Chapter 6 Determining Forest Rehabilitation Sustainability Using Soil Quality Index

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Determining Forest Rehabilitation Sustainability Using Soil Quality Index

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Introduction

There are approximately 403 million ha of forest plantation and 358 million ha of forest which are listed under protection schemes (Table 1). Forests can be categorized as natural forest, primary forest, closed forest, permanent forest estate and planted forest. Natural forest areas gazetted as protected forest, and its area had increased by 24% between 2005 and 2010, from 69 million to 183 million ha. *Dipterocarpus*, *Dryobalanops*, *Hopea* and *Parashorea* are common trees present in dipterocarp forest, which covers approximately 17.15 million ha across Malaysia with 31.9% in Peninsular Malaysia, 45.66% in Sarawak and 22.39% in Sabah (Blaser *et al.*, 2011). Of the 13.1 million ha of peat swamp forest in Malaysia, Sarawak has the largest area with 890000 ha. Mangrove forest covers 709,700 ha in Malaysia with 418,723 ha located in Sabah. With such a large area of forests to monitor, understanding their health is essential for effective forest management. Forest health can be defined as the capacity of the forest to supply and allocate sufficient amount of water, nutrients and energy needed by the flora and fauna in it, while maintaining its resistance towards biotic and abiotic stress or disturbance.

Table 1: Global tropical forest area by region

Region	Total forest area (million ha)	% of forests in ITTO producer countries	Primary forest (million ha)	% of primary forests in ITTO producer countries
Tropical Asia and the Pacific (16)	317	89	108	97
ITTO (10)	282		104	
Other (6)	35		3	
Tropical Latin America and the Caribbean (23)	907	96	678	96
ITTO (13)	868		647	
Other (10)	38		30	
Tropical Africa (26)	440	61	102	97
Total ITTO (16)	270		100	
Other (10)	170		2	
Global Total (65)	1664	85	887	96
Total ITTO Producers (33)	1421		851	
Total Non ITTO (32)	243		35	
Source: Blaser *et al.* (2011)				

Importance of rehabilitating degraded forestland

Forest rehabilitation is vital to nurture or restore degraded forest areas to its original state. Forests suffer from degradation when there's a lack of treatment or management to restore tree growth. This is especially true when a forest is constantly harvested for timber. This is best addressed by replanting specific tree species that is in demand, be it through monocultured or mix planting. The planted forest seedlings can be from indigenous or exotic species, depending on the survival rates and demand for wood production.

Impact of forest rehabilitation on soil quality

Soil is the source of nutrients for tree growth in forests. It is a complex bio-diverse environment because in order for soil to function well there needs to be integration between physical, chemical and biological properties, which is the only way to sustain soil quality and forest productivity (Susyan *et al.*, 2011). When natural forests are logged or converted into agriculture lands, it will lead to massive soil/land degradation. Without a tree canopy to cover the soil/land, direct impact of sunlight and rainfall will promote soil erosion at a rapid pace (Jennings *et al.*, 2001; Pariona *et al.*, 2003). Besides, increase in soil compaction due to usage of machinery decreases air and water pores in the soil; hence, inhibits the activities of soil macro-organisms and other microbes.

Deforestation distorts this process and renders the land to be unproductive unless appropriate rehabilitation program is carried out. The objective of forest rehabilitation is not only to provide a continuous supply of economically important woody and non-woody products, but also to restore the deforested area to its initial or original state. However, certain environmentalist bodies are more concerned with how we evaluate the success of a particular forest rehabilitation activity. The best way to evaluate forest health is through soil quality evaluation because soil properties will be immediately affected once a disturbance occurs. The evaluation of forest soil quality should not neglect any of the three important aspects of soil physical, chemical and biological properties because all of these parameters affect one another, especially when it experiences disturbance from human activities (Karlen et al., 1997). Hence, it is important to select appropriate parameters to evaluate soil quality so that one can gain a clear picture of the current soil conditions. Further actions can then be taken to restore the condition of problematic soils to its optimum levels.

Using Soil Quality Index

Soil quality indices can be defined as indices developed from soil properties which can involve the incorporation of more than one parameter that are used to evaluate and describe the quality of soil in an area. Soil quality is defined as the "capacity of the soil at a particular area or site to function within ecosystem boundaries and to sustain its biological productivity, environmental quality and enhance flora and fauna health" (Doran, 2002). Debates remain among individual and bodies in the field of soil science about the accuracy and suitability of these indices for soil quality assessment. This matter is believed to be influenced by the poor standardization of certain sampling and analysis procedures, differences in methods used, heterogeneity of the soil, differences in climatic conditions and vegetation distribution as well as poor explanations of the soil quality indices proposed (Bastida *et al.*, 2008). Differences in approaches to develop soil quality indices can be due to different techniques of implementation or sampling.

Tropical Soil Quality Index

Soil Quality Index proposed by Amacher *et al.* (2007) had been modified slightly by adding biological properties parameters when microbial biomass C and N were added into the list of indices that incorporated all three important soil properties (Table 2). In natural regenerated forest of secondary forest and rehabilitated forest, the microbial range was found to be in the range of not more than 500 μg g^{-1} soil (Dinesh *et al.*, 2003). Microbial biomass N was found to exceed 50 μg g^{-1} soil in natural forest before this study. This condition was consistent with results obtained by Dinesh *et al.* (2003) for wet tropical and semi-evergreen forests. Natural regenerated forests and rehabilitated forests showed concentration of biomass ranging from 10 to 50 μg g^{-1} soil, which proved that there was an increase in microbial activity as planted trees had a positive impact on soil quality. Table 3 shows the results of analyses of selected soil parameters. These parameters were selected based on their significance and necessity in determining soil quality for particular land areas.

The mathematical expression or formula to calculate total TSQI and its percentage were carried out using the method of Amacher *et al.* (2007), with a slight modification to fit the current TSQI (1):

TSQI1 % = {Total TSQI/ [Σ value of individual TSQI measured (13 parameters)]} x 100% … (1)

Table 2: Selected soil physical and chemical analyses of Tapah Hill and Chikus Forest Reserves

		0 – 15 cm depth				15 – 30 cm depth			
		Tapah Hill Forest		Chikus lowland Forest		Tapah Hill Forest		Chikus lowland Forest	
Parameter	Unit	PF(1)	SF	NF	PF(2)	PF(1)	SF	NF	PF(2)
Bulk density	g cm^{-3}	1.16 ± 0.01	1.24 ± 0.02	1.21 ± 0.05	1.36 ± 0.02	1.22 ± 0.01	1.26 ± 0.02	1.35 ± 0.06	1.39 ± 0.02
Coarse fragments	%	43.67 ± 1.78	49.46 ± 3.95	17.30 ± 1.52	44.14 ± 1.92	43.77 ± 1.35	47.85 ± 4.01	18.36 ± 2.01	43.13 ± 3.30
Soil acidity	pH	4.36 ± 0.11	4.19 ± 0.05	4.16 ± 0.08	4.22 ± 0.03	4.42 ± 0.10	4.23 ± 0.08	4.65 ± 0.10	4.40 ± 0.02
ESP	%	13.97 ± 0.71	17.34 ± 2.20	16.17 ± 1.63	17.62 ± 1.04	26.25 ± 2.67	24.74 ± 3.36	25.53 ± 1.14	21.20 ± 1.43
Total carbon	%	2.39 ± 0.18	1.57 ± 0.08	3.29 ± 0.44	2.29 ± 0.16	1.13 ± 0.08	1.08 ± 0.03	2.17 ± 0.33	1.68 ± 0.06
Total nitrogen	%	1.55 ± 0.09	1.11 ± 0.09	1.66 ± 0.20	1.10 ± 0.15	0.81 ± 0.05	0.77 ± 0.10	1.26 ± 0.25	0.87 ± 0.06
Exch. K	$cmol_c$ kg^{-1}	0.13 ± 0.02	0.15 ± 0.03	0.11 ± 0.01	0.11 ± 0.01	0.03 ± 0.01	0.08 ± 0.01	0.07 ± 0.01	0.11 ± 0.01
Exch. Ca	$cmol_c$ kg^{-1}	0.09 ± 0.01	0.09 ± 0.02	0.10 ± 0.01	0.11 ± 0.02	0.04 ± 0.00	0.08 ± 0.02	0.08 ± 0.01	0.10 ± 0.01
Exch. Mg	$cmol_c$ kg^{-1}	0.02 ± 0.00	0.06 ± 0.00	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.00
Exch. Al	$cmol_c$ kg^{-1}	0.08 ± 0.01	0.06 ± 0.03	0.08 ± 0.02	0.05 ± 0.02	0.06 ± 0.01	0.03 ± 0.01	0.02 ± 0.00	0.03 ± 0.01
Av. P	mg kg^{-1}	7.22 ± 2.82	9.90 ± 0.97	18.84 ± 3.42	14.91 ± 3.97	6.49 ± 1.46	6.33 ± 1.28	14.74 ± 3.76	9.01 ± 1.96
MBC	μg g^{-1}	465 ± 105	325 ± 58	824 ± 34	542 ±329	158 ± 66	124 ± 35	524 ± 115	337 ± 233
MBN	μg g^{-1}	239 ± 8	162 ± 18	149 ± 20	37 ± 4	134 ± 12	78 ± 11	113 ± 29	9 ± 4

Note: PF(1), planted forest (Tapah Hill); SF, secondary forest; NF, natural forest; PF(2), planted forest (Chikus); ESP, estimated sodium percentage; MBC, microbial biomass; MBN, microbial biomass N

Source: Arifin *et al.* (2012)

Table 3: Selected soil properties for Tropical Soil Quality Index 1 (TSQI1)

No.	Parameter	Level	Interpretation	Index
1	Bulk density (g cm^{-3})	>1.5	Possible adverse effects	0
		≤1.5	Adverse effects unlikely	1
2	Coarse fragments (%)	>50	Possible adverse effects	0
		≤50	Adverse effects unlikely	1
3	Soil acidity	3.01 to 4.0	Strongly acidic – only the most acid tolerant plants can grow in this pH range and then only if organic matter levels are high enough to mitigate high levels of extractable Al and other metals	0
		4.01 to 5.5	Moderately acidic – growth of acid intolerant plants is affected depending on levels of extractable Al and other metals	1
		5.51 to 6.8	Slightly acidic – optimum for many plant species, particular more acid tolerant species	2
		6.81 to 7.2	Near neutral – optimum for many plant species except those that prefer acid soils	2
		7.21 to 7.5	Slightly alkaline – optimum for many plant species except those prefer acid soils, possible deficiencies of available P and some metals like Zn	1
		7.51 to to 8.5	Moderately alkaline – preferred by plants adapted to this pH range, possible P and metal deficiencies	1
		>8.5	Strongly alkaline – preferred by plants adapted to this pH range, possible B and other oxyanion toxicities	0
4	Total carbon in mineral soils (%)	>5	High excellent buildup of organic C with all associated benefits	2
		1 to 5	Moderate adequate levels	1
		<1	Low – could indicate possible loss of organic C from erosion or other processes, particularly in temperate countries	0
5	Total nitrogen in mineral soils (%)	>0.5	High – excellent reserve of nitrogen	2
		0.1 to 0.5	Moderate – adequate levels	1
		< 0.1	Low – could indicate loss of organic N	0
6	Exchangeable Na (%)	>15	High – sodic soil with associated problems	0
		≤15	Adverse effects unlikely	1
7	Exchangeable K ($cmol_c\,kg^{-1}$)	>1.28	High – excellent reserve	2
		0.26 to 1.28	Moderate – adequate levels for most plants	1
		<0.26	Low – possible deficiencies	0
8	Exchangeable Mg ($cmol_c\,kg^{-1}$)	>4.17	High – excellent reserve	2
		0.42 to 4.17	Moderate – adequate levels for most plants	1
		<0.42	Low – possible deficiencies	0
9	Exchangeable Ca ($cmol_c\,kg^{-1}$)	>5.00	High – excellent reserve, probably calcareous soil	2
		0.51 to 5.00	Moderate – adequate levels for most plants	1
		0.05 to 0.5	Low – possible deficiencies	0
		<0.05	Very low – severe Ca depletion, adverse effects more likely	-1
10	Exchangeable Al ($cmol_c\,kg^{-1}$)	>1.11	High – adverse effects more likely	0
		0.12 to 1.11	Moderate – only Al sensitive plants likely to be affected	1
		0.01 to 0.11	Low – adverse effects unlikely	2
		< 0.01	Very low – probably an alkaline soil	2
11	Available P ($mg\,kg^{-1}$)	>30	High – excellent reserve of available P in slightly acidic to alkaline soils, possible adverse effects to water quality from erosion of high P soils	1
		15 to 30	Moderate – adequate levels for plant growth	1
		< 15	Low – P deficiencies likely	0
12	Microbial biomass C ($\mu g\,g^{-1}$)	>500	High	2
		200-500	Good	2
		<200	Restoration phase	1
		<100	Deficiencies	0
13	Microbial biomass N ($\mu g\,g^{-1}$)	>50	Abundant	2
		10 to 50	Restoration phase	1
		<10	Deficiences	0

Source: Arifin *et al.* (2012)

TSQI is recommended to be used as a guide for land managers that are involved in forest plantations as it shows permissible limits and level of each analysed soil parameters. Soil Quality Index by proposed Amacher et al. (2007) serves as the basis for the newly proposed TSQI, as the SQI was developed to measure forest soil around North America. In America, there are temperate and tropical climatic regions; hence, we found that SQI can only be used in tropical Malaysia. Adding soil microbial biomass C and N would make TSQI able to cover all important soil components, i.e. physical, chemical and biological parameters.

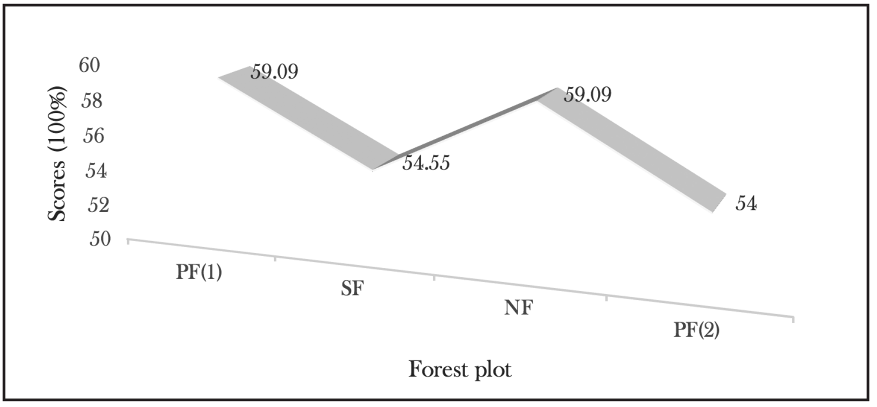

Figure 1: TSQI scores for Tapah Hill and Chikus Forest Reserves at 0-15 cm depth
Note: PF(1), planted forest; SF, secondary forest; NF, natural forest; PF(2), planted forests

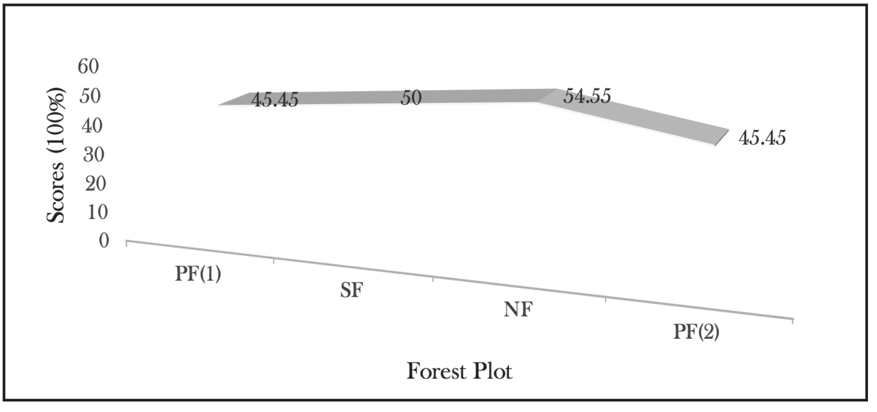

Figure 2: TSQI scores for Tapah Hill and Chikus Forest Reserves at 15-30 cm depth
Note: PF(1), planted forest; SF, secondary forest; NF, natural forest; PF(2), planted forests

Figure 1 and 2 show the score limits for Tapah Hill and Chikus Forest Reserves at 2 different depths measured using the TSQI. TSQI levels for planted forest of Tapah Hill which was found to be the same as the natural forest of Chikus. This results show that enrichment planting technique incorporated in the rehabilitation of Tapah Hill forests helps restore the quality of the forest soils to its original state or almost the same as natural forest. To determine the success of any forest rehabilitation program, a natural forest in the vicinity of the study area should always be used as the basis of comparison.

Soil quality index developed by Karam et al. (2017) is Tropical Soil Quality Index 2 (TSQI2) (2). The index was developed based on principal component analyses of the parameters analyzed and validated using 30% of raw data obtained. The formula for TSQI2 is as follows:

TSQI2 = Bulk density (1.829) + pH_w (1.086) + EC (1.332) + C/N Ratio (0.693) + CEC (1.009) + Exch. K^+ (1.104) + Avail. P (0.995) + MBC/MBN Ratio (1.040) + Microbial Enzymatic Activity (1.027) … (2)

Results of the soil quality measured using TSQI2 at 0-15 cm depths showed different levels as compared to TSQI where the planted forest of Tapah Hill did show improvement in terms of soil quality; however, the planted forest of Chikus forests had a better and higher index value (Table 4). Using TSQI2 showed higher index level for the multi-storied forest management technique implemented in Chikus Forest Reserves.

Table 4: Tropical Soil Quality Index 2 (TSQI2) results

		0-15 cm		15-30 cm	
		Before	After	Before	After
Tapah Hill	Planted forest	59.23 ± 4.81	59.30 ± 4.84	49.83 ± 1.90	50.22 ± 1.88
	Secondary forest	54.12 ± 1.44	54.17 ± 1.41	42.31 ± 2.45	42.23 ± 2.52
Chikus	Natural forest	73.95 ± 5.13	73.90 ± 5.14	67.26 ± 6.19	67.13 ± 6.27
	Planted forest	76.35 ± 12.39	76.71 ± 12.65	87.96 ± 21.81	94.92 ± 24.25

Source: Karam *et al.* (2007)

Soil Fertility Index (SFI) and Soil Evaluation Factor (SEF)

Arifin *et al.* (2008a; 2008b) used SFI (3) and SEF (4) in his study to determine the soil fertility of Kinta forest Reserves and Chikus Forest Reserves. SFI and SEF were selected to be implemented due to their already successfully used to measure soil fertility of Brazilian rehabilitated forest:

$$SFI = pH + OM + P + K + Ca + Mg - Al \qquad \ldots (3)$$

$$SEF = [Ca + Mg + K - \log(1 + Al)] \times OM = 5 \ldots (4)$$

Chikus Forest Reserves

SFI was employed to investigate the relationship between soil fertility and secondary succession rate and vegetation selection (Moran *et al.*, 2000), while SEF was used to evaluate soil fertility in different soil having clayey texture (Lu *et al.*, 2002). Table 5 shows the PCA analyses of selected soil properties in Kinta Forest reserves. The highest contribution of the PCA were availability of organic matter and nutrient contents.

Table 6 shows the PCA analyses of soil properties in Chikus Forest Reserve. The highest contribution to soil fertility are organic matter and nutrient content, just like the case of Kinta Forest Reserves. In undisturbed forest floor, organic matter is essential to supply nutrients to the soils for plant uptake. In the forest, application of fertilizers is not normally done, especially in forest rehabilitation program; perhaps, very little fertilizer needs to be applied at the beginning of the planting to booth growth.

Silviculturists and forest scientists question the efficacy of using soil data to determine the success of tree growth. Most forest plantation or rehabilitation managers rather use height, diameter at breast height (dbh) and volume to reflect the success of a project.

Table 5: Principal component analysis (PCA) of selected soil properties analysed for surface soils of Kinta Hill Forest Reserves

	Value	PC1	PC2	PC3
Variables with a high positive factor loading (>0.7)	+	CEC, TC, ECEC, TN, Clay, Exch. K, Exch. Mg and EC	Al saturation	C/N Ratio
Variables with high negative factor loading (>0.7)	-	pH	-	-
Contribution name of PC axis		44.8% Catione exchange capacity	15.9% Acidity	9.3% Organic matter

Note: Variable analyzed pH (KCl), EC, TC, TN, C/N, CEC. ECEC, Exch. Ca, Exch. Mg, Exch. K, Exch. NH4-N, Exch. Al, Avail. P, Al saturation, clay content and sand content; SOM, soil organic matter. Source: Arifin et al. (2008a and b)

Table 6: Principal component analysis (PCA) of selected soil properties analyzed for surface soils of Chikus Forest Reserves

	Value	PC1	PC2	PC3
Variables with a high positive factor loading (>0.7)	+	ECEC, T-C, EC, Exch. Al, Exch. Mg and CEC	Al saturation	pH (KCl)
Variables with high negative factor loading (>0.7)	-	-	Exch. Ca & Exch. Mg	Exch. NH4-N
Contribution name of PC axis		30.9% SOM and CEC	19.3% Divalent exchangeable bases	12.1%

Note: Variable analyzed pH (KCl), EC, TC, TN, C/N, CEC. ECEC, Exch. Ca, Exch. Mg, Exch. K, Exch. NH4-N, Exch. Al, Avail. P, Al saturation, clay content and sand content; SOM, soil organic matter. Source: Arifin *et al.* (2008a and 2008b).

Conclusion

Both TSQI1 and TSQI2 can be used to determine the soil quality at natural, secondary or planted forests. However, land managers would find TSQI1 easier to use compared to that of the TSQI2. Selecting suitable index will help land manager to be able to evaluate the current soil quality and understand the changes occur in a particular land. It is recommended that soil quality evaluation or selection of index to measure soil quality should include selected parameters from physical, chemical and biological properties of soil.

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