being cut back (Kuo et al. 2003). The plant can climb up to more than 15 m in height (Holm 1993, Zhang et al. 2004), supporting itself in other vegetation or any kind of vertical structure. It has the ability to develop dense carpets on top of other plants, effectively smothering them from light and thus negatively affecting their growth (e.g. Holm et al. 1977, Huang et al. 2000b, Kuo et al. 2003).

Mikania micrantha is regarded as a pest in a great variety of agricultural and silvicultural production systems across Asia, especially in young plantations of perennial crops, such as tea, rubber, banana, oil palm, and teak (Parker 19972, Holm et al. 1977, Sankaran et al. 2001, Feng et al. 2002, Zhang et al. 2004, GISD 2006). It is reported that *M. micrantha* seriously damages different ecosystems by smothering other vegetation (Feng et al. 2002, Zhang et al. 2004), but few studies go into detail defining the actual consequences for the environment or the economy in the Chinese region (e.g. Sankaran et al. 2001).

According to Chiang et al. (2002), the first occurrence of *M. micrantha* in Taiwan was recorded in 1986 in Wan Luan, Pingtung County. In Taiwan, the alien plant is commonly found on abandoned land, in rarely managed orchards and betel nut plantations, in forest clearings, along the edge of forests and along roadsides (Hwang et al. 2003). *Mikania micrantha* is reported to seriously damage young tree plantations and orchards (Kuo et al. 2003) and it is considered as a threat to the native flora (Hwang et al. 2003). In order to control a further spread of the American climber on the island a lot of resources have been invested by governmental as well as civil conservation organizations (Kuo et al. 2003).

The objective of this study is to identify the ecological characteristics of *M. micrantha* habitats in Taiwan. The question whether there are differences between habitats where the plant occurs frequently and habitats where the plant occurs less frequently was addressed. The study aimed to find out those driving factors, which especially contribute to a high or low abundance of the climber. In this context, it was investigated whether the alien plant occurs with high densities in certain land-use types or vegetation formations, and if *M. micrantha* prefers certain soil conditions. By looking at these two parameters, the questions whether the plant favors certain light conditions, and if it is influenced by the soil moisture regime were indirectly taken into consideration. Further, it was assessed whether there is a correlation between disturbances, particularly human-induced disturbances, and the extensive spread of *M. micrantha*.

This study tested four hypotheses: (1) In Taiwan, *M. micrantha* prefers sites with good light conditions and, therefore, preferably occurs in more open habitats. The plant does not invade dense forest stands. (2) The American climber can be found frequently in anthropogenically influenced habitats and disturbances further the establishment and spread of *M. micrantha*. (3) The alien species is especially abundant on land, which has been subject to disturbances in the past, but is currently not used, for example agricultural fallows and wastelands. (4) The plant has an increased competitive ability on sites with a good moisture regime.

This study assessed, which habitats or land-use types are potentially at a higher risk to be invaded by the climber. Consequently, the work at hand contributes to the knowledge about the ecology of *M. micrantha* in Taiwan. A better understanding of the ecology of the plant is very important for the development and performance of effective control measures.

MATERIALS AND METHODS

Study Area

The study area is situated in the south-western lowlands of Taiwan (R.O.C.), in northern Pingtung County (22° 37' N, 120° 35' E). The climate is tropical with a mean annual temperature of 24.7℃ and a mean annual precipitation of 2,540 mm (Central Weather Bureau, Taiwan 1998～2006; data retrieved for Kaohsiung County, since Pingtung County does not have a weather station). The summer months are characterized by south-western monsoon, which brings thunderstorms and typhoons with heavy rainfall, often causing flooding (Geography of Taiwan 2001). About 80% of the annual precipitation falls during the summer, while winters are dry (ibid.).

The landscape of the study area is primarily characterized by lowlands, which are bounded by the DaWu Mountain range to the east. Although DaWu Mountain rises up to 3,000 m a.s.l., the study area comprises only the lower mountains, which are below 1,000 m.

The study area is strongly influenced by human activities and today agriculture and settlements characterize the landscape. The original vegetation has almost completely been destroyed, only few remnants of natural forest, mainly *Ficus-Machilus* forests, can still be found in rugged terrain or protected sites (Hsieh and Yang 1994). Small patches of secondary forest, often predominated by *Macaranga tanarius* and *Broussonetia papyrifera*, occur on abandoned lands. The major crop is the betel nut palm, but other perennial crops, such as pineapple, mango, lychee, longan, banana, papaya, guava, citrus, wax apple and coconut are also cultivated in large quantities. Other common land-use types in the area are forest plantations, agricultural fallows, and wastelands.

The region was chosen for this study since Pingtung County is one of the three counties of Taiwan with a high abundance of *Mikania micrantha*. Moreover, research about the American climber has already been conducted at the Department of Forestry, National Pingtung University of Science and Technology (NPUST), Pingtung County (Kuo et al. 2002, Kuo et al. 2003). NPUST campus was strategically suitable as a base for investigating a wide range of *M. micrantha* habitats. The main investigation area stretched about 12 km from north to south along the western edge of DaWu Mountain range and was approximately 4.5 km wide (Fig. 1). This area only encompassed habitats of the lowlands and hill regions. In order to cover a broader spectrum of *M. micrantha* habitats, further surveys were carried out in three locations outside the main investigation area. By this means, habitats along the foothills of the mountains, habitats of the lower mountain region, as well as habitats near to the coast were included in the investigations (Fig. 1).

METHODS

Field investigations in the study area were carried out from June to September 2006. The first work phase included a general survey

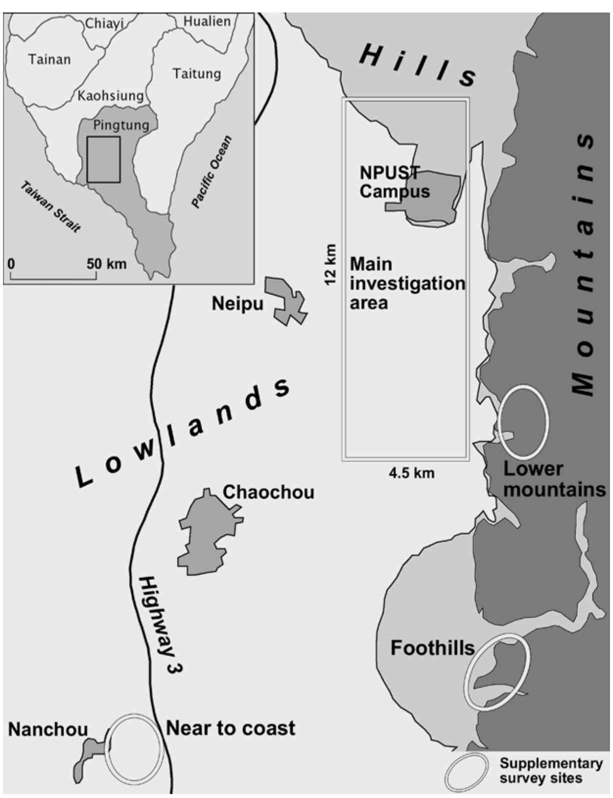

Fig. 1. Study area with main investigation area and three supplementary sites.

of *M. micrantha* occurrences within the study area. Land use was broadly categorized following the biotope type mapping standards assembled by Knickrehm and Rommel (1995). Seven land-use types were distinguished: currently not used land (CNUL), managed green spaces (MGS), agricultural plantations (AP), agricultural tree plantations (ATP), forest (F), settlement (S) and water (W). Since *M. micrantha* also occurred along property boundaries (PB), along the edge of watercourses (WE) as well as along the edge of forests (FE), these habitat types were treated as separate land use categories, although they do not represent land-use types of their own. Descriptions of all land-use categories can be found in Table 1.

General Survey of Occurrences

One main investigation area was chosen for collecting area-covering information about the distribution of *M. micrantha* as well as about the land use. In order to investigate a broader spectrum of *M. micrantha* habitats in the region, three additional areas outside the main investigation area were selected for conducting further vegetation surveys. Large-scale prints of aerial photographs (source: Agricultural and Forestry Aerial Survey Institute 1999～2002) served as working maps. Along with the recording of the occurrences of *M. micrantha*, its abundance was estimated in two grades: high (percent cover > 25%) and low (percent cover < 25%). The 25% threshold was chosen according to Braun-Blanquet's (1964) cover values. Subsequently, a map with two layers, one containing vector data of the land use for the entire investigation area, and the other including vector data of all *M. micrantha* occurrences, was created using the GIS application ArcMap (ESRI). In order to systematically choose sites for the detailed vegetation surveys, a grid with cells representing approximately 400 m × 400 m was placed on top of the map. It was demanded to carry out at least one vegetation survey in each grid cell where the alien species was present.

Due to restricted accessibility of private land, it was not possible to precisely record every single occurrence of *M. micrantha*, or identify the land-use type of 100% of all properties within the investigation area. However, the mapping covered about 80% of the *M. micrantha* sites and the land use (Appendix 1).

Vegetation Analysis

In a second step, detailed vegetation surveys, including an assessment of disturbances as well as the collection of soil samples, were carried out. The previously created map allowed a systematic selection of *M. micrantha* sites. Including the surveys outside the actual investigation area, a total of 112 sample plots were analyzed. The two *M. micrantha* abundance grades were represented as follows: 39 sites showed a low abundance of *M. micrantha* and 73 sites represented a high abundance of the invader. The size of the sample plots was 25 m^2. All plant species within the sample plots were recorded and the percent cover was estimated following the method of Braun-Blanquet (1964, see also Mueller-Dombois and Ellenberg 1974). Plant specimens were identified according to Huang et al. (1994) or with the help of the Provincial Pingtung Institute (PPI) herbarium at National Pingtung University of Science and Technology (NPUST). The nomenclature of species followed Huang et al. (1994). The mean cover percentage and the mean growth height

Table 1. Description of land-use categories / types

Land-use category	Habitat structure	Management activities / disturbances
Currently not used land (CNUL)		
Agricultural fallows, abandoned orchards, abandoned pineapple plantations, other former agricultural fields, abandoned grasslands, clearings inside of forests or within other tree dominated formations, wastelands	Vegetation structure ranges from open (tree canopy very open, cover percentage < 5%) to more closed formations (canopy cover > 35%); shrub and tree succession, tall grass or herb communities characteristic	Previously influenced by human activities, but not in use since several months to some years
Managed Green Spaces (MGS)		
Habitats along roads, dykes along watercourses or around agricultural fields, parks and gardens, graveyards	Very diverse open grass or forb dominated formations to open shrub and tree formations	Management measures carried out at least twice a year; e.g. cutting or mowing, occasional application of herbicides
Agricultural Plantations (AP)		
Agricultural land except for tree plantations, banana and papaya plantations	Usually very open; vegetation cover generally dominated by one single plant species	Management measures similar to those in agricultural tree plantations
Agricultural Tree Plantations (ATP)		
Actively managed betel nut, betel nut-banana or betel nut-coconut plantations, fruit tree orchards, nursery plantations	Usually relatively open formations with little undergrowth, rarely dense herb layer	Management measures carried out at least twice a year, but usually more frequently; e.g. use of herbicides, cutting, mowing, harvesting
Forest (F)		
Natural forests (secondary forests), silvicultural plantations, bamboo groves	Relatively closed canopy	Occasional maintenance of paths and roads
Settlement (S)		
Settlements, industrial areas, single buildings and military grounds	Percentage of sealed surfaces is above 80%	Sealing of surfaces
Water (W)		
Artificial (e.g. fish ponds) and natural area-covering water surfaces, rivers	Water body	Weeding in and draining of artificial ponds; water flow
Property Boundary (PB)		
Linear habitats along fences	Good light conditions; herbaceous vegetation predominant; usually many twining species	Occasional application of herbicides
Forest edge (FE)		
Habitats along the edge of secondary forests or silvicultural plantations	Usually well developed herbaceous layer; in some places shrubs	Rare to regular management measures, e.g. mowing or cutting
Watercourse edge (WE)		
Mainly dykes along watercourse	Usually grass vegetation, but shrubs and trees also frequent; generally rather open; wet sites	Occasional disturbances by flooding; some areas managed by mowing

Table 2. Characterization of disturbances

Disturbance type	Visual signs
Anthropogenic disturbances	
Mowing, cutting	Cut grass or branches
Driving with vehicles	Tracks on ground
Use of herbicides	Dead plants among otherwise vital vegetation
Grazing	Livestock
Earth moving	Bare ground, tracks, dumped earth
Dumping of waste	Presence of waste, e.g. household waste, plastic items, rubble, earth or plant material
Natural disturbances	
Natural death of trees	Fallen trees, broken off tree branches
Wind	Fallen trees, broken off tree branches
Flooding	Uprooted vegetation and/or bare ground along watercourse edge

for each vegetation layer (herb, shrub, and tree) were recorded. General information, including the coordinates of each site, slope inclination, habitat type, and land-use category, was collected.

The abundance of disturbances was assessed visually based on signs of management measures and natural impacts, which cause an opening of the vegetation (Table 2). Following this, the frequency with which disturbances influence a site (the history of impacts) was estimated. An important indicator for the disturbance frequency was the structure of the vegetation. According to the growth height of plants, especially of woody species, the disturbance frequency was rated either frequently or rarely. The third category abandonment included all land where currently no disturbances were noticed (Table 3).

Soil Sampling and Analysis

Soil samples were collected from 31 *M. micrantha* survey plots. Sites for the collection of soil samples were selected in a way that all possible combinations of soil types and land-use types of the area were represented. By studying soil maps (Taiwan Provincial Mountain Agriculture and Pasture Development Bureau 1984) prior to the investigations, a broad overview of the pattern of soil types in the study area could be gained. The distribution of soil types was then matched with that of the different land-use types. The soil samples were taken from the center of the plot area and comprised the upper 30 cm of soil.

All soil samples were air-dried and analyzed in the soil laboratory at the Department of Environmental Engineering, NPUST. The following soil parameters were determined: soil pH, electric conductivity (EC), total nitrogen, organic carbon content, C/N ratio and available phosphorous. Analysis methods were based on McLean (1982), Rhoades (1982), Keeney and Nelson (1982), Nelson and Sommers (1982), and Kuo (1996).

Data Analysis

In order to describe the habitat conditions of *M. micrantha*, the following parameters were taken into consideration: habitat and land-use type, vegetation formation, vegetation structure (mean cover percentage of the layers), occurrence of accompanying alien species, occurrence of indicators for soil moisture among the recorded plants, frequency of disturbances, and soil parameters. Certain parameters were determined as follows. All survey sites were assigned to three broad vegetation formation categories, i.e. tree, shrub, and herbaceous formation. This was based on the mean cover percentage of the layers. Tree formation comprised all sites where the mean cover percentage of the tree layer (> 5 m) exceeds 25%, and shrub formation comprised all sites where the mean cover percentage of

Table 3. Classification of the disturbance frequency based on the vegetation structure

Disturbance frequency	Vegetation structure	Frequency of management activities	Exemplary land-use types
Frequently (= currently managed)	Height of vegetation, esp. shrubs and trees, low; open vegetation; herbaceous vegetation predominant	Roughly every 6 months, in many cases more frequently	Managed agricultural and tree plantations, gardens, parks, roadsides
Rarely (= occasional measures)	Height of vegetation, esp. shrubs and trees, more developed; vegetation more closed	Less than twice a year	Managed agricultural and tree plantations, gardens, parks, roadsides
Abandonment	Height of vegetation, esp. shrubs and trees, more developed; vegetation more closed; high presence of woody species	Disturbance impacts in the past, but currently not managed	Agricultural fallows, wastelands

the shrub layer (1∼5 m) exceeds 25%. The remaining sites belonged to herbaceous formation.

Information about the origin of species and their categorization as alien plants in Taiwan was gathered from Whiffin (1973), Morton (1987), Huang et al. (1993∼2003), Wu et al. (2004), PIER (2007), Erhardt et al. (2000), Ng and Corlett (2002), Boufford et al. (2003), French et al. (2003), Silva et al. (2004), ISSG (2005), Danida Forest Seed Centre (2007), A Global Compendium of Weeds (2007), Federal Noxious Weed Disseminules of the U.S. (2007), eFloras (2007a,b), and NewCROP (2007).

Plant species were identified as indicators for soil moisture based on information of Huang et al. (1993∼2003), PIER (2007), eFloras (2007a,b), Clayton et al. (2006 onwards), and USDA and NRCS (2007).

The habitat and land-use type, the mean cover percentage of the vegetation layers as well as the frequency of disturbances, were directly assessed in the field.

In a first step, all parameters were evaluated in order to characterize the site conditions of *M. micrantha* habitats in general. Secondly, it was assessed whether some parameters could be associated with a high abundance of this species. Therefore, all parameters were compared between the two *M. micrantha* abundance groups (group I = sites with high abundance, group II = sites with low abundance). Differences between the two groups were statistically analyzed with the SPSS program, applying the non-parametric Mann-Whitney U test.

Differentiation of Site Conditions

According to the methodology of Ellenberg et al. (2001), this analysis examined ecological characteristics of some of the plant species present in the *M. micrantha* habitats in order to obtain more information about the site conditions. The aim was to find out whether there are differences in the site conditions between habitats with a high and a low abundance of *M. micrantha*. Therefore, information about the ecological characteristics of such species, which showed a significant difference between the two *M. micrantha* abundance groups, was collected.

Ecological characteristics of these species included the preferred range of soil pH, soil fertility, moisture requirements, tolerance of salinity, demand for light intensities, and vulnerability to disturbances. Information about the species was gathered from Holm et al. (1977), Duke (1983), Starr et al. (2003), ISSG (2005), Cook et al. (2005), PIER (2007), ICRAF (2007), and SANBI (2007).

Comparison of Land-Use Types

In order to find out whether *M. micrantha* is especially abundant in currently not used land, all land-use types were compared between areas where the plant is present and areas where it is absent. Analyzing the vector map in ArcMap (comp. *General Survey of Occurrences*), the area coverage of each land-use type for the entire investigation area was calculated. The layer with *M. micrantha* occurrences was then intersected with that of the land use, obtaining information about the area coverage of land-use types for all areas with *M. micrantha*. Subsequently, the frequency of each land-use type was estimated for all areas where the American climber is present and all areas where it is absent.

Analysis of the Disturbance Frequency

At first, the percentage distribution of each of the three disturbance frequency categories was estimated. In a next step, the category abandonment was excluded and the frequency of the remaining categories, frequently and rarely, was assessed.

RESULTS

Mikania micrantha Habitats

Dense, area-covering occurrences of *M. micrantha* can rarely be found within the study area. If the plant colonizes larger areas, its abundance is usually low. In many cases, the American climber grows in small patches, forming linear or punctual populations.

In the investigation area, *M. micrantha* colonizes abandoned betel nut plantations, abandoned orchards and abandoned pineapple fields, as well as currently not managed grassland (with shrub or tree succession). Furthermore, the climber grows along the edge or in gaps of forest plantations, for example in *Swietenia macrophylla, Calophyllum inophyllum, Araucaria spec.*, and *Juniperus spec.* or mixed species plantations, along the edge of bamboo groves, and secondary forests. In some cases, it can also be found within managed betel nut plantations, but it grows mainly along the fences around plantation properties (Fig. 2). *M. micrantha* often grows in

Fig. 2. *Mikania micrantha* habitat along fence.

mango and wax apple orchards, which are currently managed. Wastelands, transitional areas between open grassland and tree formations and areas along watercourses and roadsides represent other frequent habitats of the plant.

Parameters Determining *M. micrantha* Habitats

Land-Use Types

The land-use type CNUL attains the highest frequency among all *M. micrantha* sample plots (45.5%), the category MGS is second frequent (19.6%), followed by PB (13.4%) (Fig. 3). ATP, F, FE, and WE each account for less than 10%. The comparison of the frequency of land-use types between areas where *M. micrantha* is present and areas where it is absent shows that the majority of land-use types in areas without the alien climber belongs to the category ATP and the majority of land-use types in areas with *M. micrantha* belongs to CNUL (Fig. 4).

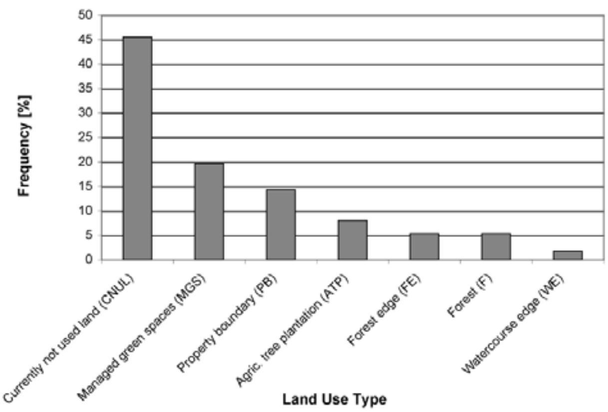

Fig. 3. Frequencies of land-use types among *Mikania micrantha* sample plots.

Comparing the frequency of land-use types between both *M. micrantha* abundance groups, percent values are very similar for the categories CNUL, MGS, ATP, and WE. Only the category PB attains a slightly higher percent value in group I and F as well as FE attain higher values in group II (Fig. 5).

Vegetation Structure

In general, *M. micrantha* occurs in relatively open habitats, as expressed in a relatively low mean cover percentage of the tree canopy (16%). The undergrowth is generally well developed, although the mean cover percentage of the herb layer does not exceed 43%. Even though high light supply in the habitat prevails, the vegetation formations are not completely open. Habitats are often diversely structured, which is represented by a mean cover percen-

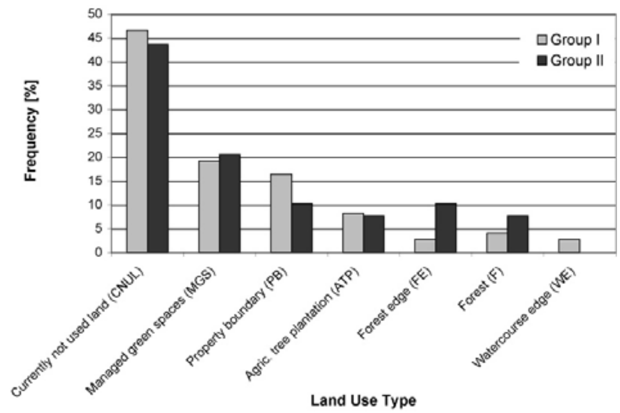

Fig. 5. Frequencies of land-use types within *Mikania micrantha* abundance groups (group I = high abundance, group II = low abundance of *Mikania micrantha*).

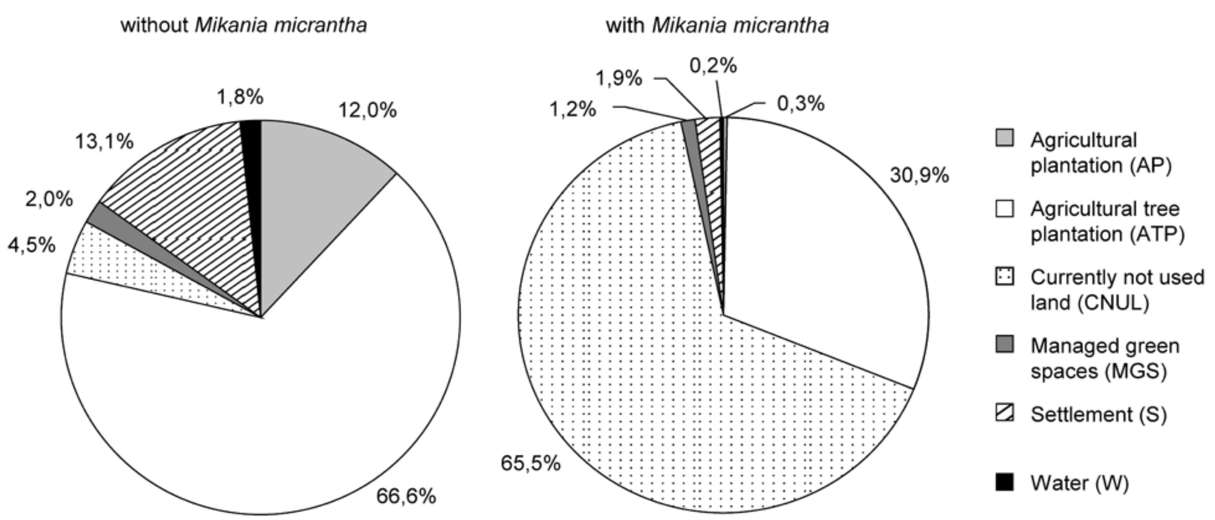

Fig. 4. Frequencies of land-use types in areas without and with *Mikania micrantha*.

tage of 22% of the shrub layer.

The mean cover percentage of the tree, shrub, and herb layer is very similar in both *M. micrantha* abundance groups. The three layers were not significantly different between the two groups (Mann-Whitney U test; $p > 0.08$). However, in those sites where the alien species occurs with a high abundance (group I) the coverage of the three layers is slightly lower (Fig. 6).

Regarding the three vegetation formations there is a significant difference between the two *M. micrantha* abundance groups (Mann-Whitney U test; $p < 0.05$). In group I, herbaceous formations are predominant (66%), however, shrub formations still amount for 26%. In group II, half of the sites constitute woody formations, which suggests that conditions are shadier here.

Soil Parameters

Box plot diagrams of data of all soil parameters are presented in Fig. 7. The soil texture in most cases of the soil samples is medium sandy clay and medium clay loam. The soil pH values range from 3.6 to 6.5, while 50% of the values lie between a pH of 4.4 and 5. Therefore, most of the soils are acidic, only some cases are near to a neutral pH. In general, an electric conductivity (EC) above 2 dS/m can potentially have a negative effect on plant growth, and a soil with an EC value above 4 dS/m is considered saline (Brady and Weil 2002). The EC values of all soil samples are below 0.5 dS/m, which indicates that soil salinity is not present in the surveyed sites. The organic carbon content of the soil samples ranges between 0.38 and 3.08%, while 50% of all values lie between 1.47 and 1.93. Total nitrogen ranges from 0.05 to 0.22%. The C/N ratio of 50% of the samples lies between 11.12 and 14.81.

Available phosphorous ranges between 3.5 and 29 mg/kg soil, while half of the values lie between 7.14 and 17.69 mg/kg. The phosphorous values of 50% of the soil samples are below 5 mg/kg.

Occurrence of Accompanying Alien Species

Habitats of *M. micrantha* are characterized by a large number of alien species, reaching a percentage of 44% referred to all sample plots. Indigenous species (Asia and Palaeotropis) occur with a frequency of 45.4%, pantropical and cosmopolitan species as well as cultivars were registered separately and they account for almost 5.8%. Species with an uncertain origin attain a percentage of 4.7% (Fig. 8). The comparison shows that alien and indigenous species attain almost the same frequencies. The major part of alien species originates from America, the second most frequent origin is Africa, and a small percentage of alien species originate from other Asian

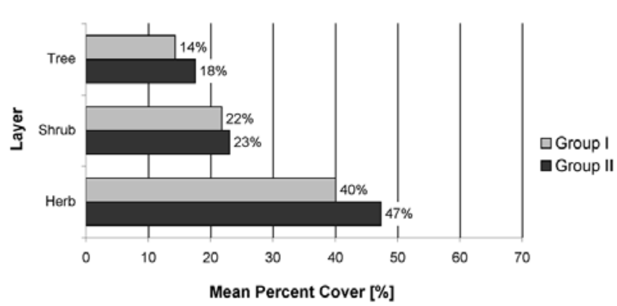

Fig. 6. Mean percent cover of vegetation layers (without *Mikania micrantha*).

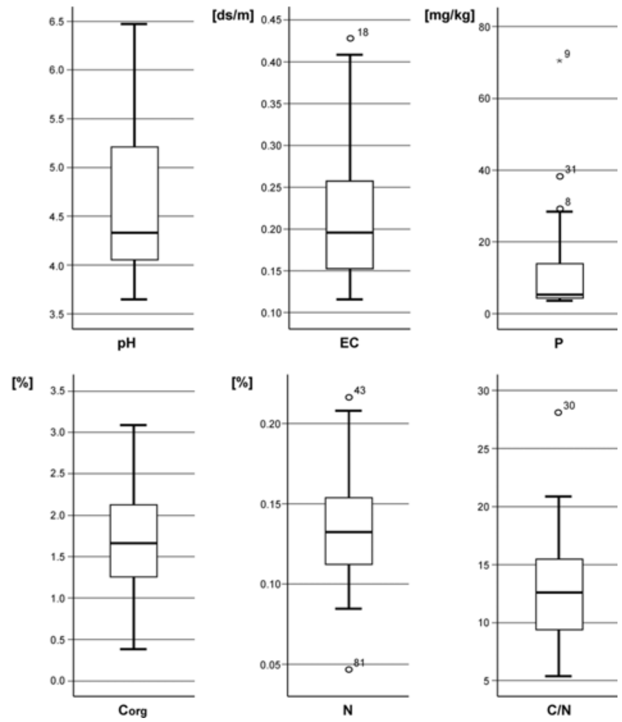

Fig. 7. Box plots of data of soil parameters (line inside box = median, ° = outlier, * = extreme).

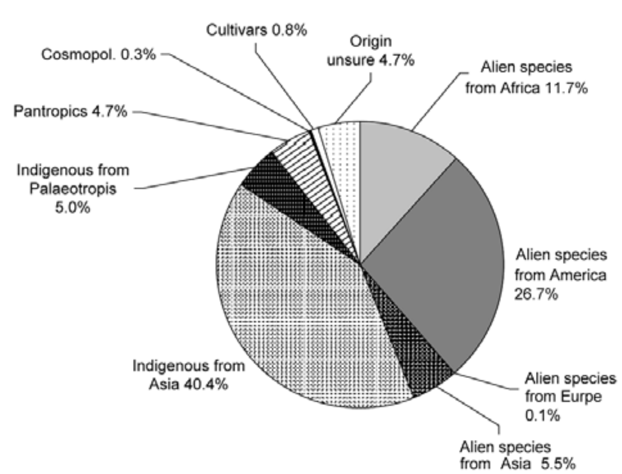

Fig. 8. Percentage of alien species according to their natural distribution area.

countries. The natural range of most of the indigenous species includes several Asian countries. Only a small number has its distribution throughout the Palaeotropics.

Moisture Indicators

Species which have been identified as soil moisture indicators are the following vascular plants: *Althernanthera sessilis*, *Anisogonium esculentum*, *Basella alba*, *Brachiaria mutica*, *Commelina diffusa*, *Cyperus distans*, *Cyperus imbricatus*, *Eclipta prostrata*, *Equisetum ramosissimum* ssp. *debile*, *Kyllinga brevifolia*, *Ludwigia hyssopifolia*, *Ludwigia octovalvis*, *Panicum repens*, *Paspalum conjugatum*, *Paspalum longifolium*, and *Scleria terrestris*. The analysis of these plants shows that moisture indicators occur slightly more frequently in group I (12.9%) compared to group II (9.1%). In 64% of all sites in group I at least one moisture indicator could be found, in group II there was at least one moisture indicator in 46% of the sites.

Ecological Characteristics of Indicator Species

Applying the Mann- Whitney U test, all plant species present in the 112 sample plots were compared between the two *M. micrantha* abundance groups. Species with a significant difference (Mann-Whitney U test; $p < 0.05$) between the groups are: *Ipomoea triloba, Macaranga tanarius, Panicum maximum*, and *Trema orientalis*. Two species, *I. alba and Passiflora foetida*, showed a statistically significant tendency (Mann-Whitney U test; $p < 0.08$). *Ipomoea alba, Macaranga tanarius*, and *T. orientalis* occur more frequently in group I (high *M. micrantha* abundance), the other three species were more frequent in group II (low *M. micrantha* abundance).

The ecological characteristics of species in group I can be summarized as follows: *I. alba* and *Trema orientalis* both prefer moist sites on well-drained soil, but the latter species can be found in a wide range of habitats. This also applies to *M. tanarius*. All three species are frequent in disturbed areas. Ecological characteristics of species in group II are: *I. triloba* occurs in a wide range of habitats, while *P. maximum* and *P. foetida* favor wet areas and more shady conditions. All three species grow well in disturbed habitats.

Assessment of Disturbances.

The evaluation of the disturbance frequency shows that the majority (60%) of those *M. micrantha* sites, which are not abandoned, is exposed to rare disturbances. 40% of the sites are influenced by frequent disturbances.

DISCUSSION

Habitat Structure

We found out that the majority of sites with a high abundance of *M. micrantha* belongs to herbaceous formations and the herb layer attains on average the highest densities of all layers, illustrating a preference of this alien species for open vegetation formations. In sites with a low abundance of the climber, a high percentage of woody formations can be noticed and the land use categories F and FE are slightly more frequent there. This shows that the plant grows less densely under shadier conditions. The alien species was not present in dense forest stands; it occurred only along the edge of forests or in clearings. The comparison of ecological characteristics of significant species (indicator species) between the two *M. micrantha* abundance groups also reveals that site conditions in group II (low abundance) are slightly shadier. Similar habitat preferences of *M. micrantha* have also been observed for its native as well as its non-native range of distribution (Holm et al. 1977, Sankaran et al. 2001). These results support the hypothesis that the alien plant grows best in open habitats with good light conditions.

Nevertheless, a significant number of *M. micrantha* habitats is not completely open. One third of all sites in the abundance group I (high abundance) belongs to woody formations, indicating that the plant can as well grow densely in habitats where shrubs and trees are predominant. Although *M. micrantha* has the ability to rapidly colonize open ground and form dense mats (Holm et al. 1977), it was observed that the climber is less frequent in open habitats with a dense grass layer. In such habitats, *M. micrantha* attains only punctually a high coverage where vertical structures, such as tall herbaceous species, or medium-sized shrubs and trees, are present. The invader seems to be most competitive with the presence of supporting structures, where it can climb on, thus raising itself out of the herb layer. This observation is supported by the result that habitats along property boundaries are more frequent in sites with a high *M. micrantha* abundance. The characteristic feature of these habitats is a fence, providing an ideal vertical structure for twining plants to climb up. Furthermore, habitats along fences are usually open towards both sides and therefore light is abound. This suggests that *M. micrantha* develops especially dense populations in locations where supporting structures combined with good light conditions are present. It could also explain why the invader occurs frequently in young tree plantations (Sankaran et al. 2001) and other perennial crop plantations (Holm et al. 1977) throughout Asia.

Soil Conditions

The analysis of soil samples shows low values for pH and low contents of total nitrogen as well as organic carbon. These results accord with the general situation of soil conditions in the study area. The average content of soil organic carbon in rural soils of Taiwan is 2% (Chen and Hseu 1997). In 50% of the sampled soils, the available phosphorous is above 5 mg/kg soil. A phosphorous content above 5 mg/kg soil is considered ideal for plant growth (Foth and Ellis 1988). Nevertheless, phosphorous values of half of the soil samples were below 5 mg/kg, and therefore not suitable for plant growth. Altogether, the alien climber grows on soils with rather low fertility and generally acidic reaction in the investigation area. Similar results have been observed in previous studies about *M. micrantha* in Guangdong province, China (Zhang et al. 2004, Ye and Zhou 2001). This leads to the conclusion that soil conditions are not a crucial factor for the establishment and spread of *M. micrantha.*

It was assumed that the American climber prefers sites with a good soil moisture regime in Taiwan, since this is the case in its native range (Holm et al. 1977). Sankaran et al. (2001) even assume that lack of water may be a limiting factor for the growth of *M. micrantha.* This is supported by the analysis of ecological characteristics of significant plant species (indicator species), which shows that site conditions are rather moist in both *M. micrantha* abundance groups. The assessment of moisture indicators reveals that slightly more soil moisture indicator plants can be found in sites with a high *M. micrantha* abundance. Nevertheless, the percentage of soil moisture indicators in sites with a low *M. micrantha* abundance is very similar to that of sites with a high abundance of the plant.

Influence of Disturbances

The landscape of the lowlands in Pingtung County has been strongly altered by human activities, and only few areas with natural vegetation can still be found (Hsieh and Yang 1994). Therefore, it is not surprising that the majority of *M. micrantha* habitats within the study area is anthropogenically influenced. Even in the lower mountain regions, the alien plant exclusively occurs in habitats, which are subject to management activities, for example along roadsides and forest margins. These observations support the hypothesis that the American climber can be found frequently in anthropogenically influenced habitats.

The assessment of the disturbance frequency shows that the majority of *M. micrantha* sites (excluding sites of the land use category CNUL) are subject to rare disturbances and less sites are influenced by frequent disturbances. This supports the hypothesis that occasional disturbances further the occurrence of the plant. For example, *M. micrantha* is second abundant in managed green spaces (MGS). Habitats in this land-use category are usually subject to rare management activities (mowing, cutting), which keep the vegetation open. In between management measures, the climber has the chance to recover. The plant might not grow up into the tree canopy, but it develops dense mats in the herb layer. The invader is also very abundant along property boundaries. Here, the application of herbicides is the major management measure. In most cases of these habitats, herbicides are regularly applied but not very frequent. The comparison of the frequency of land-use types between areas where *M. micrantha* is present and where it is absent shows that the plant does not occur in habitats where management measures are carried out very frequently.

This study shows that disturbance seems to be a crucial factor for the establishment and spread of *M. micrantha*. This generally applies to the growth habits of plant invasions (Mack 1989, Hobbs 1989) and has been observed for *M. micrantha* in other countries, for example in northern India, where the climber rapidly invades land, which is influenced by fire due to slash-and-burn agriculture (Swamy and Ramakrishnan 1988). Nevertheless, the alien species is only promoted if disturbances occur occasionally.

Influence of the Abandonment of Land

The assumption that *M. micrantha* is especially abundant in agricultural fallows and wastelands is confirmed by this study, which reveals that the majority of *M. micrantha* habitats belong to the land-use type ‘currently not used land’ (CNUL). Nevertheless, habitats within this land-use category have, in general, previously been used, which means that some form of disturbance influenced the ecosystem in the past leading to rather open vegetation formations.

The characterization of *M. micrantha* habitats suggests that there is a relationship between the initiation of succession and the occurrence of the climber. *M. micrantha* illustrates a preference for sites, which have been subject to disturbances in the past, but are currently not used and are characterized by secondary plant succession. The alien plant seems to rapidly colonize habitats in an early successional stage and reaches its highest abundance between an early and a medium successional stage. As succession progresses conditions become shadier and the abundance of *M. micrantha* slowly decreases (Fig. 9).

It is possible that the invader can establish very well in pioneer communities, which are characterized by a high proportion of ruderals (*r*-strategists), because there is less competition of other plants (comp. Rejmánek 1989). With the emergence of woody spe-

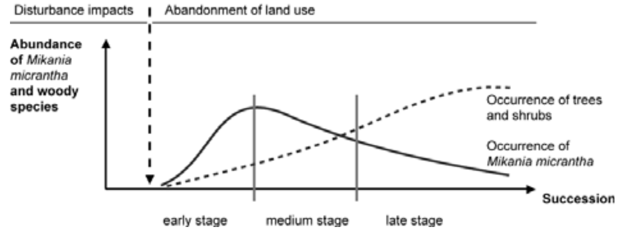

Fig. 9. Model for the abundance of *Mikania micrantha* during different successional stages.

cies, *M. micrantha* seems to attain its maximum cover. These observations are supported by Rejmánek (1989), who states that very often an invasion of non-native species does not have its maximum in the beginning (of a successional series, the author) but increases during the first 5 to 10 years and declines later (Rejmánek 1989: 372). Similar growth characteristics for *M. micrantha* have been observed during succession in slash-and-burn agriculture in India (Swamy and Ramakrishnan 1988). Only here, the plant reached its peak growth in 4～5 years old fallows, but decreased in 8 years old fallow areas.

CONCLUSIONS

A better understanding of the ecological site conditions of *M. micrantha* is very helpful to predict, which habitats or land-use types are potentially at a higher risk to be invaded by the plant. This study found out that land, which is subject to rare disturbances, or has been subject to disturbances in the past is especially vulnerable to be overgrown by the alien climber. Such habitats are found, for example, in abandoned agricultural plantations, in areas along roads and watercourses, in areas surrounding building grounds, but also in forest clearings or gaps. It is assumed that the plant is less abundant in agricultural plantations, because they are intensely managed. The economic impact of the American climber in Taiwan has not yet been studied in detail, but it is assumed that the majority of agricultural plantations is intensely managed, independent from the presence of the climber. These observations lead to the conclusion that *M. micrantha* does not pose an economical threat to managed agricultural systems or light-limited forest plantations.

This study concludes that *M. micrantha* was considered an aggressive invader in Taiwan in the beginning of this decade, but the impact of the climber can now be considered minor for the intensively managed land found in Pingtung County. In late successional series, *M. micrantha* does not pose a threat to other plants; it rather occupies a niche within near-natural forest ecosystems. Nevertheless, based on the study of ecological site conditions of *M. micrantha*, general recommendations can be made for the habitat management to prevent a further spread of the alien species in Taiwan. Disturbances, especially the opening of the ground as well as the vegetation cover should be avoided. It is recommended to create shady conditions in tree plantations. Furthermore, it is advised to use groundcover plants in agricultural and silvicultural plantations in order to prevent the establishment of *M. micrantha*.

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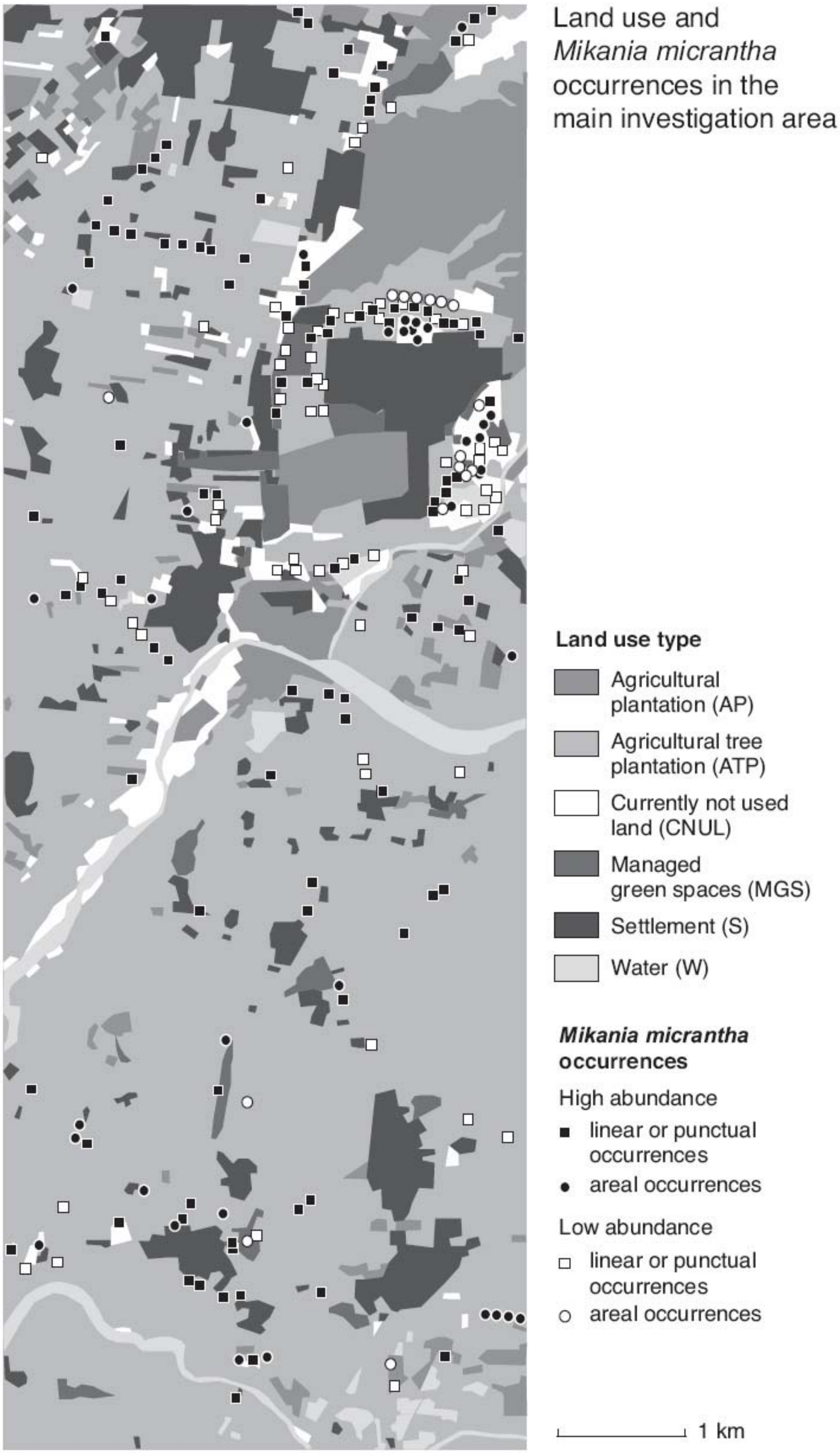
Land use and
Mikania micrantha
occurrences in the
main investigation area
Land use type
Agricultural plantation (AP)
Agricultural tree plantation (ATP)
Currently not used land (CNUL)
Managed green spaces (MGS)
Settlement (S)
Water (W)
Mikania micrantha occurrences
High abundance
linear or punctual occurrences
areal occurrences
Low abundance
linear or punctual occurrences
areal occurrences
1 km

Appendix 1.