Resource Degradation in High Altitude Agro-ecosystems: An Overview of the Ecological Capital Management in Tea Plantations in the Highlands of Uva in Sri Lanka

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Abstract

The mountain environment in the Uva region typically called as Uva highlands is characterized by natural forests, grasslands, agricultural lands, plantations, home gardens and non-agricultural lands. Predominant agro-ecosystems are the tea plantations and smallholding cropping systems. However these highlands face rapid degradation of the environment and production resource base. There are unmistakable symptoms of the emerging unsustainability of current patterns of resource use and production practices in mountain agro-ecosystems. The objective of the present study was to examine some aspects of the ecological capital management in tea plantations in the Uva highlands in Sri Lanka.

The findings of the study confirmed that the land based management activities were most critical in the plantation tea sector. Most of the plantations are highly prone to erosion causing poor quality soil. Soil organic carbon and the acidity are in critical levels in most of the plantations. The ecological capital management activities have a significant effect on the productivity and the quality of the tea plantations. An inter estate analysis of the quality of the ecological capital indicated that most of the tea estates are in the range of marginal value. Long-term management plans have to be implemented in order to make the tea plantations viable. Along with soil conservation activities, replanting and infilling activities have to be accelerated. Ecological capital management strategies need to be restructured for the sustainability of the tea plantations in the highlands of Uva region in Sri Lanka.

Introduction

By mid nineteenth century, many Sri Lankan tropical mountain forests were cleared in order to plant coffee and cinchona. Coffee plantation covered 20,500 hectares in 1847, increased to about 32,200 hectares by 1857 and to 110,500 ha by 1873. Approximately 20,200 ha were converted from *chena* lands (De Silva 1981).

By then the coffee blight was taking hold, and after 1880 coffee gave way to tea plantations. Tea cultivation was extremely efficient, and tea soon became Sri Lanka's single largest foreign exchange earner. In conventional business terms the transformation of natural forests to plantation agriculture was highly successful.

James Taylor, a British planter acknowledged as the pioneer of the Island's tea industry, experimented with various types of tea plants to find those that are suitable to both the climate and the soil. He first planted tea for commercial purposes on a nineteen acres of land on Loolecondera estate Deltota in 1867. Soon other planters followed and brought large areas of thick jungles under cultivation, which slowly changed the landscape of the central region of the country.

The mountain environment in *Uva* region typically called as Uva highlands is characterized by various types of agricultural activities. Predominant agro ecosystems are the tea plantations. A large area of poorly managed tea plantations characterizes these mountains. These activities have further accelerated the environmental degradation resulting in increased marginalizaiton of previously productive lands, reducing fertility in the highlands and increasing the silt load in dams for irrigation projects downstream. Therefore an alternative resource management system for the perennial agro-ecosystems such as tea plantations in the deforested hills is needed for the sustainability of the highlands in *Uva* region.

In view of the above situation, this paper attempts to investigate the current pattern of ecological capital management strategies used in the plantation tea sector of the highlands of *Uva* region in Sri Lanka.

Conceptual Framework and the Methodology

Ecological Capital Management in Agro-ecosystems

Sustainable agro-ecosystems are defined as systems that use both biophysical and socio-economic resources to produce outputs that the present socioeconomic environment (today's society) values more than the value of purchased inputs (i.e. the system is economically viable), while at the same time maintaining the future productivity of the biophysical environment (i.e. the system is ecologically sustainable).

The agro-ecosystems interact with the socio-economic environment through the purchase of input and sale of output. It interacts with the biophysical environment through the degradation of natural resources caused by some agro-ecosystem outputs (pesticide, manure, etc.) and through the use of resources as inputs from production processes (water, nutrients, etc.).

Sustainability of agro-ecosystems will require explicit consideration of all environment relationships. Inputs that will not negatively affect the environment or systems that regenerate the natural resource base, but are not economically viable, will not be adopted by farmers (Pezzey, 1989: 88). The development of economically viable systems that degrade the resource base to the point that natural resource productivity decreases, cannot sustain system of production longer than society is willing to subsidize external purchased inputs. Extensive production systems that are managed in such a way that their production exceeds the productivity of the natural resource bases, may be economically viable in the short-run, but the income produced by these systems are, in effect, being borrowed from future generations (Barbier, 1989).

Therefore, agro-ecosystem management can be conceptualized not in a two-way linkage (natural system-economic system) but a three-way linkage incorporating social/institutional /cultural dimensions also (figure 1).

Agro-ecosystems are embedded in both socio-economic and biophysical environments in local, national and global levels. Therefore, external as well as internal factors may crucially affect the system imbalance.

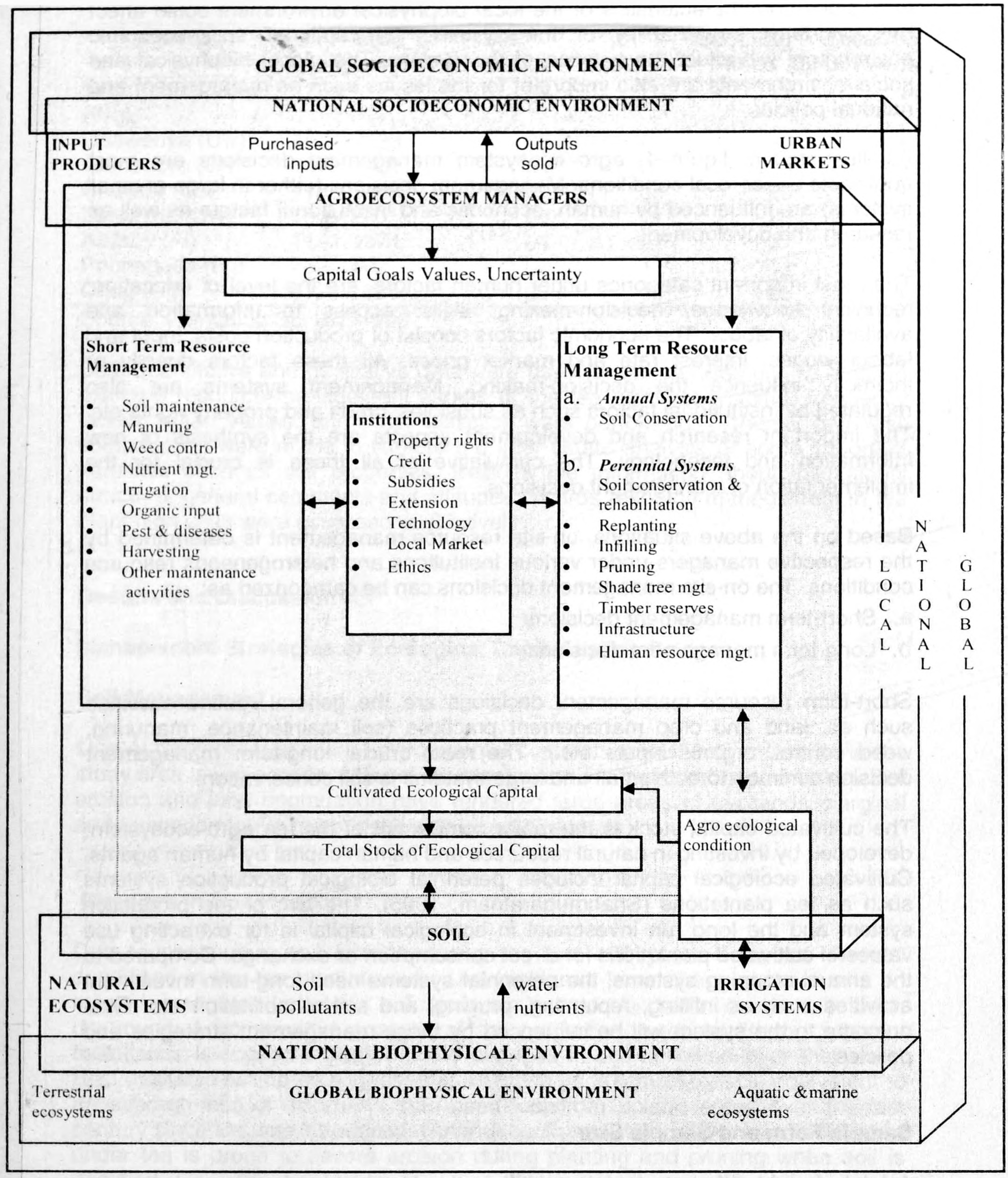

Figure 1. Conceptual framework of ecological capital management in agro ecosystems

Conceptually agro-ecosystems are inclusive of the decision-making arrangements that govern them. Large perennial and smallholding cropping systems are depicted as interacting with soil (which is also a component of the national and global biophysical system). In addition to the local market and social institutions, the characteristics of the local biophysical environment could affect the long-term sustainability of the system. The national socio-economic environment will affect the balance of the system. The global biophysical and social environments are also important for the issues such as management and national policies.

As illustrated in figure 1, agro ecosystem management decisions are most applicable under local conditions. Management decisions (either in large or small systems) are influenced by human, economic and institutional factors as well as research and development.

The most important categories under human factors, are the level of education, technical knowledge, decision-making, skills, access to information and availability of labour. The economic factors consist of production costs, input and labour wages, interest rate and market prices. All these factors directly or indirectly influence the decision-making. Management systems are also regulated by institutional factors such as subsidies, credit and property rights etc. The important research and development aspects are the synthesis of new information and technology. The cumulative of all these is crucial for the implementation of management decisions.

Based on the above situations, on-site resource management is determined by the respective managers under various institutions and heterogeneous resource conditions. The on-site management decisions can be categorized as:

a. Short-term management decisions
b. Long-term management decisions

Short-term resource management decisions are the general routine activities such as, land and crop management practices (soil maintenance, manuring, weed control, organic inputs etc.). The most crucial long-term management decision common to both small and large systems is soil conservation.

The cultivated capital stock is the major component of the tea agro-ecosystem; developed by investing in natural resources and human capital by human agents. Cultivated ecological capital includes perennial biological production systems such as tea plantations (Shanmugaratnam, 1995). The aim of the production system and the long run investment in ecological capital is for extracting use values of cultivated plantations for direct consumption or exchange. Compared to the annual cropping systems, the perennial systems need long-term investment activities such as infilling, replanting, pruning, and soil rehabilitation etc. Final outcome to the system will be influenced by these management strategies and policies.

Sample Form and Sample Size

A total of eight different plantation units in the *Uva* highlands were selected for this study (table 1). The tea plantations were randomly selected within the study area and the field data were collected from plantation records. The data were gathered from total number of 339 fields from 35 divisions in the above plantations. This represents a total area of 4548 hectares in the study area.

Table 1. Distribution of the Tea Plantations

Estate	Elevation (meters)	Total Divisions	VP Fields	Seedling Fields	Total No of Fields
Welimada Group (Wg)	1200	04	20	22	44
Udaweriya (Uw)	1707-2133	06	01	43	44
Glenanore (Gn)	1372-1432	04	07	24	31
Chelsea (Cs)	1182-1455	02	05	20	25
Dickwella (Dw)	750-1200	03	14	25	39
Aislaby (Al)	1191-1374	04	21	37	58
Poonagalla (Pg)	762-1402	07	11	43	54
Craig (Cg)	1128-1528	05	16	28	44

Source: Plantation Survey, 1998

Both quantitative and qualitative data were used for the assessment. In order to examine resource management aspect of the tea agro-ecosystems, frequency tables, mean values, and other statistics were performed. Fisheres' pair wise comparisons were made to explore the inter estate analysis of some important variables such as soil properties. Besides the information about institutional structure, general comments and attitudes towards resource management in tea plantation units were assessed qualitatively.

Results and Discussion

Management Strategies of Ecological Capital in Tea Sector

Soil Management

One of the most significant environmental costs of agricultural production in the study area is soil erosion. Most of the plantations are highly prone to erosion. Soil erosion and land degradation have rendered large areas of tea lands marginal and uneconomical in many parts of the *Uva* highlands.

Changes in Soil Horizon

Due to continuous soil erosion during the last 100 years or more, the soil conditions in the tea plantations in *Uva* highlands have changed drastically. In most investigated estates, soil horizons up to A_2 have completely been destroyed. A comparative analysis of soil properties in tea lands and adjacent forestlands is a good indicator of the changes in soil condition over the years. Best available estimates suggest that as much as 30 cm of topsoil, equivalent to an average loss of 40 t/ha/yr, has been lost from upland areas over the last century since tea was introduced. (Anandacoomaraswamy 1994). Land cultivation under tea is prone to severe erosion during planting and pruning when soil is exposed.

Bulk Density

The bulk density measures the degree of compaction. The mean bulk density of the selected estates is around 1.18 Mgm^{-3}, which is high above the average bulk density of virgin forest soils. Anandacoomaraswamy et al. (1988) has also compared the bulk densities of soil under tea cultivation and adjoining forest in different sites and reported that in all locations and depths, forest soils had lower bulk density than tea soils. Some of the reasons for soil compaction are lower organic matter content, treading by workers and beating action of rainfall.

Organic Carbon Content of Tea Soils

The organic carbon percentage in most plantations was below critical level. (Table 2) The mean organic carbon content in tea estates in the study area was 2.16%, which is well below even the critical carbon level of 2.5 percent.

Table 2. Organic Carbon Status of the Tea Soils

Estate	Average organic carbon %	Std. Dev	% Fields below critical level*	% Extent below critical level
Wg	1.69	0.463	90.62	68.07
Uw	3.18	0.486	11.11	18.89
Gn	3.74	1.236	36.08	34.05
Cs	2.78	1.016	32.20	30.50
Dw	1.75	0.458	73.22	81.4
Al	2.01	0.431	65.51	78.33
Pg	1.50	0.363	97.95	88.23
Cg	2.52	0.555	18.18	23.09
Mean	2.16		53.10	52.82
Pooled Std. Dev	0.069			

* Critical organic carbon level = 2.5%
Source: Field Survey 1998 (Plantation Management Records)

Glenanore estate had the highest organic carbon content (3.74%) followed by Udaweriya (3.18%). Fisher's pair-wise comparison indicated that there was a significant variation among tea estates in relation to organic carbon. Soil organic carbon percentage is a major indicator of the soil nutrient conditions. This highlights the land degradation extent in study area over the last couple of decades.

The relationship between organic carbon content in tea soils in different altitude is given in Figure 2. The soils in the tea plantations in high elevation consist of comparatively high carbon percentage than other plantations. This is mainly due to the accumulation of organic matter under low temperature conditions. The temperature progressively declines with elevation. A similar pattern has been determined by Tolhust (1961) and Ananda Coomaraswamy et al. (1988).

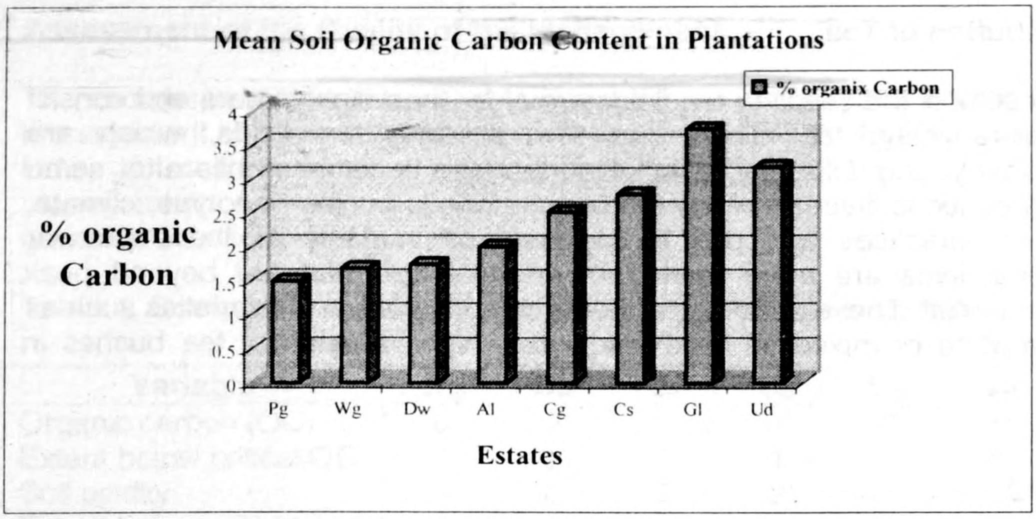

Figure 2. Mean soil organic carbon content in plantations

Sandanam and Anandacoomaraswami (1982) reported that five percent of organic matter was present in Red Yellow Podzolic soils under well-managed tea plantations. The relative low organic matter content of soils of tea lands in the *Uva* highlands is mainly due to excessive soil erosion over a long period of time. Organic carbon is one of the factors that determine soil fertility. Higher organic carbon results in high water and nutrient holding capacity of the soi!, thus contributing to an increase in yield.

Soil Acidity

Normally tea soils are acidic in nature. For the optimum production, the most suitable pH range is between 4.5-5.5. The mean acidity of the tea estates in the study area was around 4.51 with standard deviation of 0.36 (table 3). Field wise data indicated that considerable hectarage of the plantations is below the critical level. According to the estate managers of the estates studied, tea soils are becoming more acidic over time. Over-fertilization of the fields with acid forming fertilizers such as Ammonium Sulphate is one of the major factors for the increasing acidity in tea fields.

Table 3. Soil Acidity Condition

Estate	Average pH level	Std. Dev	% Fields below critical pH* level	% Extent below critical pH level
Wg	4.18	0.225	30.89	44.78
Uw	4.45	0.180	23.40	27.67
Gn	4.55	0.403	12.90	17.15
Cs	4.57	0.418	28.00	25.88
Dw	4.49	0.307	17.94	10.95
Al	4.56	0.444	27.58	33.86
Pg	4.66	0.338	7.40	5.59
Cg	4.48	0.470	13.63	20.07
Mean	4.51		20.21	23.24
Pool St Dev	0.366			

Critical level of soil acidity = pH 4.2
Source: Field Survey, 1998 (Plantation management records)

Age Distribution of Tea

More than 90% of the seedling tea fields are older than eighty years and consist of pre-war seedling tea. There are few seedling tea fields, which are comparatively young. Like any other plant, tea also becomes senile after some time. The economic lifespan of the tea bush depends on the genotype, climate, management practices and pest or diseases. A majority of these pre-war seedling tea fields are more than 100 years of age and are beyond peak cropping potential. These seedling tea fields comprise of old tea varieties such as high/China/white or mixed jat, and leads to a high variation of tea bushes in estates.

Replanting

Replanting of old seedling tea with high yielding clonal materials is negligible in the study sites. Figure 3 shows the average replanting of old seedling tea with VP tea since 1993. Annual replanting was even below the one percent of the area under tea cultivation of the study sites.

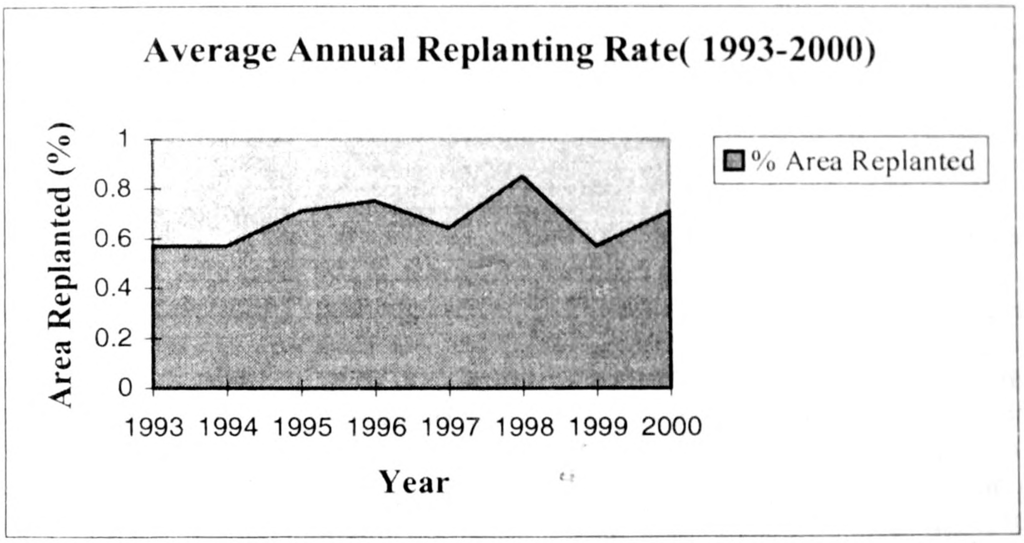

Figure 3. Average annual replanting rate in the study sites

The estimated replanting area for the year 1999 and 2000 were 0.6 and 0.7 percent of the total area respectively. With this rate of replanting it might take more than 100 years to replace the old bushes with new clones in the *Uva* highlands.

Plant Density

Maintenance of proper plant density is necessary for both ecological and economic reasons. The recommended optimum number of tea bushes per hectare in higher elevation ranges between 9,000-10,000 and 12,500-13,500 for seedling and VP fields respectively. The mean average plant densities per hectare were far below the recommended rate in all estates.

Mean vacancy rate in seedling and VP fields in the investigated plantations was around 20 and 10 percent respectively. High vacancies lead to low ground cover thereby aggravating the erosion problem and declining soil fertility and yield.

Assessment of the Quality of the Management

The composite matrix (table 4) provides selected indicators of ecological capital management of the estates studied. The overall ecological capital management index in most estates is within the range of 1-1.5. With respect to the management of ecological capital, none of the plantations can be considered as good within overall quality of the management.

Table 4. Composite matrix of inter estate resource management

Variable	Wg	Ud	Gl	Cs	Dw	Al	Pg	Cg
Organic carbon (OC)	0	2	2	1	0	0	0	1
Extent below critical OC	0	2	1	1	0	0	0	1
Soil acidity	0	0	2	2	1	2	2	1
Extent below critical acidity	0	1	2	1	2	1	3	2
Seedling:VP	2	0	0	1	1	1	1	1
Proportionate age of VP fields	3	-	3	3	3	2	2	3
Stand per ha a. Seedling	0	0	1	0	1	2	0	1
b. VP	1	-	2	2	2	1	2	2
Vacancy rates a. Seedling	0	0	1	0	1	2	0	1
b. VP	1	-	2	2	2	1	2	2
Replanting	1	0	1	1	1	1	1	1
Infilling	1	0	1	1	1	1	1	1
Land Labor ratio	1	1	3	1	1	1	1	1
Shade trees	2	3	0	2	2	2	2	2
Potential yield a. Seedling	1	1	2	2	2	2	1	2
b. VP	2	-	3	3	1	3	2	2
Overall quality of ecological capital management	0.93	0.83	1.63	1.44	1.31	1.37	1.25	1.56

Remarks:
3= Good 2=Satisfactory 1=Unsatisfactory 0=Critical

Conclusion

Assessment of the current resource management indicated that the investigated tea plantation units are not sustainably managed in the *Uva* highlands in Sri Lanka. Land degradation was evident in most of the tea plantations. Several crucial needs of management of ecological capital have not been adequately met. One of the most crucial factors is the diminishing availability of organic materials to maintain soil fertility. Hence, the depletion of soil fertility due to poor maintenance and soil erosion has led to the marginalization of tea lands, resulting in decreased productivity. In relation to soil acidity, considerable extent under tea cultivation is in critical condition.

Majority of the area is comprised of old seedling tea bushes, which are known as pre-war seedling tea. The annual rate of replanting is less than what is required to clear the backlog of old tea cultivation. Infilling, an activity, at one time routine, has been neglected in these tea plantations. Present land: labor ratio in most of the tea estates is below the required level.

Estate management focuses on maximized yield via agronomic practices such as high application of inorganic fertilizer. Excessive use of artificial fertilizer in tea estates is prominent. This short-term strategy to increase yield will adversely affect the status of ecological capital stock in the long run. Stone terraces and contour drains are established in tea plantations. But the maintenance is not satisfactory. Most of the conservation structures are not repaired. The situation is more critical in seedling fields compared to VP tea fields.

In order to make the tea plantations viable in the long run, ecological capital management strategies have to be restructured. Soil organic carbon can be improved through the application of organic manure. This will be a vital strategy to cut down the heavy usage of inorganic fertilizer and thereby minimize cost and adverse effect on soil. Investment on replanting and infilling activities is an important possible strategy in long-term management of tea plantations. Vacancy filling practices have to be adopted to maintain appropriate ground cover. Tea nurseries have to be organized and established to meet the requirement of seedling in above activities. The poor attention on effective soil conservation is an area where much attention has to be focused. With proper drains, terraces, use of mulches and cover crops, the soil erosion could be minimized. Weed management techniques are also very important, especially in land with low bush densities, and until full coverage of the land by the crops.

Acknowledgment

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Table A.1.Criteria for Matrix Scoring of Inter Estate Resource Management

Variable	3	2	1	0
Organic carbon %	>4	3-4	2.5-3	<2.5
% Extent below critical carbon	<10	11-20	21-41	>40
Soil acidity	5-5.5	4.5-5	4.2-4.5	<4.2
% Extent below critical acidity	<10	11-20	21-41	>41
Seedling:VP	60:40	70:30	80:20	90:10
Proportionate age of VP fields (50 % of the extent)	<30	30-40	40-50	>50
Stand per ha (from ratio of the recommended	>0.90	0.85-0.90	0.8-0.85	<0.80
a. Seedling				
b. VP	>0.95	0.9-0.95	0.85-0.9	<0.80
Vacancy rates a. Seedling(%)	<10	11-15	16-20	>20
b. VP	<5	6-10	11-15	>15
Annual replanting (ha)	>1.5	1-1.5	0.5-1	<0.5
Infilling	Routine	Annual	Seldom	Never
Land Labor ratio	>3	2.5-3	2-2.5	>2
Shade trees (ratio from recommended cover)	>0.9	0.75-0.9	0.5-0.75	<0.5
Potential yield: (Kg Mt/ha/yr) a. Seedling	>1400	1000-1400	800-1000	<800
b. VP	>2500	2000-2500	1800-2000	<1800
Overall Quality of the ecological capital mgt.	2.1-3.0	1.1-2.0	0.1-1.0	0

Remarks:

3= Good 2=Satisfactory

1=Unsatisfactory 0=Critical