LANDSCAPE EVALUATION FOR THE REHABILITATION OF AN ERODED DRAINAGE BASIN IN THE NORTHERN PART OF OKINAWA ISLAND, SOUTHWEST JAPAN

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INTRODUCTION

In the northern part of Okinawa Island landscape management based on natural geo-ecosystems in a drainage basin has been traditionally carried on. A conservation-based management system of the landscape has been historically adopted to the character of small drainage basins in the humid sub-tropical environment (Nago City, 1974).

Both land and land use have been managed by the people according to the landscape systems in the drainage basins. Here the concept of land will be defined as a complex of natural conditions or resources in the landscape, and landscape system as a complex of land system and land-use system (Mabbutt, 1968).

Such traditional management systems, however, have broken down in some parts of the region through agricultural modernization or urbanization. Especially cultivation of pineapple (*Ananas comosus*) or construction of public institutions on the hillsides from 10 years before cause an abrupt change of the landscape. Environmental deterioration in drainage basin has rapidly occurred through the development of hillsides, for example, artificial reformation of land or renovation of pineapple field using bulldozers. Serious soil erosion through dynamic processes in the drainage basins has occurred, which has not only changed the land itself but also brought some confusion of land use through an inflow of reddish soil to channel, paddy field or seashore. The conservation problems of both land and land use in correspondance with landscape systems in drainage basin have been also under discussion.

If we want to solve such problems, to conserve landscape systems and to rehabilitate the landscape in drainage basins in northern part of Okinawa Island, we have to seek better connection between land and land use by fundamental understanding of the physical characteristics of such basins (Watson, 1972).

We discuss in this report what are the standpoints when we consider the rehabilitation of an eroded drainage basin and we present the methodology of landscape evaluation as a basic part of landscape planning. We also explain some results of our case-study in a small drainage basin so that the discussion will be led into concreteness.

LANDSCAPE EVALUATION FOR THE REHABILITATION OF THE ERODED DRAINAGE BASIN

Standpoints for the rehabilitation of the eroded drainage basin

A drainage basin can be recognized as a naturally divided area. It is a geomorphological unit which has been formed through long evolutional process. Drainage basins are systematically composed of landscape hierarchy from lower order to higher order. Land and land use have been traditionally balanced in a drainage basin and substantial circulation has been smoothly performed through the drainage system of the basin.

Accelerated soil erosions brought about by land-use demand which exceeds the carrying capacity of natural geo-ecosystems, also occur according to the drainage system. The drainage basin is also a fundamental unit when we consider landscape evaluation, planning and management for the rehabilitation of an eroded drainage basin.

Therefore we reinforce our understanding of the manner of operation of the physical and biological processes to build a plan for the rehabilitation of the eroded drainage basin and to seek a better system of the landscape in a small drainage basin.

Fig. 1 shows the landscape evaluation process according to the landscape hierarchy based on drainage system.

The area suffered from strong human intervention on the land surface, natural conditions in the drainage basin are very changed in comparison with its past conditions (Yamamoto, 1976). For the rehabilitation of eroded drainage basin, the geomorphological base of

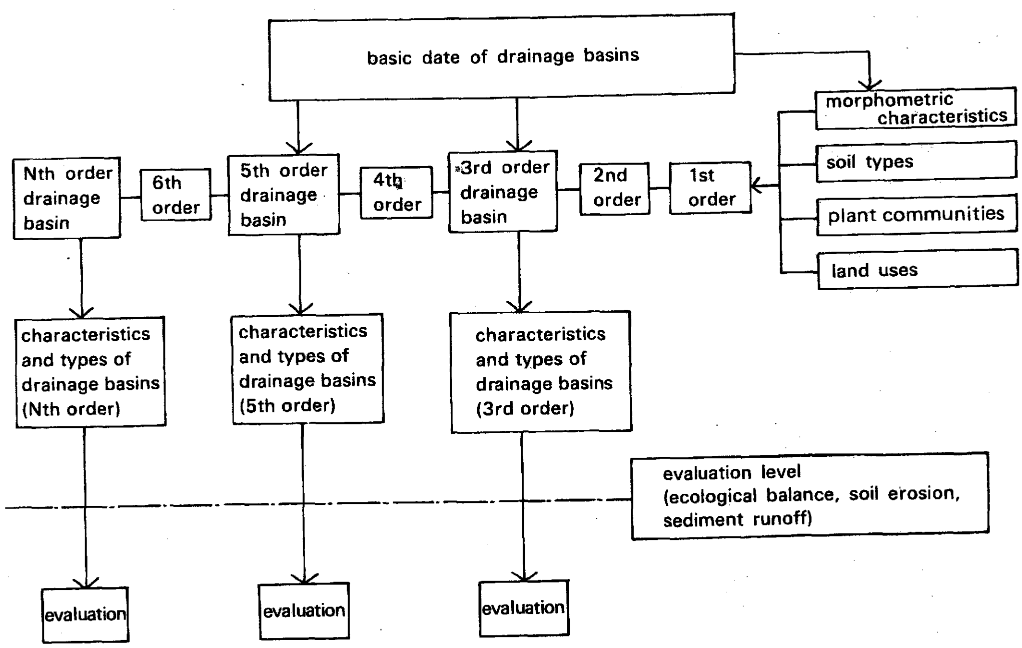

Fig. 1 Landscape evaluation system according to the drainage-based landscape hierarchy. The catchment area of Horton's N'th order streams is defined as N'th order drainage basin.

drainage basin is to be conserved without artificial reformation of it as far as possible and technical measures against soil erosion are required. The biological base should be considered to keep biological diversity for the conservation of land itself and for the stabilization of geo-ecosystems in the drainage basin. On the other hand, land utilization based on the characteristics of the land must be considered to conserve the landscape permanently while keeping the balance of land and land-use systems in the drainage basin.

Framework for the conservation of an eroded drainage basin

The ridge of the hill and the valley bottom should be noted as important parts to develop landscape management completely within a drainage basin and to cause little environmental deterioration to the other landscape. First of all we must present such a framework for landscape conservation in small drainage basins, while the total framework for conservation in comparatively large drainage basins will be presented by the accumulation of frameworks in smaller drainage basins (Fig. 2).

Better land use from the view point of the potentiality of land

To conduct land use with careful consideration of the stability of geo-ecosystem in drainage basin, better land use adapted to the potentiality of land should be presented. Here

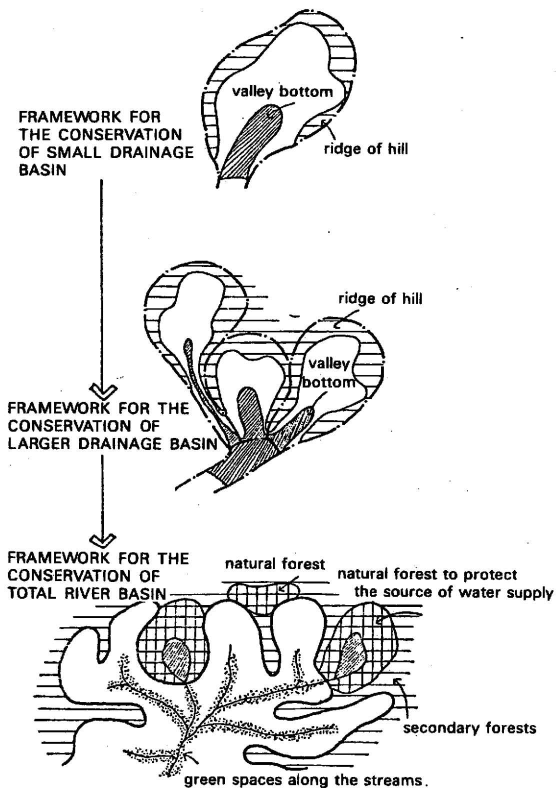

Fig. 2 Conceptional framework for landscape conservation in drainage basin units.

the potential is given in qualitative terms by Young (1973) as degree of suitability for various forms of land use. Land classification and landscape evaluation to grasp the suitability of each land unit for the land-use items are required to estimate the potential of land for better land use.

In the areas where environmental deterioration in drainage basin has occurred, the limitation of land utilization will be presented as a result of landscape evaluation. A concrete method which presents better land use from the view point of land potentiality, will be shown as a case-study.

Technical measures for the rehabilitation of eroded drainage basins

In order to rehabilitate the eroded drainage basin, it is important to consider how technical measures should be used in landscape planning (Olschowy, 1973), Especially when we try to conserve the biological diversity, it is necessary to present a certain method for landscaping based on bio-engineering.

In a region like the northern part of Okinawa Island, wherein serious land reformations in a short time have already occurred, it is necessary to consider the technical measures corresponding not only to various sites but also to various time-stages.

In artificially reformed land, planning the restoration of the site itself by means of technical measures such as top-soil recovery or the landscaping with plant materials in correspondence with each stage of plant succession should be considered (Fig. 3).

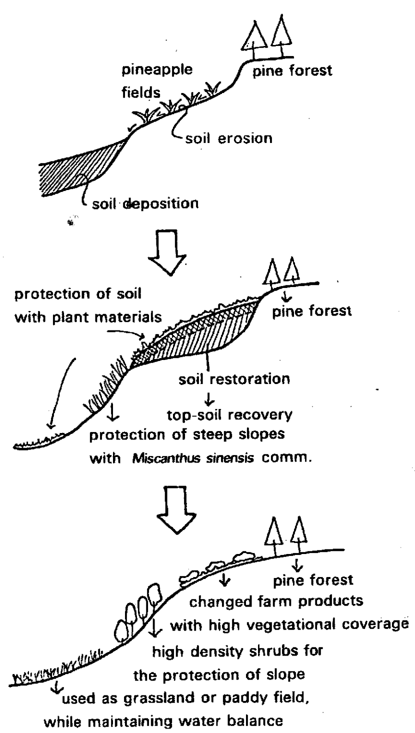

Fig. 3 Schema of the landscape recovery.

A CASE STUDY IN A SMALL DRAINAGE BASIN

In the former chapter, methodological background has been investigated for the conservation of the landscape in a drainage basin in the northern part of Okinawa Island. A small drainage basin with an area of some 0.01km² is recommended as a fundamental unit for landscape evaluation and planning in a region where such intensive land use has been carried on.

Here we apply the method of landscape evaluation to a third order drainage basin measured by the maps of 1:5,000 scale as a spatial unit. In order to discuss its methodological problems, a small drainage basin with an area of 0.053km² in the Yabu River basin located in Nago City, Okinawa Prefecture (Fig. 4) has been chosen as a case to discuss. Herein serious reddish soil erosions have occurred.

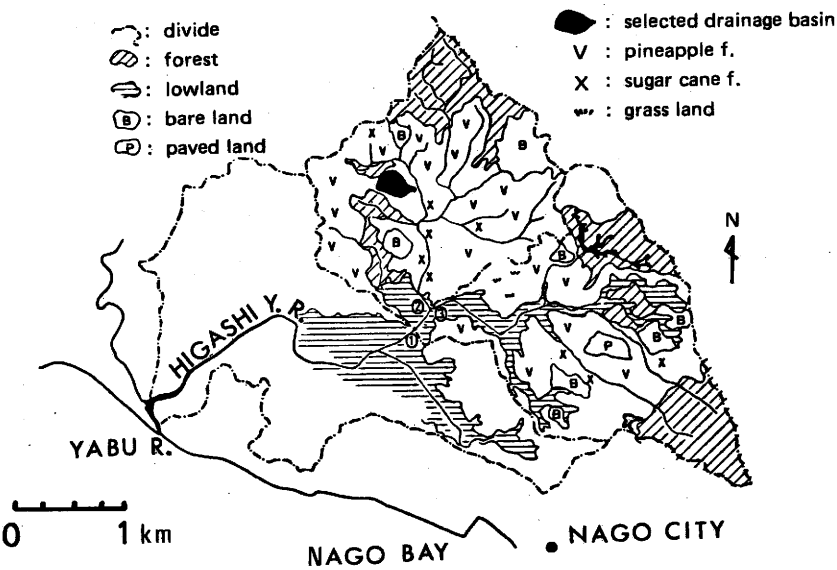

Fig. 4 Study area.

LANDSCAPE INVENTORIES IN THE STUDY AREA

As the first step in the process of the landscape evaluation, the present situation of the selected basin was surveyed. We attached here the importance of analysis of land use, vegetation and physical setting including water runoff and sediment yield.

Land use

Sloping surfaces in this basin had been utilized mainly as woodland, and paddy field had been restricted only to the lower reaches for a long time. However, from late 1960's, exploitation of pinery has occurred in the Northern part of Okinawa Island. In this basin pineapples have been planted out on the gentle slopes and flat grounds, which were made by cutting off the original slopes and piling up the lowland and the steep slopes with bulldozers.

This artificial reformation of land brought about a marked change of land use. The survey in August 1975 represented the percentages of each land use; pinery: 55%, grassland and woodland: 34% and bare land: 11%. The bare land has been created to plant pineapples, but is not yet planted.

The introduction of agricultural land use with land reformation has made soil erosion active and caused reddish flow with suspended sediment.

Vegetation

A phytosociological vegetation survey was done in the basin and eight plant communities were selected. Differential species of each of the plant communities are shown in Fig. 5-a and the spatial distribution of plant communities is shown in the actual vegetation map (Fig. 5-b).

Most of these plant communities are affected by strong human intervention. A succession series of plant communities according to the human intervention is suggested as Fig. 6 (Niiro, 1971; Miyawaki, 1977). Considering such succession series is very important when we consider the landscaping method with plant materials.

As a result of stem volume sampling, stem volume of trees seems to become less with the increase of human intervention and the decrease of vegetational stability.

Physical setting

The bedrock of the basin is phyllite, named Motobu Formation (Paleozoic), which has been weathered deeply more than 30m. Gentle slopes, which correspond to Surface I by Nishimura, *et al.* (1973), distribute the upper reaches with gravel layer of a few metres thickness.

This basin has a relief of 52m and altitude of outlet is 12m a.s.l. Steep slopes distribute along stream channels, which have incised the weathered phyllite. The annual rainfall measured at a meteorological observatory 2km away from this basin is 2,400mm.

Soils are classified into three groups representing upland reddish soils, hillside yellowish soils, and depositional bottom land soils. The reddish soils with gleyed A horizon develop on the gently sloping land surfaces, vegetated by *Pinus lutchuensis* community. Strong human impacts which cause the destruction of soil horizons, or serious soil erosion have not been undergone in the plant communities such as *Castanopsis sieboldii* community, *Schima wallichii ssp. likukiaensis* community, and *Pinus lutchensis* community constituting of tree layers.

But most of the soils in this basin have been truncated and new parent materials added by strong human intervention. Every plant community on the soils has gained its ecological sites throughout the history of the landscape change. Dynamic stability of land surface may be the most important condition for the plant communities as a physical base. Quality of plant communities seems to have been determined by the activeness of soil erosion in the basin.

The Ao horizon is lacking in the area of *Elaeocarpus japonicus* community. The area suffered from severe soil erosion at the time of bare land or grass land preceding the

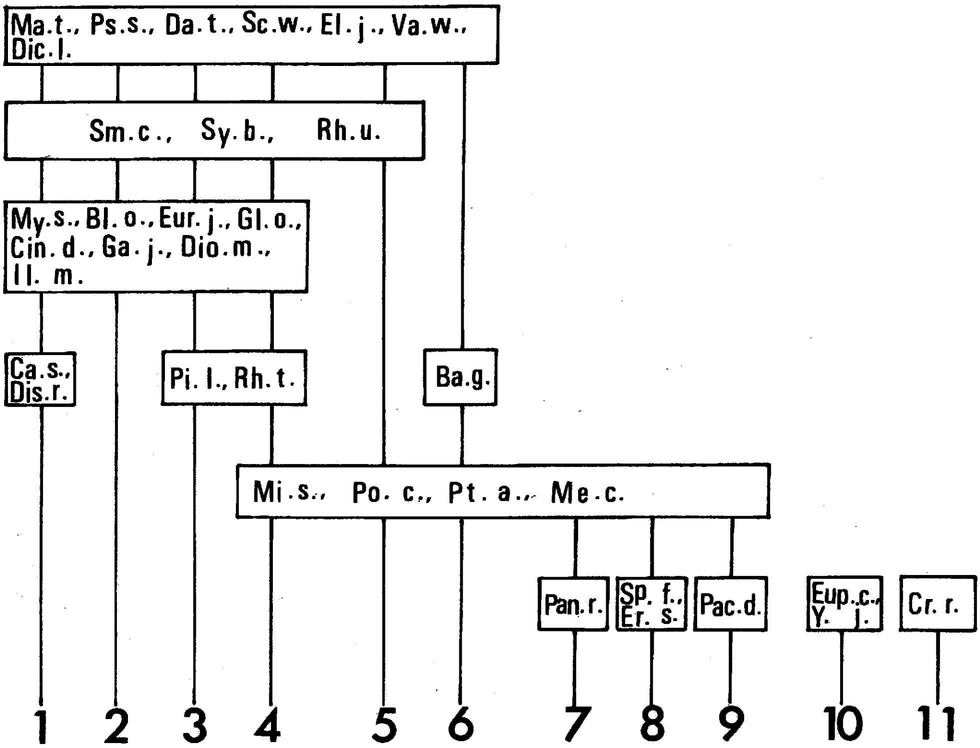

Fig. 5-a Differential species of each plant community

Ma. t. : *Machilus thunbergii*
Ps. s. : *Psychotria serpens*
Da. t. : *Daphniphyllum teijsmannii*
Sc. w. : *Schima wallichii ssp. liukiaensis*
El. j. : *Elaeocarpus japonicus*
Va. w. : *Vaccinium wrightii*
Dic. l. : *Dicranopteris linearis*
Sm. c. : *Smilax china var. kuru*
Sy. b. : *Syzygium buxifolium*
Rh. u. : *Rhaphiolepis umbellata*
My. s. : *Myrsine seguinii*
Bl. o. : *Blechnum orientale*
Eur. j. : *Eurya japonica*
Gl. o. : *Glochidion obovatum*
Cin. d. : *Cinnamomum doederleinii*
Ga. j. : *Gardenia jasminoides*
Dio. m. : *Diospyros morrisiana*
Il. m. : *Ilex maximowicziana*
Ca. s. : *Castanopsis sieboldii*
Dis. r. : *Distylium racemosum*
Pi. l. : *Pinus lutchuensis*
Rh. t. : *Rhodomyrtus tomentosa*
Ba. g. : *Bambusa glaucescens*
Mi. s. : *Miscanthus sinensis*
Po. c. : *Polygonum chinense*
Pt. a. : *Pteridium aquilinum*
Me. c. : *Melastoma candidum*
Pan. r. : *Panicum repens*
Sp. f. : *Sporobolus fertilis*
Er. s. : *Erigeron sumatrensis*
Pac. d. : *Pacpalum dilatatum*
Eup. c. : *Euphorbia chamaesyce*
Y. j. : *Youngia japonica*
Cr. r. : *Crassocephalum rubens*

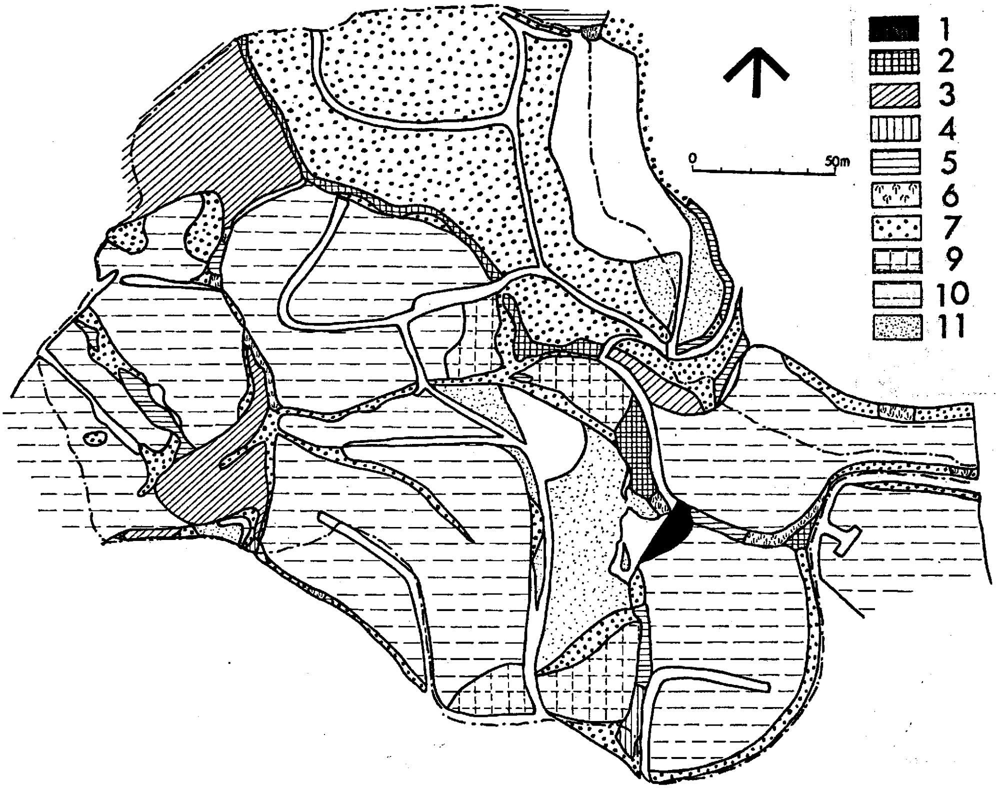

Fig. 5-b Actual vegetation map of the survey area

1. *Castanopsis sieboldii* community
2. *Schima wallichii ssp. lukiaensis* community
3. 4. *Pinus lutchuensis* community
   (3. Typical subordinate comm. 4. *Miscanthus sinensis* subordinate comm.)
5. *Elaeocarpus japonicus* community
6. *Bambusa glaucescens* community
7. 8. 9. *Miscanthus sinensis* community
   (7. *Panicum repens* subordinate comm., 8. *Sporobolus fertilis* subordinate comm., 9. *Pacpalum dilatatum* subordinate comm.)
10. Upper field plant community
11. Renovated field plant community

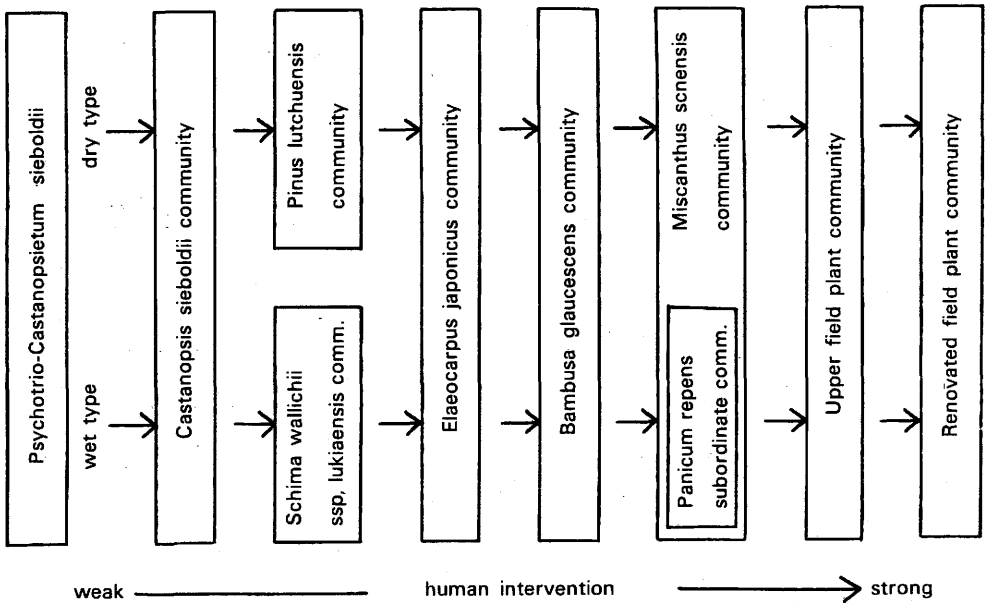

Fig. 6 Succession series of plant communities in the study area.

formation of shrub layers, such as *Cinnamomum doederleinii, Elaeocarpus japonicus. Bambusa glaucescens* community and *Miscanthus sinensis* community are found in abandoned areas in pineapple fields and on cuttings of roads. These areas have experienced large scale land reformation 5-15 years before and A horizon was taken out of these areas by soil erosion. On the ground surface of the cultivated pinery, which belongs to the upper field plant community, B and BC horizons of reddish soils are exposed. Present soil erosion is most active on the bare land and the pineapple field planted 1-2 years before. Suspended materials, which are delivered from bare land and pineapple field, are reddish clay. The relationship between plant communities and soil erosions is shown in Table 1.

Concerning the characteristics of sediment runoff, water discharge was measured and suspended sediment was sampled at every rainfall from June to October 1975.

Observed data on the 11th and 12th of August 1975 are shown in Fig. 7. The volume of discharge at the peak stage reached 0.0178 l/s for the rainfall of 2.7mm from 11.40 to 11.50 of the 11th of August and 0.0390 l/s for the rainfall of 5.7mm from 12.15 to 12.30 of the same day. They were 11 and 24 times greater than the discharge of low stage respectively. Concentration of suspended sediment was not observed at the same time as the former rainfall. The reason can be deduced that there had been no antecedent rainfall for two days. Highest concentration of suspended sediment was 8.4 g/l in the case of runoff of the latter rainfall. Total amount of the suspended sediment of both rainfalls was 230kg (4.3t/km^2). By the runoff of 1.3mm rainfall of the 12th of August, 1kg suspended sediment was transported from the channel. Peak discharge was 0.0028 l/s, which 4 times greater than the discharge of low stages respectively.

Table 1 Relationship between plant communities and soil erosion

Soil erosion \ Plant comm.	Ca. s. comm.	Sc. w. comm.	Pi. lu. comm.	El. j. comm.	Ba. g. comm.	Mi. s. comm.	Up. fi. comm.	Re. fi. comm.
Surface exposure	+	+	+	+ +	+ +	+ +	+ +	+ + +
Height of tree layer (m)	20	20	15	8	5	2.5	1.5	0.2
Absence of A horizon	–	–	–	–	+	+ +	+ + +	+ + +
Sheet erosion	–	–	–	–	–	–	+	+ + +
Rill erosion	–	–	–	+	+	+ +	+ +	+ + +
Gully erosion	+	+	+	+	+	+ +	+ +	+ + +
Sheet flood	+	+	+	+	+ +	+ +	+ + +	+ + +
Sediment runoff	+	+	+	+	+	+ +	+ +	+ + +

The volume of suspended sediment in this catchment increased with the increase of discharge. Fig. 8 shows the regression between water discharge and suspended sediment load. Regression is expressed by the following equation:

$$Qst \doteqdot 0.5Q^{2.0}$$

where Qst is the discharge of suspended sediment (g/s) and Q is the water discharge (l/s).

The value of the exponent is as similar as that obtained in the Morogoro river catchment, Tanzania (Rapp, *et al.*, 1972), which has an area of 19.1km^2, produces considerable losses of soil and water, and is cleared land under fallow (44% of the catchment) and cultivated plots (11%). The value of the coefficient is in the same order as that. And it is 100 times greater than that of a small drainage basin on the margins of Exeter, England (Walling, 1974), which has an area of 0.26km^2 and is largely in a natural state.

Judging from this regression equation, this studied basin delivers much sediment to the lower reaches. Most of the sediment yield in this basin is the result of active soil erosion and water runoff in the pineapple field and the bare land. These losses of soil and water can be reduced to acceptable proportions by conservation measures on slopes. The regression equation may provide a useful measure of sediment yield, and the reduction of sediment yield is estimated by the lowering of the values of the exponent and the coefficient.

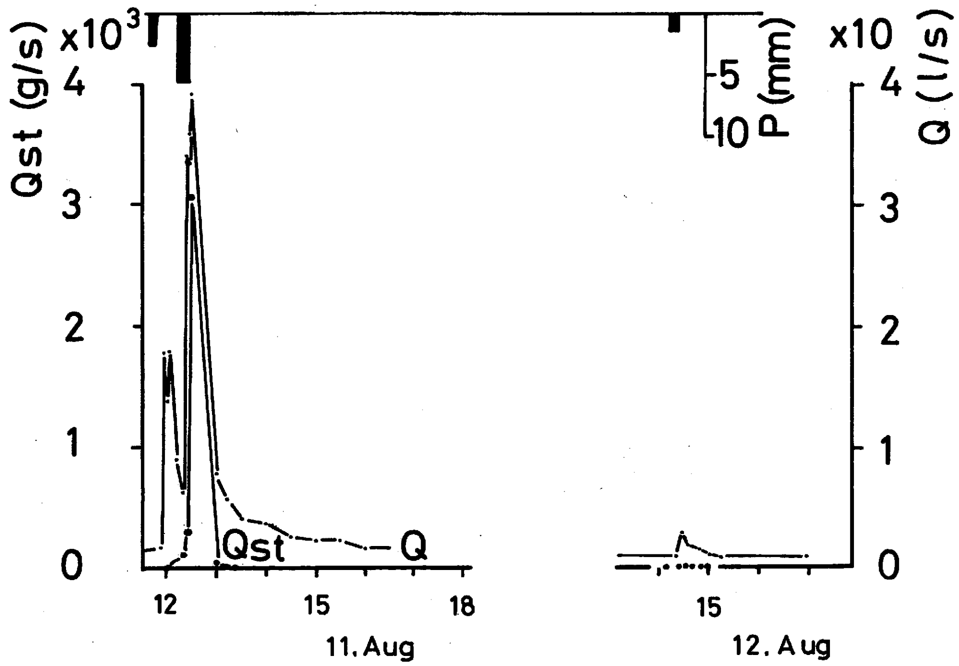

Fig. 7 Rainfall, water discharge and suspended sediment discharge in the small drainage basin. P is rainfall (mm), Q is water discharge (l/s) and Qst is suspended sediment discharge (g/s).

LANDSCAPE EVALUATION IN THE STUDY AREA

Conservation of slopes and soils in the eroded drainage basin

In steep slopes (gradient of 15°–35°) soil erosion such as rill or gully erosion is active rather than gentle slopes. In very steep slopes (gradient of over 35°) small landslides occur in addition to soil erosion. Source areas of suspended sediment in this basin are the slopes exposing reddish and yellowish soils, which are mostly used as pineapple fields or bare lands, and the very steep slopes along the steam. The areas are extracted as a principal framework for the landscape conservation and planning. It is necessary to conserve and rehabilitate these areas not to spread soil erosions and suspended sediments to the lower streams.

The steep and very steep slopes ought to be covered with high vegetational coverage because of it being very effective for the protection of soils. It is also necessary to clarify better connection between slope and land use.

In steep slopes land use with high vegetational coverage is desired, e.g. woodland or grassland. In very steep slopes high density woodland or grassland should be brought up and managed. Intensive land use including pinery is not to be permitted (Nago City, 1974).

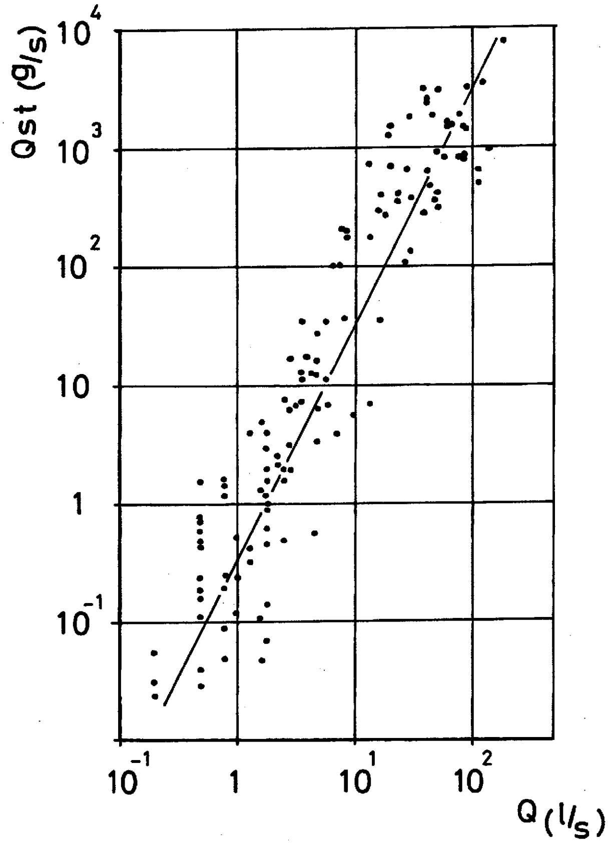

Fig. 8 Relationship between water discharge (Q) and suspended sediment discharge (Qst).

If pinery is still considered in such slopes, farm products with high vegetational coverage such as tea or orange should be cultivated in addition to pineapple. Bare lands must be protected against soil erosion by planting grasses. In pineapple field the way of planting pineapples must be improved so as not to erode soils. It is desirable that pineapple fields are restricted to the gentle slopes, the paths in the field parallel the contour lines and mulching is actively used so as not to expose the soil surface to the raindrops.

The areas, wherein plant communities and soil horizons are natural or semi-natural, are to be maintained and preserved as they remain biologically valuable space in the artificially reformed landscape.

Evaluating the potentiality of land for better land use

Each evaluational phase for the conservation of the drainage basin is summarized and overlaid in Fig. 9.

Comparing with the results of the evaluation of land potentiality and actual land use, the ecological quality of which is indicated in the vegetation map, direction of rehabilitation and landscaping of the eroded drainage basin was considered and suggested. As a result, it is

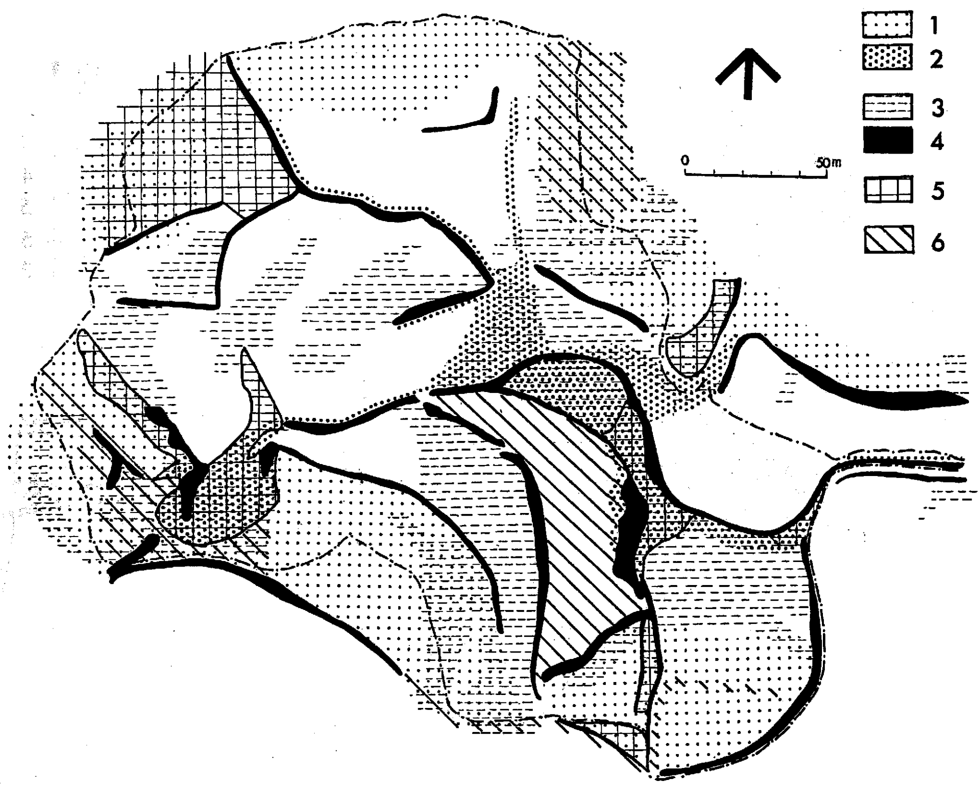

Fig. 9 Landscape evaluation for the rehabilitation of drainage basins in the study area;

I. Frameworks for the conservation of the basin;
1. conservation of the ridge of the hill
2. conservation of the valley bottom

II. Rehabilitation of slopes and soils;
3. steep slopes (more than 15 degrees): land use with high vegetational coverage is desired.
4. very steep slopes (more 35 degrees): high density woodland or grassland should be brought up and managed.
5. natural or semi-natural vegetation and soils: the areas are to be maintained and preserved.
6. renovated bare lands: they must be protected against soil erosion by planting grasses.

presented as how landscape management ought to be. Fig. 10 show an example of landscape plan in the case of continuing pinery while protecting the land from soil erosion.

CONCLUDING REMARKS

In this paper a method of landscape evaluation for the rehabilitation of drainage basins was discussed and a case-study in the small drainage basin was pursued. Here we showed

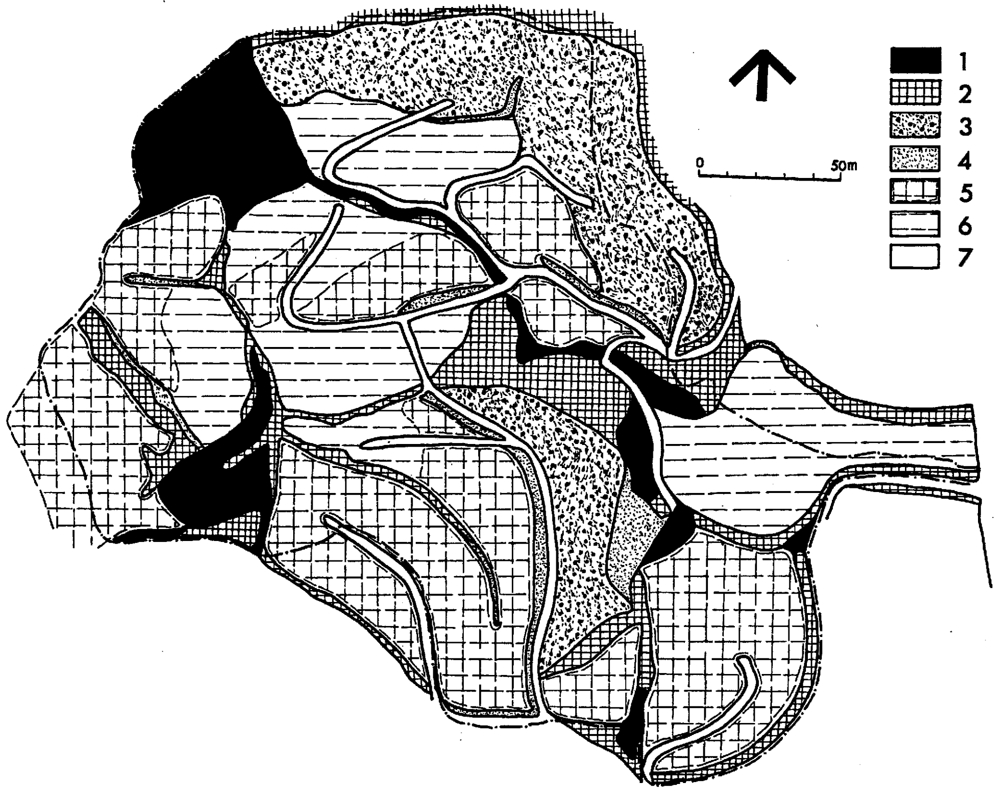

Fig. 10 An example of landscape plan in the study area;

I. Conservation of natural and semi-natural forest:
   1. forest of *Castanopsis sieboldii* or *Pinus lutchuensis*.
II. Conservation of shrubs:
   2. high density shrubs.
III. Management of grasses:
   3. grassland.
   4. grasses to protect very steep slopes.
IV. Management of farm products
   5. farm products with high density vegetation coverage.
   6. pineapple.
V. Others:
   7. paths (changed parallel to the contour lines).

some conceptional flow charts for the conservation and rehabilitation of eroded drainage basins and some phases in the planning process of the landscape, *i.e.* landscape inventories, evaluation, planning and management.

We discussed, however, only some parts of the problems concerning the conservation and rehabilitation of eroded drainage basin. Firstly, fundamental investigation on some landscape factors is not enough. Investigations must be done including comparison with other types of small drainage basins. Secondly, a case-study in a 5th order drainage basin could not be done. It is necessary to organize the hierarchy of landscape evaluation in a larger river basin.

Lastly, methods of technical proceduces, especially bio-engineering, should be concretely presented.

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