Assessment of Impact on Landscape Development to Ecological Service Values and Goods Using Integrated Remote Sensing and GIS Techniques

Mazlan Hashim, Zulkifli Yusop, Ab Latif Ibrahim, Norsahida Said, and Helmi PRamlee
Faculty of Geoinformation Science & Engineering
Universiti Teknologi Malaysia,
UTM 81310 Skudai, Johor Bahru, Malaysia
Tel: +6075530873, Fax: +6075566163, email: mazlan@fksg.utm.my

Toshinori Okuda, Sen Nishimura, Mariko Suzuki and Toshiaki Kondo
Tropical Forest Ecology Laboratory
National Institute for Environmental Studies
Tsukuba, Japan

Abstract: Amongst the impacts of converting forest to agricultural activities is the degradation of ecology service values and goods (ESVG). Impacts on ESVG can be devastating in environmental, biological, and socio-economics manners. This paper highlights the study undertaken on the impacts of agricultural development in $0.8x10^6$ ha of forest dominated landscape in Pasoh Forest Region (PFR), Malaysia, within period of 8 years from 1995 to 2003. Three folds of impacts on agricultural development examined and analysed are: (i) relationship of total soil loss and changes in land use pattern, (ii) mapping trends of ESVG for PFR in 1995 and 2003, and (iii) risk assessment of ESVG based on simulation of converting $339x10^3$ha of primary forest into mass-scale oil palm plantation. Results of this study indicated that although only minor changes of about 1464ha (~0.2% of PFR) of primary forest was converted to agricultural activities, it have significantly increased the total soil loss from $59x10^6$ to $69x10^6$ t/ha/yr. The mean rate of soil loss within PFR is $0.8x10^6$ t/yr, and if translated into ESVG term, costing US$4.8x10^6/yr. However, majority of the soil loss within all land use classes are within range of very low - low risk categories (<10 t/ha/yr). Estimated cost of ESVG for PFR was US$179x10^6 in 1995, declined to US$114x10^6 in 2003 due to 0.2% reduction of forested land. Converting $339x10^3$ ha primary forest into mass plantation cost less than original forest within period of 20 years examined; the 20^{th} year of conversion, the ESVG of plantation and to-remain as forest cost US$963x10^6 and US$575x10^6, respectively. This difference, however, is only marginal when full 17 attributes of ESVG were considered.

Key words: rapid assessment, Remote Sensing, GIS, tropical rain forest, landscape zoning assessment

1. Introduction

Agriculture plays an important part in the overall economic development of most developing countries like Malaysia through its contribution to the Gross Domestic Product (GDP), employment and foreign exchange earnings. In 1996, the share of agriculture has declined to 13.6 percent. Total agricultural production for the period from 1994 to early 2000 showed an increasing trend. In the developing world, the need to provide adequate food for a rapidly expanding population has put enormous pressure on existing productive land and brought marginal land under cultivation. This has result in deforestation of the tropical forests and drainage of wetland areas. In semi arid and arid regions, lands have been brought into production with use off irrigation. In many cases, this has led to an accumulation of salt in the soil. The subsequent loss of vegetation cover leaves the land open to soil erosion and eventual desertification. Soil erosion represents one of the most serious depletions of natural resources in the world today. Rapid forest conversion and land development activities have resulted in accelerated soil erosion in many parts of the word. Global erosion rate was estimated at 75×10^9 ton/year. Over the past several thousand years, deforestation, crop agriculture and grazing have promoted the greatest soil erosion and these activities continue to hold that dubious distinction on a worldwide basis today.

Apart from the above erosion effect, the accumulated effect to agricultural development is degradation of ecology service values and goods (ESVG) not only in the area in which the development taken place but also effecting the linking ecosystem services. Ecosystem services have been estimated (Constanza et al, 1997) for realism of guideline for evaluating ESVG prior and after any land related development were taken place. Using Pasoh Forest Reserve (PFR) as study area, this study is a part of joint research between Japan and Malaysia scientists in understanding various issue related to tropical forest ecosystem (NIES, 2003). We collect, analyze, and deliver vital ecological information to decision makers pertaining to forest-related industries and management. Most importantly this information are conveyed in simple form, easy to understand together with the economic values for any decision on developing the land or changing it use. To meet management needs, the landscape models are required in assess the effects of different management scenarios. These scenarios often require decision-making horizons spanning broad temporal and spatial scales. Often, simulation models are the only way to assess alternatives that could be tested under such real-world conditions (Mladenoff and Baker, 1999). From this synthesis, the value for ecosystem service per unit area for each landscape feature can, therefore be estimated. Although there are problems inherent in producing such an estimate (Blamford et al, 2002; Constanza et al, 1997), this mechanism is essential in order to make the range of potential values of the services of ecosystems more apparent.

The minimal impact risk attributed due to landscape development to its ecological regime has been the main concern in supporting sustainable development. However, in the tropical regions, risk assessment on landscape development still perceived to have minimum impact, judging from the rate of conversion of forested areas to other uses (Pulzl and Rametsteiner 2002, Adger et al 1995, Bishop 1999, Peters et al 1989). Conversion of logged-over forests to agricultural land, namely large scale plantation for industrial crop such as such oil palm is perceive a good option in Malaysia economically other than creating better employment opportunities compared to the productive forest. This is economically true, evident by the amount of increasing standard of living to rural settlers of large scale plantation schemes in Malaysia since early 70's. Since then, conversion of forested land to agricultural activities particularly large scale oil palm plantation area has profoundly increased from 320 thousands to 2.1 millions hectares in 2000; and it is projected to occupies 5.10 millions hectares by 2020 (Jalani et al, 2002). In 2000, about half of rubber plantations opened since 1970 was converted to oil palm due more profitable returns of export commodity prices of palm oil products.

In economical term, the market value of a land is determined by its size, location and the accessible infrastructural facilities. The likelihood of land use change in the vicinity also influences the current land value, i.e. maintaining a forest reserve within designated residential area is favorable to the current and future value and vice-versa. Apart from economic value, the ecological service values to any piece of land area that are not at all accounted into the present market values. Worst still these ecological values are evaluated based on scientific method to benefits human (Constanza et al,1997; de Groot,1992; de Groot,1987) not widely known to political masters, decision makers and even majority of the stakeholders in tropical regions, where majority are found in the developing countries. In these regions, sustainable economy and its growth seems to be the paramount agenda compared to sustainable development (ADB, 2004), although such a growth only achievable through sustainable land-related development. Subsequently, the mapping of ecology service values and goods (ESVG) of PFR for 1995 and 2003 is undertaken. Trends of changes in land use pattern within the temporal data sets and ESVG were then analyzed and the impacts were then determined.

2. Materials and Methods

2.1 Study area

The present study was conducted in an old-growth, lowland dipterocarp forest within the Pasoh Forest Reserve (lat 2°59′N, long 102°18′E), which is located in the state of Negeri Sembilan, about 70 km southeast of Kuala Lumpur, Malaysia (see **Figure 1**). The mean annual rainfall from 1974 to 1992 at Pasoh-Dua (lat 2°56′N, long 102°18′E), 6 km south of the reserve, was 1842 mm, with distinct rainfall peaks in April–May and November–December (based on data provided by the Malaysian Meteorological Service). The soil is the Bungor–Malacca Association Type (based on data provided by the Malaysian Soil Science Division), which develops mainly from shale, granite, and fluviatile granite alluvium parent materials (Allbrook, 1973). The topography consists mainly of flat alluvial areas, with smaller expanses of swales, riverine areas, and gently rolling hills.

The overall vegetation type in the reserve is lowland dipterocarp forest, which is characterized by a high proportion of species in the Dipterocarpaceae (Okuda, 2003). On the basis of floristic evidence, the primary forest in the study area was generally homogeneous, with no evidence of major disturbance, and appeared to be representative of the lowland forest of the south-central Malay Peninsula. Lowland dipterocarp forest is one of the most species-rich communities in the world, with more than 200 tree species per hectare. In contrast, the southern and eastern edges of the reserve had been selectively logged from the mid-1950s until the early 1970s, and at the time of the study represented regenerating forest.

2.2 Ecological service values and goods

The ecological service values and goods are defined by Constanza et al (1997) as the benefits human populations derive directly or indirectly from the ecosystem functions. The ecosystem functions, on the other hand refer to various habitat, biological or system properties or processes of ecosystems. Both the ecological service and goods often combined for simplicity and termed as ecological services. Large numbers of ecosystem services have been identified and reported in many previous studies such as de Groot (1987), Turner (1988) and de Groot (1992). A total of 17 attributes of ESVG (Constanza et al,1999) are considered here within the context of tropical ecosystems. These categories only included renewable ecosystem services adopted from average global value of ESVG. The ecosystems services and functions do not necessarily show a one-to-one correspondence; hence, some of these ecosystem service values are still contentious, particularly in developing countries like Malaysia where the pressure of land related developments is so great for obtaining better standards of living. In this study, two sets of ESVG were computed for PFR. First, ESVG based on full 17 attributes of ESVG, and secondly selected 11 attributes only, customized to sounds logic to have direct relationship with the land use. There is large variation in the value ESVG over the years since it was incepted (early 90's), because such values are very much subjective to large variety of countries location and priorities in their environmental up keeping status. ESVG for examples are well established and highly priced in developed nations but in the rest of world, even the ESVG contention seems unnecessary when there are more prioritized critical agendas. By using these values, it formed as attributes to the corresponding spatial data, readily created in spatial database, thus mapping of ESVG is possible.

2.3 Methods

The entire method employed in this study is divided into three: (i) analysis of impact of agricultural development on soil loss from 1995 to 2003, (ii) mapping and analysis of changes in the ecology services values and goods in 1995 1and 2003, and (iii) simulation of impact on ecology services values and goods for period of five years for converting secondary forest into palm oil plantation within a catchment in the study area. The followings describe each of the method employed in the analysis.

2.3.1 Analysis of impact of agricultural development on soil loss from 1995 to 2003

The total soil loss of PFR was determined using universal soil loss equation (USLE) (Morgan, 1974) Eq. (1) for 1995 and 2003 was used to analyze the impact of agricultural development on soil loss. The soil loss in USLE is calculated, such that:

$$A = R.K.LS.CP \qquad (1)$$

where A is soil loss (ton/ha/yr), R is rainfall erosivity factor, K is soil erodibility factor, L is slope length factor, S is slope-steepness, C *is* crop management factor and P is erosion control practice factor.

The land use pattern for both 1995 and 2003 were determined using multi-temporal Landsat-5 Thematic Mapper data set, were used as C-factor in USLE. The *CP* factor can be replaced by vegetation management factor, and for Peninsular Malaysia the values of CP classes found in PFR is tabulated in Table 1. The erosivity factor K used is also tabulated in Table 1. Within an area, the total soil loss calculated per set given land use pattern in 1995 and 2003, hence, can be therefore use as basis for landscape risk assessment of agricultural development on soil loss.

2.3.2 Mapping and analysis of changes in the ecology services values and goods

Using GIS the land use maps (1995 and 2003) produced by classifying multi-temporal Landsat TM data sets and other ancillary data were compiled in spatial database of PFR, from where the ecology service values were derived. These values referred to certain ecological system values and goods per given area. The absolute ecological service values and ecology goods (ESVG) are very critical in making the results realistic as in real world. As guidelines to such approach, adaptation to special paper released by FAO (Bann, 1998) are used in this study. The ecological services focused for PRF are those related only tropical forest landscape using partial (11 attributes) and full 17 attributes for ecological services and goods (Constanza et al, 1997). The modified proposed 11 ecological values are only have directly linked to the landscape features that can be tangibly accepted by stakeholders, such that comprised of 7 ecological service values and 4 ecological goods. For the entire PFR, 10 landscape features are used to derived their respective ESVG.

2.3.3 Analysis on impact on ecology services values and goods for period of five years for converting secondary forest into palm oil plantation within a watershed area

Changing the land use option would also change in the C (crop management factor) and P values (erosion control factor) from the previous land use. Resultant of change in CP factor would effect differently in the erosion risk effect, such that the amount of soil loss in primary forest is within very low risk (mean of 10 ton/year) could change to variable risk range moderately high to moderately very high risk (50-100 ton/year). To change the land use option, say for example from its present land use, i.e. from primary forest to oil palm plantation, the value of resultant C*P would shift to 0.125 from 0.003 (please refer Table 1) which means that tendency of erosion is about 42 times from its present land use.

In simulating the landscape scenario changes, the ESVG on the existing land use and after the conversion is determined in an annual basis for period of ten years. In this study, an emulation of converting primary forest for large oil palm plantation. Figure 1, show the proposed primary forest (with an area of 339,630ha) for this project is fragmented forest, surrounded by large rubber and oil palm plantations apart from mixed sundry cultivations.

The critical issues in the creating the simulation are the costs for each ESVG for specific landscape features. Adaptation to ESVG proposed in annual world ecosystems (Constanza et al, 1997) have used in calculating both these values in this study. FAO (2003) guidelines for estimates of economic values of forest benefits have also been adapted for complimenting the incomplete ecology goods (EG) in Contanza et al (1997). The EG for oil palm plantation has been based on the average previous years of prices of oil palm products for 1995-2003 (MPOB, 2005) and special banker's report (Bank Bumiputra-Commerce, 2004). The average prices of oil products used in the EG are for prices of crude palm oil, palm kernel, crude palm kernel oil and palm kernel cake. Each plantation of 1ha produces an average of 18 ton of fresh fruit bunches a year. With average oil extraction rate is 20%, this yields an average of 3.5ton/ha/yr of crude palm oil. Analyzing the trend of production of oil palm products from 1995 to 2003, only 42.8% of the crude palm oil exported and the remaining are exported as oil palm products after further processed by downstream industries producing palm kernel (28.8%), crude palm kernel oil (12.9%) and palm kernel cake (15.5%). With this production ratio and the average yield generated from oil palm plantation is US$2792/ha/yr. The average total production cost is US$1048/ha/yr., plus additional initial cost for; (i) acquiring and developing the land - US$790/ha., (ii) waiting to crops maturity of first 3 years about US$1711/ha/yr, (iii) upkeeping inclusive of fertilizer US$252/ha/yr, and (iv) collection, general charges, manufacturing and dispatch of oil palm products at US$353/ha/yr. Each of the breakdowns for the production costs have been based on Pow (2003). The detailed lists for production cost is similar to Moll (1987), however, the values are out of date.

3. Results and Discussions

Within 1995 to 2003, the changes in this vegetated landscape features have been very minimal. Table 2 tabulates the land use pattern and its trend of changes within the 8-year period. The primary forest decreased by less than 1% of total area (0.8 mil ha). The primary and secondary forests still dominantly land use, occupying more than 44 percent. Agricultural crops formed 51.8 and 51.6 percents in 1995 and 2003 land use pattern, respectively. The main changes in the landscapes over 8 year is the reduction of 1464ha (0.2% of PFR) of forested areas, namely the primary forest. All the other 12 classes have increased in area, with rubber, oil palm and mixed cultivation formed major changes that have taken place. In total, the agricultural land development is taking place at annual rate of about 160ha per year.

The impact of soil loss due to the above-mentioned development is shown in Table 3, where the erosion rate within each of land use classes were tabulated. Within the vegetated land use classes, primary forest remain the least prone to soil loss with mean of 10-12 ton ha^{-1} yr^{-1}. It is interesting to note that soil loss within secondary forest is within mean range 59-69 ton ha^{-1} yr^{-1}, similar to that of rubber and oil palm plantations. The highest erosion rate is recorded within mixed cultivation classes (trees and non-trees) with mean annual of 970 and 1071 ton/year in 1995 and 2003, respectively. Agricultural lands in PFR is contributing as main source of soil loss 53mil ton yr^{-1} in 1995 and 63 mil yr^{-1} in 2003, where in both year formed 90 percent of total soil loss due erosion in the entire area. Non-vegetated classes; the urban area and related development as well as quarry and mines area contributed merely an average of 1 ton yr^{-1} or less.

The trends of soil loss for each of the land use class in 1995 and 2003 were analyzed, and later are grouped into 4 erosion risk categories, namely: (i) very low risk (0-1 ton ha^{-1} yr^{-1}), (ii) low risk (1-10 ton ha^{-1} yr^{-1}), (iii) moderate risk (10-50 ton ha^{-1} yr^{-1}), and (iv) moderate high risk (50-100 ton ha^{-1} yr^{-1}). Table 3 also tabulates the area extent for each class under each erosion risk categories. In this vegetated dominated landscape, the erosion risk categories have been within low of less than 10 ton ha^{-1} yr^{-1} for entire area. Only 0.1% of the area is under moderate to moderately high risk in 1995. The same trends of erosion risk within the land use classes in 2003. The oil palm and rubber plantations posed the most risks to erosion with various levels growth to the maturity. This is evident by the existing of erosion risk of very low to moderately high risk for these two crops, with majority of the soil loss in the very low to low range depicting of both these crops reading age of maturity where loose soil under these trees seems unlikely.

The total ecological services and goods for 1995 is US$179 millions and US$114 millions in 2003 after subtracting the corresponding soil loss due to erosion. **Table 4 and 5** tabulate the ecological services values and goods for PFR in 1995 and 2003. The decrease of US$65 millions between the 8 year period is attributed to the conversion of 1389 ha (about 0.2%) of forested areas into agricultural development activities., mainly oil palm and rubber plantations apart from increasing importance of mixed sundry cultivation for cash crops.

The average annual conversion of forested lands to various other landscape development dominated by agricultural crops is about 174 ha year $^{-1}$, equivalent to about US$8 million deficit annually in term of ecological services and goods. In term of risk assessment, it is noted that under non-comprehensive accounting for ecological services and goods the price for conversion of every hectare of forested land in PFR is about US$46,000. The question remains unanswered to most stakeholders and the government, where and how is the physical earning from ecological services can generate income to sustain livelihood of population in the area? Until this issue of compensation for preserving ecological service values is "settled', the 174 ha yr $^{-1}$ conversion rate of PFR forested lands to other economical oriented classes is unstoppable to various pressures of sustaining living. This fact has been based on the real data of the area and not estimation nor prediction of any surrogate data.

On analyzing on whether or not conversion of 339,630ha of primary forest to oil palm plantation would give significant impact to ESVG, Figure 2 illustrates the net assets generated for keeping primary forest as commercial forest in 20 years against the asset derived from oil palm plantation. When only 11 ESVG parameters are considered, the entire annual assets generated from oil palm plantation (after maturity period to 20th year) is evident that it is very profitable option even though the initial investment in considered high and pose high risk for crop failures. The nett asset yields from oil plantation with the average mean calculated from past 10 years market prices is US$2374 ha yr^{-1}, lucrative venture for improving if not strengthening rural economics. In the calculation the production cost is given 2% interest for increment in cost compounded from 1st to 20th year of plantation, and the oil palm asset yields is maintained throughout to represent the possibility of fluctuation of the market price. Subsequently, when full 17 parameters of ESVG are used, the total asset generated for ESVG indicated clearly that the EVSG assets are very much higher throughout the 20-year period. At the end 20th year, the asset generated from full ESVG worth sum of US$963 millions compared to US$575 millions generated from oil palm. At the same period, EVSG only valued at US$481 millions when partial (11) parameters are considered.

Adopting all the full ESVG parameters for sustainable landscape development in no doubt very important, however, the implementation is seems as constraints to activities in improving rural economics. Eradicating poverty has much focused in rural area as the numbers of hardcore poverty are mainly located in rural areas. Studies by Arif and Tengku Mohd (2001) showed incidence of poverty in oil palm smallholders reduce from 30.3 to less than 8% percents in 1970 and 1990, compared to other rural economic activities viz. rubber smallholders, coconut smallholders, paddy farmers, fishermen, estate workers and other agriculture. In fact the idea of mass plantation of commodity crops – rubber and oil palm have been initiated as early 1957 in Malaysia to resettle rural population to large plantation schemes with an objective to uplift their economics. Aggressive efforts of such schemes have met objectives and by 2000 total cumulative area under oil palm amounted to 685,520ha. Within this success stories of uplifting rural economic in oil palm plantation, how is the linking of ESVG to such activities be created. Most of the ecological service values contribute to vast environment issue and not localize, making obligation of respective managers in development of landscape difficult to consider as the benefits is unforeseen. In developing countries, uplifting standard of living of rural populations is one of the main agenda of most governments. As such, two questions seldom raised regarding obligation to ESVG: (i) the unhealthy earth is a result of rampant harvests for the developing nations, so restricting development of our lands would restrict our economic growth, (ii) if EVSG implemented fully, who going to compensate for the obligation? These are basic question but it the root of ESVG implementation, apart from developing all the related technical requirements such as the prices to all ecology service values and goods, localized to represent the country and its global contexts.

4. Conclusions

Study on the risk assessment due to landscape development using GIS undertaken in 3 terms (2002-2004) of Eco-Frontier Fellowship at NIES has been presented. The main focus of the study is to assess risks due to the landscape development, which are categorized into: (i) creation of spatial database from baseline information, (ii) structuring the simulation model based on spatial analysis in the GIS, and (iii) mapping ecological service values and goods, (iv) analyses of rate of landscape development from relation to generated impacts in term of changes in ESVG before and after development at PFR, and (v) analysis of simulated risks on development based on ESVG. Only last two tasks results are reported in this report, the others have been reported in the last two previous reports.

Results of this study that about 1464ha (about 0.2% of PFR) of primary forest have been converted to agricultural activities and have significantly increased the erosion rate at total soil loss from 59 to 69mil ton/ha/yr. The mean rate of soil loss for PFR is 0.8mil ton/ha/yr and if translated into ESVG term, the soil loss costs about US$4.8mil/yr. Majority of the resultant soil loss within all land use classes are within range of very low - low risk categories (<10 ton/ha/yr). ESV for PFR were costing US$179 mil in 1995, declined to US$114 mil in 2003 due to 0.2% reduction of forested land. The annual asset of converting 339,630ha primary forest into mass plantation determined from ESV cost less than original forest within period of 20yrs examined, i.e. at 20^{th} year of conversion, the plantation and original forest cost US$963 and US$575 millions, respectively. However, realistic parameters and compromising values of ecology services and goods used in PFR has yet to acceptable against stakeholders as well as sound to the policy makers as we anticipated such rapid assess of proposed landscape development only for modeling per se but it implementation is of practical for future sustainable landscape development.

Acknowledgments

I deeply thank UTM for the supports and AIRIES financial assistance for conducting the studies. Thanks also due to all fellow scientists at NIES, Japan and FRIM for valuable comments to enable this study.

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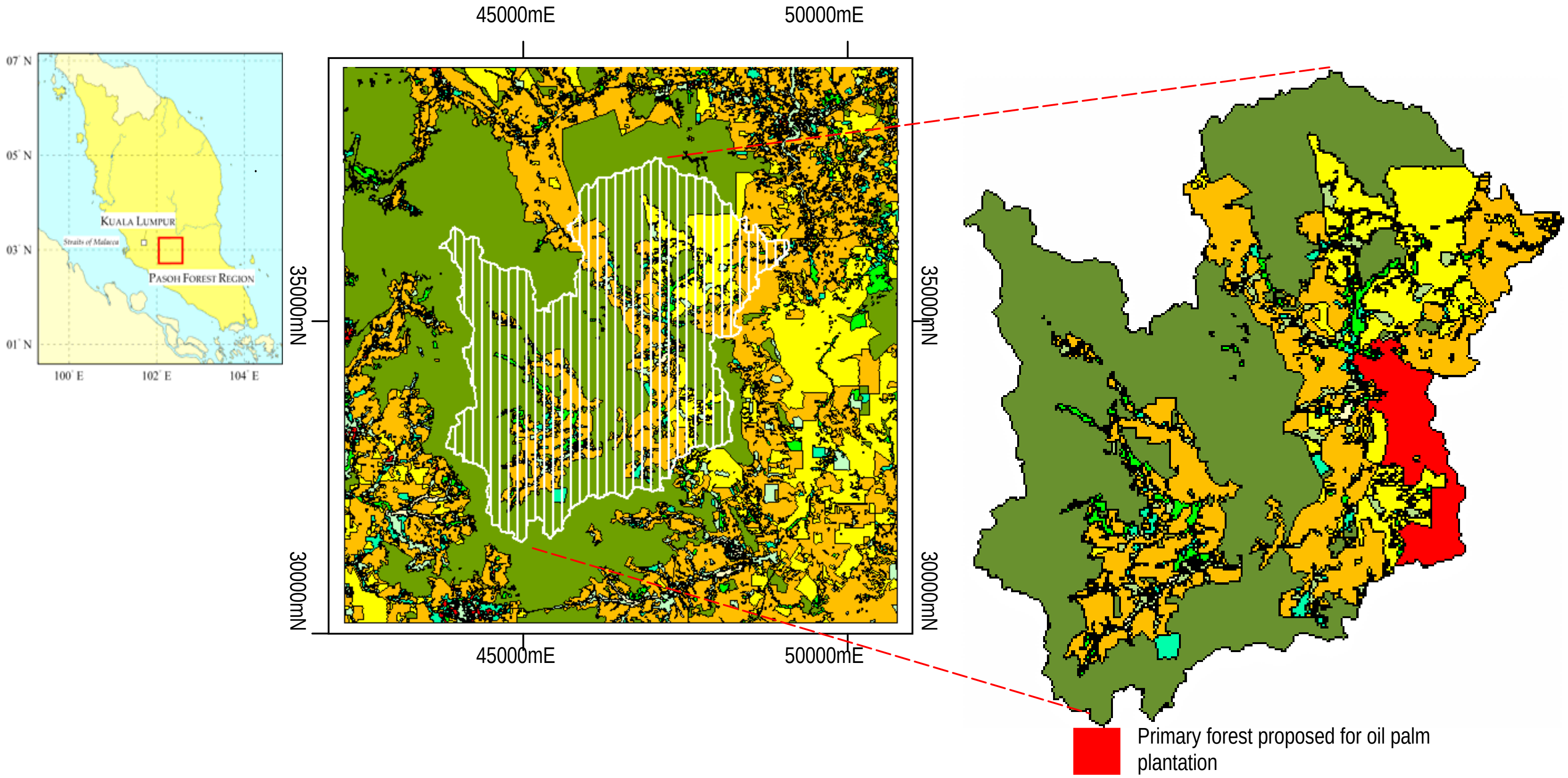

Fig. 1: **Study area; Pasoh Forest Reserve and vicinity (PFR) with area of 0.8 millions hectares. The Sungai Teriang catchment used in simulation of the cost of annual ecological services values and goods against the asset generated by the proposed by converting existing about 339,630ha of primary forest (demarcated in solid red colour) into oil palm plantation.**

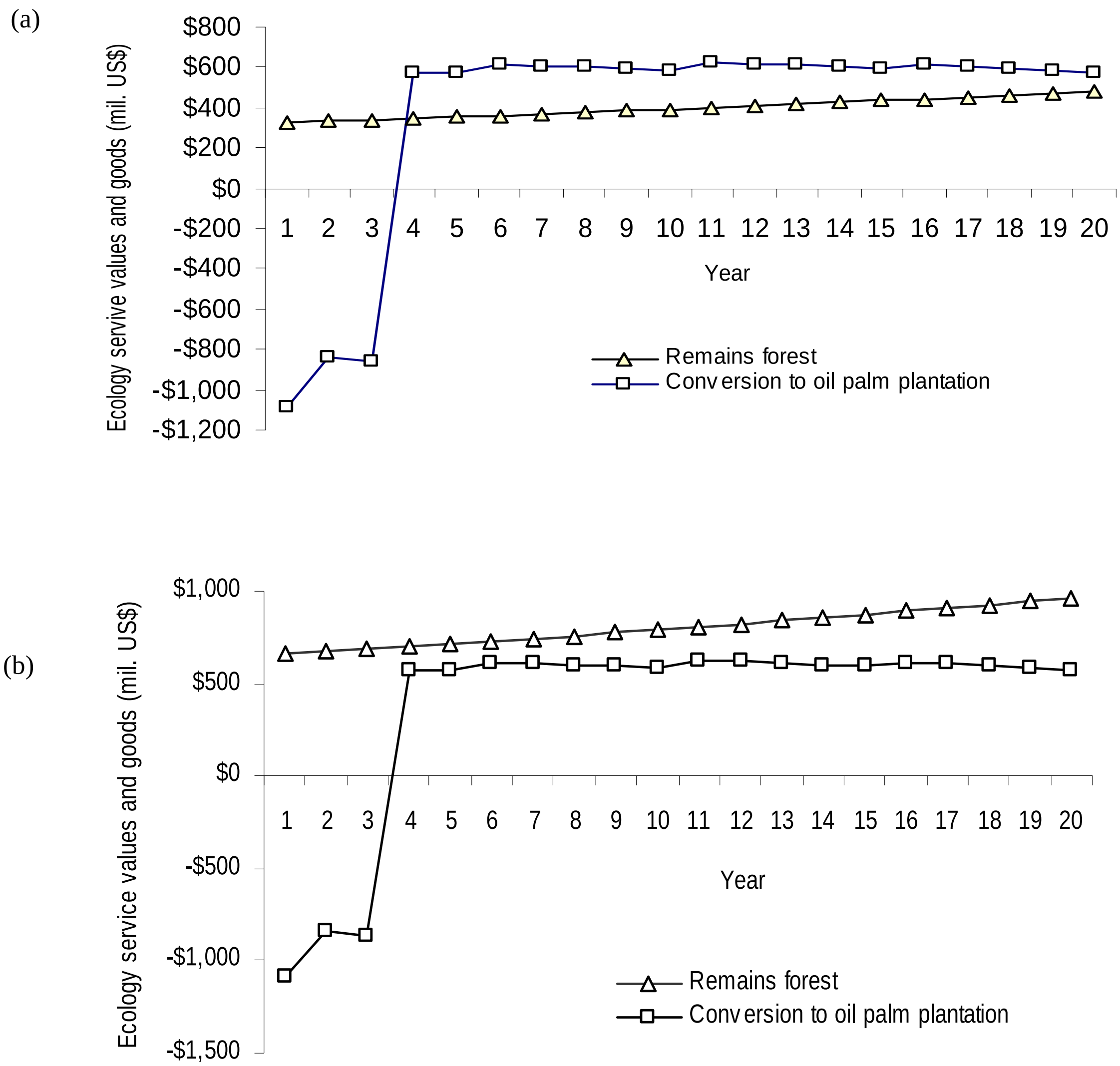

Fig. 2: Annual assets of keeping primary forest (339,630ha) intact versus converting it into mass oil palm plantation using: (a) 11 parameters of ecology service values and goods, and (b) the entire 17 recommended parameters of ecology service values and goods.

Table 1: **The C and P factors found in PFR for simulating the risk of landscape management options (a), and the K factor used (b)**

(a)

Land use options	C	P	C*P
1. Agriculture			
• Oil Palm plantation	0.5	0.25	0.125
• Rubber plantation	0.2	0.25	0.100
• Orchard (inc sundry tree cultivation)	0.3	0.5	0.015
• Pasture	0.02	1	0.020
2. Forest			
• Primary Forest	-	-	0.003
• Commercial forest (secondary forest)	-	-	0.015
• Shrubs (*belucar*)	0.02	1	0.020
• Clearings due to logging	-	-	0.015
3. Built-up areas			
• Urban	0.005	1	0.005
• Housing	0.003	1	0.003
• Cleared/barren land	1	1	1

(Source: Hashim, 2004)

(b)

Soil Series	Symbol	% clay	% silt	% fine sand	% organic matter	K
Reverine Alluvium Telemong	RVA-TMG	62	21	10	6.25	0.071
Rengam- Tampin	RGM-TPN	22.5	6.5	26.5	2.5	0.190
Bungor- Durian	BGR-DRN	26.5	21	46.5	1.6	0.180
Batu Anam Durian	BTM-DRN	37	24.5	34	1.515	0.290
Tampin- Rengam	TPN-RGM	22.5	6.5	26.5	2.495	0.190
Durian-Malacca	DRN-MCA	42.5	20	35	1	0.260
Bungor- Malacca	BGR-MCA	42	15	35.5	1.6	0.230
Durian-Tavy	DRN-TVY	34.5	30.5	31.5	0.5	0.350
Inland-Swamp-Local Alluvium	ISA-LAA					0.280

(Source: Hashim, 2004)

Table 2: (a) Land use pattern in PFR in 1995 and 2003 and its change use change pattern within the given period, and (b) Erosion rate for each given land use classes in 1995 and 2003.

(a)

Broader term of land use [1]	Land-use element [2]	Area of land use class (ha)		Changes [3] (ha)
		1995	2003	
Urban and related development	City	2130.627	2151.899	+ 21.272
	Cemetery	87.302	90.126	+ 2.824
Quarry and mines	Quarry	119.468	119.586	+ 0.118
	Mines	518.778	518.778	-
Mixed cultivation	Sundry Non Tree Cultivation	3201.623	3207.957	+ 6.334
	Sundry Tree Cultivation	34494.578	34633.937	+ 139.359
Grassland	Grass	25087.623	25186.034	+ 98.411
Paddy	Paddy	5832.417	5845.914	+ 13.497
Rubber	Rubber	266873.894	267720.392	+ 846.498
Oil Palm	Oil Palm	107734.269	107995.135	+ 260.866
Primary forest	Primary Forest	341094.066	339630.061	- 1464.006
Secondary forest	Secondary Forest	22870.14	22944.966	+ 74.826
	Total land area	810044.785	810044.785	

(b)

Broader term of land use [1]	Land-use element [2]	Erosion rate **1995** (ton/year)		Erosion rate **2003** (ton/year)	
		Erosion	Mean	Erosion	Mean
Urban and related development	City	577.399	0.271	640.684	0.281
	Cemetery	23.222	0.266	28.209	0.313
	Quarry	28.672	0.24	29.059	0.243
Quarry and mines	Mines	129.695	0.25	113.326	0.257
Mixed cultivation	Sundry Non Tree Cultivation	99535.257	31.089	117331.027	36.575
	Sundry Tree Cultivation	31419455.36	910.852	37113380.55	1071.59
Grassland	Grass	556493.65	22.182	657254.743	26.096
Paddy	Paddy	1190921.227	204.19	1404328.845	240.224
Rubber	Rubber	13800049.06	51.71	16286770.05	60.835
Oil Palm	Oil Palm	7307507.732	67.829	8617903.778	79.799
Primary forest	Primary Forest	3502012.776	10.267	4102391.507	12.079
Secondary forest	Secondary Forest	1348126.202	58.947	1591210.447	69.349
	Total soil loss (ton/yr^{-1})	59224860.25		69891382.23	

Note: 1= terms used in computing ecological services and goods; 2= the conventional land use mapping classes; and 3=changes of area in given classes reported as '+' for increment and '-'as reduction of area, respectively

Table 3: Soil loss due to erosion in 1995 and 2003 according to risk categories.

		Soil loss in **1995** group into risk categories#				Soil loss in **2003** group into risk categories#			
Broader term of land use*	Land-use element**	1	2	3	4	1	2	3	4
Urban and related development	City	2073.484	54.857	2.284		2133.71	18.189		
	Cemetery	86.579	0.723			88.711	1.415		
Quarry and mines	Quarry	119.454	0.014			118.669	0.917		
	Mines	516.624	2.154			495.511	23.267		
Mixed cultivation	Sundry Non Tree Cultivation	3114.426	87.197			3120.242	87.715		
	Sundry Tree Cultivation	34044.424	446.23	3.924		34169.557	463.384	0.996	
Grassland	Grass	24926.969	159.121	1.533		24995.524	188.926	1.584	
Paddy	Paddy	5809.636	22.781			5837.73	8.184		
Rubber	Rubber	262174.189	4697.061	2.644		262786.969	4920.158	13.265	
Oil Palm	Oil Palm	106045.166	1683.759	2.674	2.67	105905.887	2082.985	3.589	2.674
Primary forest	Primary Forest	339611.198	1478.97	3.9		338269.57	1355.207	5.284	
Secondary forest	Primary forest	22661.477	208.664			22739.822	203.027	2.117	
Total land area effected by erosion by risk categories		800661.902	8841.531	14.675	2.67	9353.374	26.835	2.674	

Total soil loss in 1995 = 59224860.25 ton/ha/year
Total soil loss in 2003 = 69891382.23 ton/ha/year

Note :
* terms used in computing ecological services and goods;
** are the conventional land use mapping classes;.
# is the categories of erosion: 1= Very low risk (0-1 ton ha^{-1} yr^{-1}), 2= Low risk (1-10 ton ha^{-1} yr^{-1}), 3= Moderate risk (0-1 ton ha^{-1} yr^{-1}) and 4= Moderate high risk (0-1 ton ha^{-1} yr^{-1})

Table 4: Ecology service values and good in PFR for 1995

		Ecological sevices							Ecological goods					
	Area (ha)	Water supply #	Erosion control #	Carbon stock *	Carbon sequestration *	Waste treatment #	Recreation #	Cultural and artistic info #	Food production #	Raw materials #	Medical resources *	Ornamemtal resources *	Total rate (USD/ha)	Cost of individual landscape
Landscapes features 1995														
Tropical Primary Forest	341094.066	8	245	8	8		112	2	32	330	50	250	1045	356443298.97
Tropical secondary forest	22870.140	8	245	6	6		112		32	330		250	989	22618568.46
Grassland/ rangelands	25087.623						2		67	29			98	2458587.05
Rock (quarry and mines)	638.364									50			50	31918.20
Oil palm	107734.269	2								1200			1202	129496591.34
Rubber	266873.894	2								77			79	21083037.63
Paddy	5832.417								54				54	314950.52
Urban	2217.929												0	0.00
Other sundry crops cultivation	37696.201								54				54	2035594.85
Total land area	810044.903													
--Soil loss due erosion (ton/yr)	59224860.250												6	355349161.50
Total ecologial services and goods in 1995														**$179,133,385.52**

ecological services values and goods based on Constanza et al (1997)

* Ecological services values and goods adopted from FAO (2003) –estimates of economic values of forest benefits.

Table 5: Ecology service values and good in PFR for 2003

		Ecological services							Ecological goods					
	Area (ha)	Water supply #	Erosion control #	Carbon stock *	Carbon sequestration *	Waste treatment #	Recreation #	Cultural and artistic info #	Food production #	Raw materials #	Medical resources *	Ornamental resources *	Total rate (USD/ha)	Cost of individual landscape
Landscapes features 2003														
Tropical Primary Forest	339630.061	8	245	8	8		112	2	32	330	50	250	1045	354913413.75
Tropical secondary forest	22944.785	8	245	6	6		112		32	330		250	989	22692392.37
Grassland/ rangelands	25186.034						2		67	29			98	2468231.33
Rock (quarry and mines)	638.364									50			50	31918.20
Oil palm	107995.135	2								1200			1202	129810152.27
Rubber	267720.392	2								77			79	21149910.97
Paddy	5845.914								54				54	315679.36
Urban	2242.025												0	0.00
Other sundry crops cultivation	37841.894								54				54	2043462.28
Total land area	810044.604													
--Soil loss due erosion (ton/yr)	69891382.230												6	419348293.38
Total ecologial services and goods in 2003														$114,076,867.13

ecological services values and goods based on Constanza et al (1997)
* ecological services values and goods adopted from FAO (2003) –estimates of economic values of forest benefit