J. For. Res. 5: 123−131 (2000)

Evaluation of Environmental Functions of Tropical Forest in Kinabalu Park, Sabah, Malaysia Using GIS and Remote Sensing Techniques: Implications to Forest Conservation Planning

Mui-How Phua*,[1] and Mitsuhiro Minowa**

*Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo 113–8657, Japan.
**Faculty of Agriculture, The University of Tokyo, Tokyo 113–8657, Japan.

Environmental functions of tropical forest can serve as criteria for forest conservation planning in the tropics. The objective of this study is to evaluate the environmental functions of tropical forest in Kinabalu Park, Sabah, Malaysia, using GIS and remote sensing techniques. Field data, statistical data, including weather data with geographic localities, maps and satellite image are collected. Linear regression models are developed for forests of different geological substrates, based on the relationships between altitude and biodiversity (Fisher's alpha index). Biodiversity conservation function map is derived with the statistical models and a digital elevation model. Coupling with extensive literature review, an evaluation matrix for evaluating soil and water conservation functions including landslide prevention, flood prevention and drought prevention functions, is constructed. To evaluate the soil and water conservation functions, a weighted linear combination method is used with GIS layers of topography, geology, soil depth, rainfall and slope. Forest areas in Kinabalu Park are derived with land cover mapping using Landsat-TM image. Areas having high values of biodiversity conservation, flood and drought prevention functions are covered with mainly lowland rain forest. On the other hand, areas with high values of the landslide prevention function are covered with mainly subalpine forests. Using the environmental functions, a conservation index is computed to represent forests that are important to conservation. Based on the *CI*, the lowland rain forest receives highest priority in protection. In fact, it is located in the boundary areas of the park and thus exposed to illegal activities.

Key words: environmental functions, forest conservation, GIS, Kinabalu Park

As a consequence of rapid loss of tropical forest, forest conservation has become an important activity in development planning of a country especially in the tropics. While development is important to a nation, forest conservation is vital to ensure the "resource" is adequately secured for future generations and to maintain at a high percentage cover to tackle many environmental problems such as global warming. Forest conservation can be classified into ex-situ and in-situ conservation. In-situ conservation founded on the basis if and only if acquisition of large pieces of land is feasible. Otherwise, ex-situ conservation is the only way to conserve a species in an artificial environment such as zoo. For long-term management, there is a need to identify which land of a protected area to be emphasized in forest conservation planning with appropriate criteria.

It is well known that a forest possesses so-called functions such as biodiversity conservation function and soil and water conservation functions. Various terms have been used to represent these functions such as environmental preservation functions (Sawada and Tsuyuki, 1988) and ecological functions (Kato *et al.*, 1997; Kato, 1998). They are often being considered as services or goods of forests or ecosystems in studies related to monetary valuation of the environment (Costanza *et al.*, 1997; Kumari, 1996). In this study, all these "functions" are termed "environmental functions" in a loose sense, referring to roles or capabilities of the forest ecosystem in maintaining a sound environment that contribute to safety and comfort of the society. They can serve as quantitative criteria to forest conservation planning.

Biodiversity has been the most frequently employed measures of ecological value for forest conservation. Perhaps chief amongst measures of biodiversity is species richness. Greater number of species tends to embody more genetic diversity, more organismal diversity and greater ecological diversity (Gaston and Spicer, 1998). Biodiversity indexes such as Fisher's alpha index and Shannon-Wiener index provide better measure of biodiversity because how numbers of individuals are distributed across species is also considered. In Kinabalu area, the Fisher's alpha index and the Shannon-Wiener index were found indicative of species number per plot (Aiba and Kitayama, 1999). By binding the soil, forest plays an important role in landslide prevention. Forest can also enhance water retention capacity and ground water recharge by processes such as interception of raindrops that slowing down the rate of infiltration into the soil and result in reduced possibility of drought and flood occurrences. Despite their importance, these soil and water conservation functions are seldom being considered quantitatively in forest conservation planning.

There are many ways to evaluate the environmental functions of forest depending on factors such as purpose, data availability and scale. A regional scale is attempted in this study as it is bounded by scale and availability of data especially maps. It is conceivable as an appropriate scale to conservation planning because what a conservation planner concerns is the spatial distribution pattern and overall understandings of the matter under investigation. Geographic information system (GIS) is an excellent tool that enables input, storage, and manipulation of spatial data for conservation planning purposes. Its capability dealing with spatial

[1] Corresponding author.

dimension has promised a way to evaluate the environmental functions of forest for conservation planning. The objective of this study is to evaluate the environmental functions of tropical forest in Kinabalu Park using GIS and remote sensing techniques.

Study Area

Kinabalu Park is located at the northern part of Kota Kinabalu, the capital of the state of Sabah, Malaysia, between 116°28′ and 116° 45′E and between 6° and 6°30′N (Fig. 1). Kinabalu Park was gazetted in 1964, with an area of 711 km^2, as the first national park in the State of Sabah and has its boundary changed several times before gaining the present size, 753.7 km^2. Kinabalu Park, with the Low's Peak at 4,095.2 m, contains the highest mountain between the Himalayas and Mount Whelm in Irian Jaya. Lowland areas with an elevation less than 600 m are found mainly in the northern and eastern part of the park while the summit areas are located in the southern part of the park. At the southern part where the park office is found at about 1,680 m, elevation rises to over 4,000 m in only 8.85 km (climbing trail length). Temperature is basically a function of elevation. The lapse rate was reported as 0.55°C/100 m (Kitayama, 1992). At the park's headquarters at about 1,680 m, the mean air temperature is 18.4°C and decreases to 9.7°C at 3,780 m, near the tree line in the park.

Vegetation of Mount Kinabalu has been studied, but no one yet could give an absolute number of the species present in the area. Biogeographic studies have shown that this mountain is the meeting place of flora from the Indo-Malaysian (*e.g.*, Dipterocarpaceae), East-Asian (*e.g.*, Fagaceae) and Australian (*e.g.*, *Dacrycarpus* sp. and *Leptospermum* sp.) floristic regions. Six discrete vegetation zones namely upper lowland rain forest (< 1,200 m), lower montane rain forest (1,200–2,350 m), upper montane rain forest (2,350–2,800 m), lower subalpine forest (2,800–3,400 m), upper subalpine forest (3,400–3,700 m) and alpine (> 3,700 m) are delineated based on their great variations in the dominant type, the species composition and the forest structure (Kitayama, 1991). The critical elevations show that the vegetation types are in fact distributed along the elevation gradient. However, mapping the defined vegetation zones using aerial photographs proved to be difficult. It was not able to draw a line to separate the lower and upper montane rain forests (Kitayama, 1991).

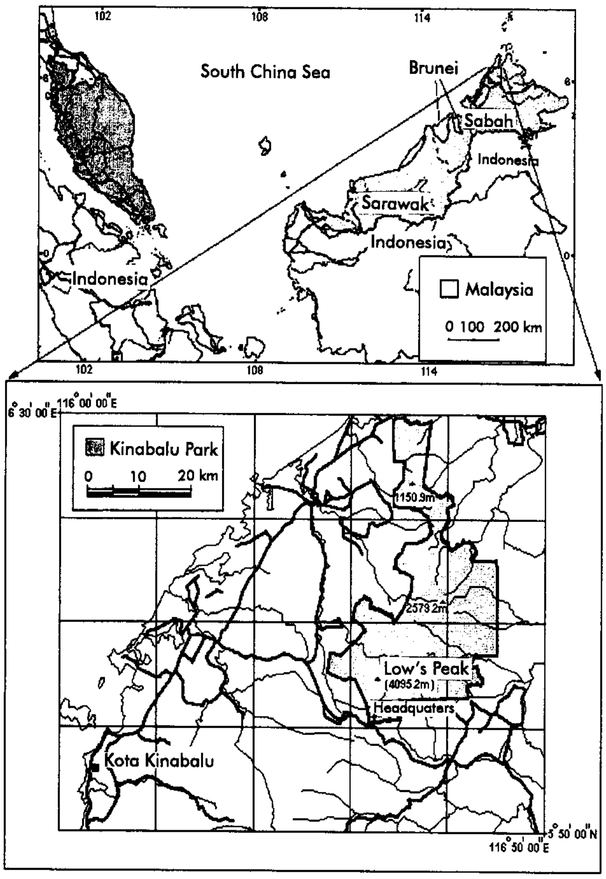


Fig. 1 Location of Kinabalu Park.

Methods

The environmental functions of forest are defined as biodiversity conservation and, soil and water conservation functions including landslide, flood and drought prevention functions in this study. Procedure to derive the environmental functions is shown in Fig. 2. Field data, maps and weather data with localities are collected. Coupling with existing knowledge, the field data is used to develop linear regression models for deriving the biodiversity conservation function with a digital elevation model (DEM). A GIS database is constructed by digitizing the maps and the weather data. A scoring matrix based on extensive literature review on soil and water conservation evaluation is constructed for deriving the soil and water conservation functions with the GIS data.

1 Biodiversity conservation function

In Mount Kinabalu area, it is found that species richness (Kitayama, 1992) and the Fisher's alpha index (Kitayama, 1996) decrease as altitude increases. Influences of geological substrates on the altitudinal pattern of biodiversity were

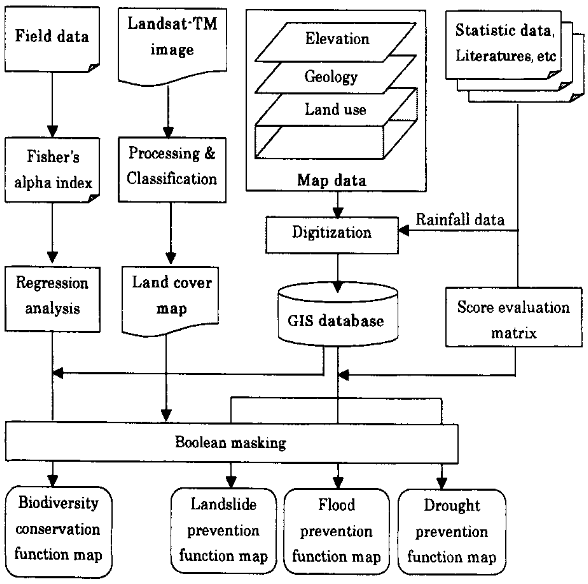


Fig. 2 Procedure of environmental functions evaluation of tropical forest using GIS and remote sensing techniques.

reported (Aiba and Kitayama, 1999). In this study, the Fisher's alpha index calculated from field data using the below formula is used as the indicator of biodiversity conservation function (Source: Kitayama, 1996; Aiba and Kitayama, 1999).

$$S = \alpha \ln\left(1 + \frac{N}{\alpha}\right)$$

where S is the total number of species per stand, α is the alpha index and N is the total number of individuals per stand.

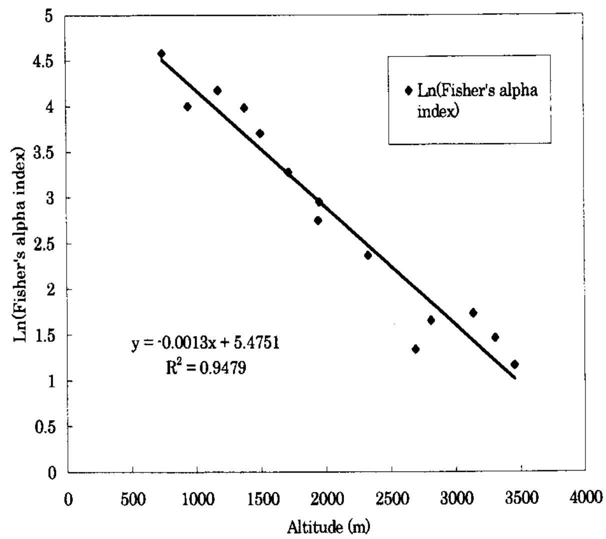
Upon transformation with a natural log on the index, linear regression analysis between the altitude and the biodiversity is carried out separately on non-ultrabasic and ultrabasic substrates. Altitude governs the general decreasing pattern of biodiversity with increasing altitude in both geological substrates and this is shown in the Adjusted R Squares which are more than 0.94. The biodiversity decreases at a greater rate on the ultrabasic forest compared with that of the non-ultrabasic forest. The coefficients of the linear regression models are significant at 1% and 5% for the non-ultrabasic and ultrabasic forests, respectively (Figs. 3 and 4).

Altitude is derived as a DEM by digitizing contour maps (1:50,000) at 200 feet. As this study attempt to evaluate the biodiversity at a regional scale, raster cell size of 100 m is used for analysis. Ultrabasic and non-ultrabasic substrates are digitized based on a geology map (1:100,000) and a vegetation map (1:50,000). Most of the ultrabasic features in both maps are similar but some discrepancies are unavoidable and this might be the results of different specialties and different methods of mapping used. The vegetation map (Kitayama, 1991) was produced using monochromic aerial photographs where cloud cover was a problem. Thus, the most secured approach is adopted where the polygons of ultrabasic substrates of both maps are merged and used in subsequent analyses. Polygons of the two substrates are used to extract the DEM into ultrabasic and non-ultrabasic DEMs where the biodiversity conservation functions on non-ultrabasic and ultrabasic substrates are derived using the empirical relationships.

2 Soil and water conservation functions

In this study, the soil and water conservation functions refer to landslide prevention, flood prevention and drought prevention functions. Landslide prevention function of forest can be considered in terms of landslide hazard. The more hazardous an area is, the more important is to keep the forest in place. This is because forest is known to have an important role in preventing landslides by binding the soil with its roots. Generally, the drought and flood prevention functions of forest refer to water retention capability of forest. Forest plays an important role in recharging ground water by increasing the rate at which rainwater infiltrates into the soil.

Environmental factors employed in the GIS evaluation of the soil and water conservation functions are based on extensive review of related literatures especially reports of studies on quantification and evaluation of forest functions by the Japanese Forest Agency (Japanese Forestry Agency, 1989, 1990, 1991, 1998), Kato *et al.* (1997) and Kato (1998). Taken data availability into account, the environmental factors of



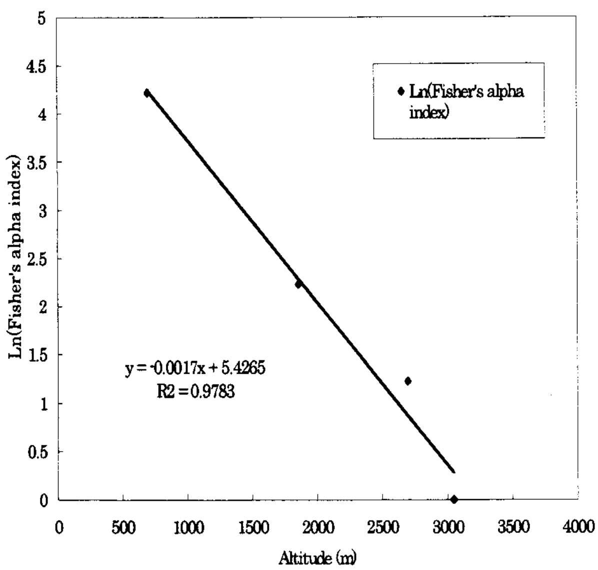
Linear Regression Model Summary (Dependent variable: Ln(Fisher's alpha index)

	R	R Square	Adjusted R Square	Std. Error of the Estimate
Altitude	0.9736	0.9479	0.9436	0.2814

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	5.4751	0.1967		27.8424	2.85E-12
ALTITUDE	-0.0013	8.74E-05	-0.9736	-14.7716	4.63E-09

Fig. 3 Relationship between altitude and Fisher's alpha index (non-ultrabasic).



Linear Regression Model Summary (Dependent variable: Ln(Fisher's alpha index)

	R	R Square	Adjusted R Square	Std. Error of the Estimate
Altitude	0.9891	0.9783	0.9675	0.3218

Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	5.4265	0.4028		13.4718	0.0055
ALTITUDE	-0.0017	0.0002	-0.9891	-9.5003	0.0109

Fig. 4 Relationship between altitude and Fisher's alpha index (ultrabasic).

slope, rainfall, soil depth, geology and topography are employed. Scoring approach is adopted where an evaluation matrix is constructed for evaluating the soil and water conservation functions (Table 1). Wherever necessary, modifications are made based on reference specific to Borneo where the study area is located (Douglas, unpublished report).

In this study, the role of vegetation is treated as a pre-requisite for the functions to be realized. In another word, even if a pixel has a high value for a particular soil and water conservation function, as contributed by the environmental settings, it is of no such value at all if forest is not present. Until the existence of forest cover on the ground is known, the soil and water conservation functions produced in this study are only "potential functions" resulted from the environmental settings.

Weighted linear combination of GIS layer that has been widely used in GIS-based studies such as in Kato *et al.* (1997) is adopted. Weights that describe the relative importance of each factor towards the function are referred to these studies as they have been consulted with experts' opinions. Realization of the weights and scores in the evaluation matrix for the GIS evaluation of the soil and water conservation functions in a weighted linear combination form is as below.

Landslide prevention function $=(0.3\times$ Slope$)+(0.2\times$ Annual Rainfall$)+(0.2\times$ Soil Depth$)+(0.15\times$ Geology$)+(0.15\times$ Topography$)$

Flood prevention function $=(0.2\times$ Slope$)+(0.2\times$ Annual Rainfall$)+(0.25\times$ Soil Depth$)+(0.15\times$ Geology$)+(0.2\times$ Topography$)$

Drought prevention function $=(0.1\times$ Slope$)+(0.25\times$ Annual Rainfall$)+(0.3\times$ Soil Depth$)+(0.15\times$ Geology$)+(0.2\times$ Topography$)$

Slope layer is derived from the DEM. Surface geology layer is constructed by using geology maps (1: 100,000). A scoring scheme is generated to derive soil depth map (Table 2). Soil depth at the lowlands ranges from 2 m to more than 10 m but it is much less at greater altitude (Burnham, 1974). Soil depth is divided into thick, medium and thin based on altitude by referring to field observations (Source: Kitayama, 1992; Burnham, 1974). To generate the layer of annual rainfall, data from 13 climate stations are acquired and imported into a GIS as point layer (Source: Department of Meteorology of Malaysia, Sabah Branch and Dr. Kitayama, K.). Only year 1996 data are complete for all the stations because some stations were built only very recently but it should not a problem to serve as a general rainfall map in the study area since it is a normal year. The rainfall data (November 1995–October 1996), when plotted against the elevation data, do not show any distinctive moisture gradient along the elevation. Average, minimum and maximum rainfall of the study area are 3,274.42mm, 2,451.4mm, and 5,486.8mm, respectively. The locations of the stations are acquired from the Department of Meteorology of Malaysia, Sabah Branch as well as acquired with a portable GPS for the stations located in Kinabalu Park. Voronoi polygons are generated from the point data and are converted into a raster layer.

Topography as categories of divergence, convergence and slope can be derived from a DEM. Topography can be derived using a DEM with the widely used D8 algorithm where a depressionless DEM is first generated and a flow direction (FD) matrix is then approximated by the direction of steepest downhill slope within a 3×3 neighborhood cells (Moore *et al.*, 1991; Burrough and McDonnell, 1998). The resulting new set of cells is called the set of local drain direction (ldd). Each ldd cell indicates the FD or the direction water will flow out of the cell where:

$$\mathrm{FD}=d=f \text{ for } \max_{(f=1,8)} (W_f \mid Z_{ij}-Z_{i,i\pm 1,j,j\pm 1}\mid)$$

d, direction; W_f, distance weight (1 for NSEW neighbors and $1/\sqrt{2}$ for diagonals); z, elevation.

It is encoded as an integer to correspond to the orientation of one of the eight cells that surround the cell (x) as follows:

64	128	1
32	x	2
16	8	4

Flow accumulation map is then calculated by accumulating the

Table 1 Scoring matrix for soil and water conservation function evaluation.

Landslide prevention

	High = 3	Medium = 2	Low = 1
Topography	Convergence	*etc.*	Divergence
Geology	Igneous (Granite)	Igneous (Ultrabasic)	Sedimentary (Volcanic origin, alluvium)
Soil depth	Thin	Medium	Thick
Annual rainfall	>4000 mm	3001–4000 mm	≤3000 mm

Slope: higher is more hazardous.

Floods prevention

	High = 3	Medium = 2	Low = 1
Topography	Convergence	*etc.*	Divergence
Geology	Igneous (Granite)	Igneous (Ultrabasic)	Sedimentary (Volcanic origin, alluvium)
Soil depth	Thick	Medium	Thin
Annual rainfall	>4000 mm	3001–4000 mm	≤3000 mm

Slope: higher is better.

Droughts prevention

	High = 3	Medium = 2	Low = 1
Topography	Convergence	*etc.*	Divergence
Geology	Igneous (Granite)	Igneous (Ultrabasic)	Sedimentary (Volcanic origin, alluvium)
Soil depth	Thick	Medium	Thin
Annual rainfall	≤3000 mm	3001–4000 mm	>4000 mm

Slope: higher is worse.

Table 2 Soil depth classes based on altitude.

Altitude (m)	Soil depth (m)	Depth class
≤1500	>1	Thick
1501–2800	0.51–1	Medium
2801–3699	≤0.5	Thin

upstream elements for each pixel based on the drainage direction from its eight neighboring pixels.

Divergent areas are approximated as ridge lines that can be extracted by selecting pixels without upstream elements (Burrough and McDonnell, 1998). Convergent areas where surface water accumulates can be represented as streams. Streams networks can be defined by using a threshold of the upstream elements in the flow accumulation map (Moore *et al.*, 1991; Tarboton *et al.*, 1991). However, there is no physical basis to determine the threshold (Tarboton *et al.*, 1991). In this study, a GIS procedure is devised to determine the threshold. The Strahler's first order streams are first digitized from the topographic maps. A 100 m-buffer of the streams is generated and divided into 100 m grids where a point is randomly placed on each grid. The random sampled points are then overlaid on the flow accumulation map and data on upstream elements are extracted to compute the mean upstream element. As the threshold determines start point of a stream, it is conceivable that mean upstream element from the first order streams could serve as the threshold. The mean, with an upstream element of 37, is in agreement with the findings of Tarboton *et al.* (1991), between 20 and 50 for 21 DEM datasets. All the values of the GIS factors are standardized to scale between zero to one to eliminate differences in measurement units.

3 Land cover classification

The biodiversity conservation function and the soil and water conservation functions are not possibly exist on an area without forest cover. There is a need to know whether or not forest exists on the ground. Land use maps available to this study cover only a part of the Kinabalu Park. For this, a Landsat-TM satellite image taken on June 14, 1991 is acquired to generate a land cover map through supervised classification using the maximum likelihood algorithm. For the purpose of delineating forest areas in the Kinabalu Park, five land cover classes are broadly defined and they are forest, mangrove, water, bare land and others (grasslands, shrub, agricultural and paddy lands). The classes are attributable to either Anderson Level I or II (Anderson *et al.*, 1976). As such, the class definition is compatible to classes in land use maps (1:25,000) produce in 1991. Post-classification processing is carried out with a Boolean decision rule with an elevation threshold of 119 m is developed by sampling on the mangrove class of land use layer on the DEM. The mangrove forests that are found in areas with elevation more than 119 m are considered misclassified and are processed. The land cover map generated is shown in Fig. 5.

To determine the accuracy of the classification using the GIS approach, the land use maps is digitized into a GIS vector layer. Although there is a definitional difference between a land use and a land cover, the land cover class definition employed in this study is compatible with the land cover extracted from the land use maps. Overall classification accuracy is 82.15%, which can be considered as very good. The main purpose that is to obtain forest areas is also achieved because producer's accuracy and user's accuracy are 72.43% and 79.22 %, respectively (Table 3).

Results

1 Environmental functions of tropical forests

The land cover map produced using satellite image classification is used to generate a Boolean mask comprises of forest and non-forest areas. It is resampled into 100 m-pixel resolution to facilitate the resolution of the environmental functions maps. There are small areas that are not covered by the satellite image are however covered by the land use maps. All the environmental function maps are processed with the Boolean mask to mask out non-forest areas.

As mentioned in previous section, the vegetation map (Kitayama, 1991) contains only the forest types of lowland rain forest, montane rain forest, lower subalpine and upper subalpine forests and we adopt it only to ease our summary and interpretation of the resulted environmental functions. The environmental functions maps are interpreted by overlaying forest types on them where a 500 m-grid for the lowland

Table 3 Accuracy assessment matrix of land cover classification.

Cover class (Land use map)	Landsat-TM				User accuracy (%)
	Non forest	Forest	Mangrove	Total	
Non forest	102321	11162	974	114457	84.05
Forest	15673	42590	537	58800	79.22
Mangrove	3746	11	2793	6550	64.89
Total	121740	53763	4304	179807	
Producer accuracy (%)	89.4	72.43	42.64		82.15

Table 4 Environmental functions by forest types.

	Lowland	Montane	Lower subalpine	Upper subalpine
Biodiversity conservation function				
Minimum	3.037	0.466	0.0147	0.527
Maximum	5.124	4.390	1.969	2.267
Mean	4.406	3.180	1.441	1.571
SD	0.300	0.601	0.233	0.369
Landslide prevention function*				
Minimum	0.005	0.186	0.454	0.453
Maximum	0.600	0.710	0.789	0.779
Mean	0.366	0.454	0.651	0.646
SD	0.118	0.103	0.068	0.072
Flood prevention function*				
Minimum	0.253	0.249	0.227	0.269
Maximum	0.865	0.799	0.617	0.660
Mean	0.608	0.523	0.421	0.461
SD	0.121	0.107	0.072	0.099
Drought prevention function*				
Minimum	0.349	0.307	0.234	0.289
Maximum	0.997	1	0.579	0.574
Mean	0.703	0.653	0.394	0.418
SD	0.139	0.123	0.054	0.081
Conservation index				
Minimum	37	31	30	30
Maximum	77	72	55	57
Mean	62.156	55.101	42.716	44.787
SD	6.157	6.406	4.961	6.226
Count	967	991	765	235

*Standardized values. Values of biodiversity conservation function is Ln (Fisher's alpha index).

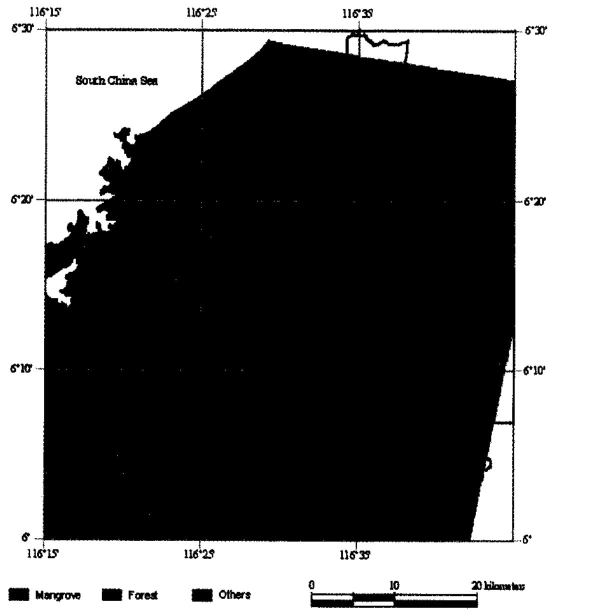


Fig. 5 Land cover map of Kinabalu Area, Sabah, Malaysia (Blue line shows the boundary of Kinabalu Park).

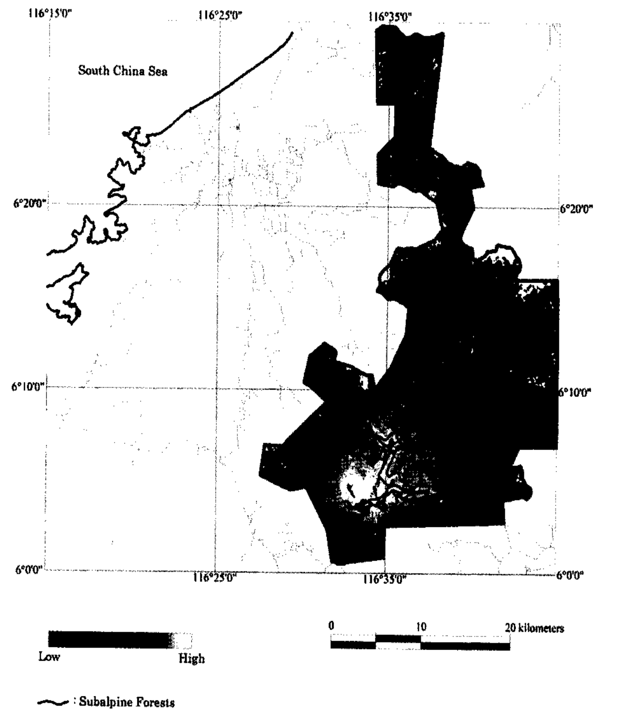


Fig. 7 Landslide prevention map of Kinabalu Park, Sabah,Malaysia.

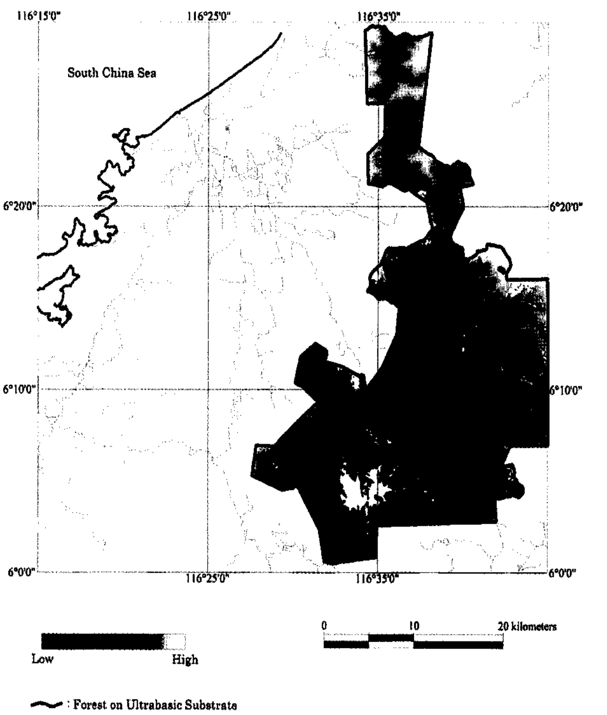


Fig. 6 Biodiversity conservation function map of Kinabalu Park, Sabah, Malaysia.

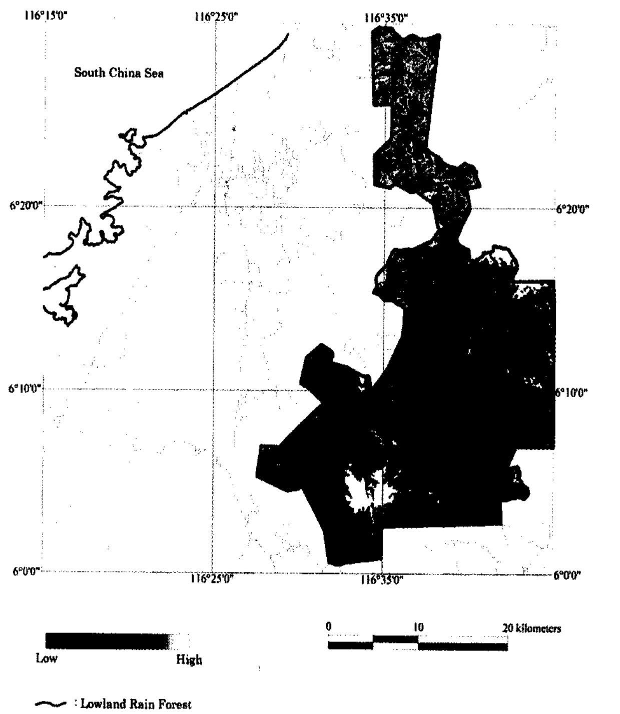


Fig. 8 Flood prevention function map of Kinabalu Park, Sabah, Malaysia.

rain forest and the montane rain forest and a 100 m-grid for the subalpine forests are generated and a point is randomly placed on each grid. Data on the environmental functions are extracted from the point except areas that are not covered by the satellite image. Descriptive statistics are produced for interpretation (Table 4). Biodiversity distribution in the park is shown in the biodiversity conservation function map in Fig. 6. The lowland rain forest possesses the highest mean value of biodiversity and decreases when forest type changes to montane rain forest. The biodiversity decreases markedly in the transition process from the montane rain forest to the lower subalpine forest. The lower subalpine and upper subalpine forests have very close biodiversity values. This is in conformity with the conclusive findings of Kitayama (1991,

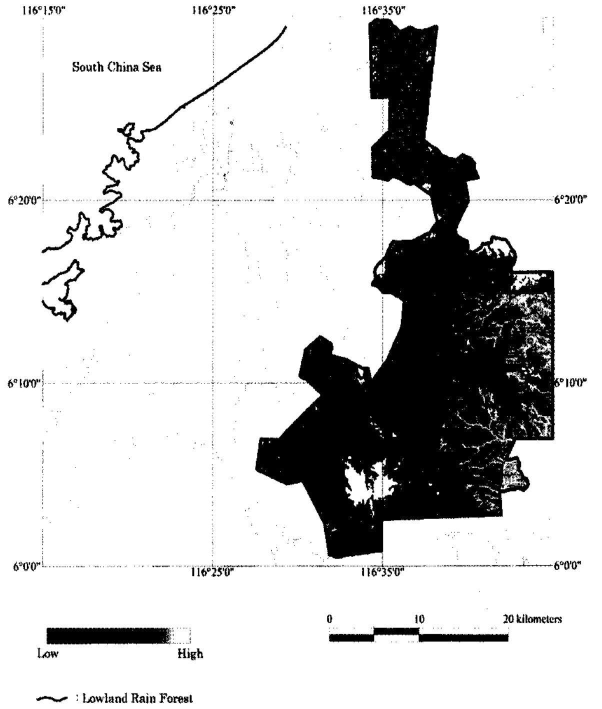


Fig. 9 Drought prevention function map of Kinabalu Park, Sabah, Malaysia.

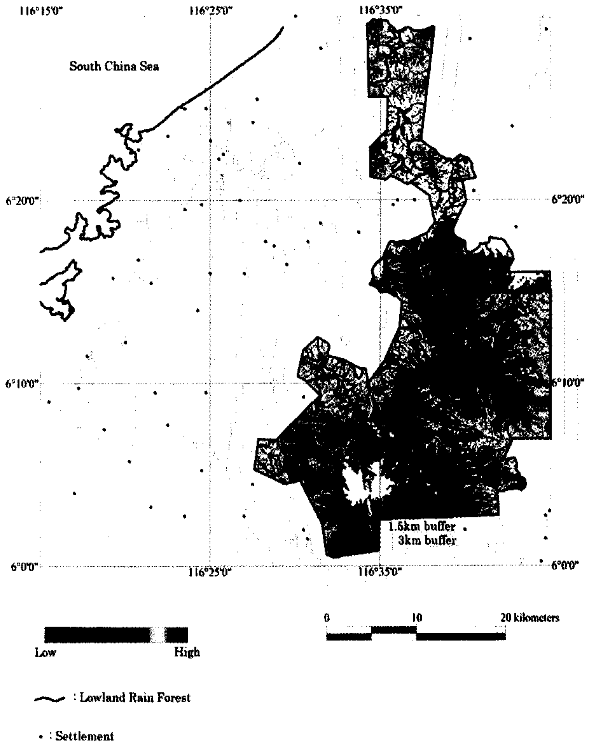


Fig. 10 Conservation index map of Kinabalu Park, Sabah, Malaysia, and hypothetical buffer zones.

1992, 1996) and Aiba and Kitayama (1999).

The soil and water conservation functions are also interpreted in similar way. In terms of landslide prevention, areas covered with the lowland and montane rain forests play little roles compared with areas covered with the subalpine forests (Fig. 7). The subalpine forests, located at higher elevations, are more susceptible to landslide than those that located at lower elevations. It is therefore important to protect the subalpine forests in order to maximize the soil binding effects of the root systems and the rain interception effect of the forests. In terms of flood and drought prevention functions, the patterns are similar to the biodiversity conservation function where areas with highest values are covered with mainly the lowland rain forest, followed by the montane rain and followed by the subalpine forests (Figs. 8 and 9). The forest at these highly important areas should be emphasized because it can play a very important role in ground water recharge by enhancing the water retention capacity of the soil, provided no extreme weather conditions.

2 Conservation index of tropical forests

A conservation index (*CI*), indicating area that is important to conservation in terms of the environmental functions, can be calculated based on standardized values, as follow:

$$CI = (BCF + LPF + FPF + DPF)/4 \times 100$$

Where *BCF*, *LPF*, *FPF*, and *DPF* are biodiversity conservation, landslide prevention, flood prevention and drought prevention functions, respectively.

The *CI* is proposed as a simple and flexible averaging form so that additional functions or criteria can be incorporated at ease. Other criteria such as fragility, uniqueness and rarity can be incorporated whenever available. The *CI* that combines the environmental functions into an index provides an overall idea about areas to be emphasized in conservation planning (Fig. 10). The areas covered with the lowland rain forest are dominating other areas as indicated in the *CI* due to its shares from the biodiversity conservation, flood prevention and drought prevention functions. In contrast, the areas covered with the subalpine forests show much lower *CI* value than that of the lowland rain forest. While the biodiversity conservation, flood and drought prevention functions are decreasing in corresponding to the changes of forest type from the lowland rain forest to the subalpine forests, only the landslide prevention function is increasing.

Discussion

1 Evaluation of the environmental functions

As a simple and fast approach for planning purposes, the GIS evaluation approach is globally applicable. The environmental functions evaluation using GIS techniques can be found in temperate regions but are rare in the tropics. The GIS approach used in study in Japan was suggested for applications in Southeast Asia based on its relative similarity in the land characteristics (Kato *et al.*, 1997). The GIS evaluation approach is similar to the widely known case of soil erosion evaluation using the Universal Soil Loss Equation (USLE) with GIS techniques. Though, unlike the USLE, the GIS evaluation approach produces only relative importance regarding the soil and water conservation functions.

Sawada and Tsuyuki (1988) evaluated the landslide prevention, soil erosion, flood prevention and water conservation functions, pollutants (nitrogen and phosphorus) purification functions and a function related to comfort of habitation using the GIS approach with a grid size of 50 m × 50 m for watershed management purpose. The GIS approach for evaluation of the environmental functions has been further developed into the approach that incorporates weights to encounter the relative importance of different factors on a particular function (Kato *et al.*, 1997; Kato, 1998; Zheng and Nagumo, 1994). The landslide prevention, soil erosion, water retention capacity and air pollution control functions were evaluated at a national level with a spatial resolution of 1 km × 1 km for conservation of rural landscape (Kato *et al.* 1997; Kato, 1998). On the other hand, Zheng and Nagumo (1994), at a scale of forest compartment that comprises broad-leaf and needle-leaf forests, emphasized only forest variables of management intensity, density and age in the GIS evaluation.

Data availability is a problem facing studies using the GIS evaluation approach (Sawada and Tsuyuki, 1988; Kato *et al.*, 1997), especially in Asian countries (Kato *et al.*, 1997). In this study, factors used mainly referred to the factors in Japansese Forestry Agency (1998) but unavailable factors are unavoidably excluded. History of landslide, floods and drought are among listed factors in Japanese Forestry Agency (1998) but were not available to this study.

Surface geology, topography, slope and annual rainfall are the common factors used to evaluate the landslide prevention function in Sawada and Tsuyuki (1988), Kato *et al.* (1997) and this study. Regarding soil factors, we used soil depth while Kato *et al.* (1997) used soil texture. Land use and vegetation types are two additional factors included in Sawada and Tsuyuki (1988) and Kato *et al.* (1997). Slope direction and elevation are other additional factors used in Sawada and Tsuyuki (1988). Flood prevention function was evaluated in Sawada and Tsuyuki (1988) and in this study. The factors used in Sawada and Tsuyuki (1988) and this study are generally similar except factors related to soil and land use. As soil factors are concerned, we employed soil depth compared with soil classes in Sawada and Tsuyuki (1988). Land use is not relevant as the land use of the study area is a park. On the other hand, only this study evaluated the drought prevention function.

In this study, the forest is considered as having an enhancement effect on the soil and water conservation functions. The functions will be devastated or may no longer exist if the forest as an integrated part of the forest ecosystem is vanished. It is realized by constructing a land cover map using satellite image. This is founded on the well-known differences of discharge between a bare ground and a forest area on granite rock (Japanese Forestry Agency, 1990).

Forest types may have played a role in the soil and water conservation functions due to different structures they posses. However, the relationships between various forest types and the functions have not well established yet. Positive and negative effects of various variables of forest exist at the same time and which are dominant are not known. For example, large leaf area possessed by the lowland rain forest may allow more slow water discharge into the soil through the process of interception but it also provides more area for evaporation. The forest types as a factor layer if and only if the relationships between the forest properties and the indicators of the soil and water conservation are well established. As the evaluation approach is weighted linear combination of map layers, it is flexible to include additional data layer.

Biodiversity is a widely used criterion in planning activities related to forest but have not been dealt in these studies. It is especially important to forest conservation planning where the more diversify an area, the higher its conservation value. Though, needs to stress here is that other biological criteria such as rarity should also be considered in practice. To determine the biodiversity value of a particular area with field survey, a great deal of time and money are needed. Besides, lack of expertise, an acute problem in the tropics, makes it a difficult task to accomplish. Points data that from field survey is an invaluable source of data for GIS mapping at a regional scale, provided an environmental gradient exists.

2 Implications to forest conservation planning

The ultrabasic forest is a unique ecosystem and should be given high priority in conservation irrespective of the *CI* values. For the areas of non-ultrabasic forests (lowland, montane and subalpine forests), the *CI* can serve as a guide to the park management regarding which area is important in terms of the environmental functions. The areas covered with the subalpines forests, which are important in terms of landslide prevention, are relatively protected from illegal activities as their distributions are far from the boundary. Furthermore, there are no settlements within the park. On the other hand, the areas with highest *CI* that are covered with the lowland rain forest are geographically distributed at the boundary area of the park and are relatively exposed to illegal activities (Fig. 10). This depicts a practical management problem in terms of forest protection because the park stretches about 54 km and about 32 km in North-South and East-West directions, respectively. With a boundary length that comes up to about 205 km and with the park headquarter located in the South, protecting the park against illegal activities is surely not an easy task.

As a result of the UNESCO's Man and Biosphere Program, a concept of model biosphere reserve that emphasizes incorporation of local people's needs and perception in the establishment and management of reserves was born. It was described as a protected area that consists of a core and a buffer zone surrounding the core area (Well and Brandon, 1993). The core area is usually the most important area that corresponds to the main objective of initial designation of the protected area. The buffer zone plays an important role by separating the core area from intensive human use areas. There is no general way to define the core area except to follow the main interest of the protected area designation. If protecting the forest with highest values of environmental functions is the objective of the management of Kinabalu Park, the areas covered with the lowland rain forest can be thought as the core area. If the biosphere reserve model is to be adopted, a buffer zone in the surrounding areas of the park is inevitable. In practice, however, it is not an easy task as land is a prime resource. Buffer zone establishment is rarely successful due to lack of legal authority of the park or protected area agencies over the zone, to failure of incorporating local knowledge and recognizing local people needs (Sanjay and Weber, 1994). A 1.5 km buffer surrounding the park boundary easily includes five settlements and another 1.5 km buffer from the first one adds five more settlements into it (Fig. 10). If a buffer zone is to be established to enhance the forest conservation of the park, careful planning is vital to minimize conflicts between local people and the park management.

Conclusion

Beside the overwhelming biological criterion, soil and water conservation functions are also useful to guide the management in conservation planning. The biodiversity conservation function represents biological resources conserved for future generations while the soil and water conservation functions contribute towards safety and comfort of society. They are quantitative criteria that can be derived with GIS-based evaluation techniques. This study demonstrates the use of GIS and remote sensing techniques for evaluation of the environmental functions in Kinabalu Park. The biodiversity conservation function map is evaluated by integrating GIS data and statistical models based on field data. The soil and water conservation functions are evaluated with weighted linear combination of GIS data based on existing knowledge. Remote sensing techniques contribute to mapping of forest areas in the park. The *CI* is potentially useful to forest conservation planning provided that appropriate criteria are considered.

This study would not be possibly accomplished without the map data as well as other data. For this, we would like to express our gratitude to staffs of Department of Agriculture of Sabah, Tuaran Agriculture Research Center, GIS Section of Sabah Institute for Development Studies, Sabah and Meteorological Department of Sabah. We are indebted to Dr. Kitayama Kanehiro of The Japanese Forestry and Forest Products Research Institute for his invaluable field data on tropical forest in Kinabalu Park. Dr. Sawada Haruo of The Japanese Forestry and Forest Products Research Institute is thanked for the satellite data. Professor Suzuki Masakazu of Laboratory of Erosion Control and Hydrology of Department of Forest Science, The University of Tokyo, is sincerely thanked for discussions on soil and water conservation. We are grateful to Associate Professor Tsuyuki Satoshi of Laboratory of Global Forest Science of Department of Global Agricultural Sciences, The University of Tokyo, for advice on this manuscript.

Literature cited

Aiba, S. and Kitayama, K. (1999) Structure, composition and species diversity in an altitude-substrate matrix of rain forest tree communities on Mount Kinabalu, Borneo. Plant Ecol. 140: 139–157.

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E. (1976) A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Professional Paper 964. 28pp, U.S. Government Printing Office, Washington, D.C.

Burnham, C.P. (1974) The role of the soil forming factors in controlling altitudinal zonation on granite in Malaysia. *In* Altitudinal zonation in Malesia, Transaction of the Third Aberdeen-Hull Symposium on Malesia Ecology. Flenley, J.R. (ed.), 119pp, University of Hull and University of Aberdeen Press, Hull, 59–74.

Burrough, P.A. and McDonnell, R.A. (1998) Principles of geographic information systems. 333pp, Oxford University Press, Oxford.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paroelo, J., Raskin, R.G., Sutton, P., and Van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. Nature 387: 453–467.

Gaston, K.J. and Spicer, J.I. (1998) Biodiversity: An introduction. 113pp, Blackwell Science Press, Oxford.

Japanese Forest Agency (1989) A survey on methods of socioeconomic evaluation and scientific management: Development of evaluation methods of forest functions. Japanese Forest Agency, Tokyo. (in Japanese)*

Japanese Forest Agency (1990) A survey on standards and quantification of forest functions methods. Japanese Forest Agency, Tokyo. (in Japanese)*

Japanese Forest Agency (1991) A survey on standards and quantification of forest functions methods. Japanese Forest Agency, Tokyo. (in Japanese)*

Japanese Forest Agency (1998) A survey on forest evaluation methods for conservation of environmental functions. Japanese Forest Agency, Tokyo. (in Japanese)*

Kato, Y. (1998) Evaluation of land conservation functions of cultivated and forested lands using GIS. *In* Environmental conservation and agriculture and forestry. Minami, K. (ed.), 216pp, Asakura Shoten Press, Tokyo, 94–104. (in Japanese)*

Kato, Y., Yokohari, M., and Brown, R. (1997) Integration and visualization of the ecological value of rural landscape in maintaining the physical environment of Japan. Landscape Urban Plann. 39: 69–82.

Kitayama, K. (1991) Vegetation of Mount Kinabalu Park, Sabah, Malaysia, map of physiognomically classified vegetation. 45pp, East-West Center Press, Honolulu, Hawaii.

Kitayama, K. (1992) An altitudinal transect study of the vegetation on Mount Kinabalu, Borneo. Vegetatio 102: 149–171.

Kitayama, K. (1996) Patterns of species diversity on an oceanic *versus* a continental island mountain: a hypothesis on species diversification. J.Veg. Sci. 7: 879–888.

Kumari, K. (1996) Sustainable forest management: myth or reality? Exploring the prospects for Malaysia. Ambio 25: 459–467.

Moore, I.D., Grayson, R.B., and Ladson, A.R. (1991) Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. Hydrol. Processes 5: 3–30.

Sanjay, K. and Weber, K.E. (1994) A buffer zone for biodiversity conservation: Viability of the concept in Nepal's Royal Chitwan National Park. Environ. Conserv. 21: 333–341.

Sawada, H. and Tsuyuki, S. (1988) Digital analysis for evaluating functions of forest and agricultural lands in a watershed. Paper presented in The 16th Congress of the International Society of Photogrammetry Commission VII: 365–374.

Tarboton, D.G., Bras, R.L., and Rodriguez-Iturbe, I. (1991) On the extraction channel networks from digital elevation data. Hydrol. Processes 5: 81–100.

Wells, M.P. and Brandon, K.E. (1993) The principles and practice of buffer zones and local participation in biodiversity conservation. Ambio 22: 157–162.

Zheng, Y and Nagumo, H. (1994) A forest activity classification method using a geographic information system. J. Jpn. For. Soc. 76: 522–530.

*The titles are tentative translations from the original titles by the author in this paper.

(Accepted April 7, 2000)