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## Landuse conversion impact assessment on landscape provisioning service for rice sufficiency in Langkat Regency, Indonesia

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### Abstract

Landscape analysis has been performed to assess the impacts of landuse conversion on landscape provisioning service for rice sufficiency in Langkat Regency, Indonesia. In this study, we used 30-m Landsat satellite images in 1989, 2001, and 2010 to analyze a change of landuse. A field survey was implemented to collect socio-economic data in order to examine the driving factor of the changes. The results showed that forest was the dominant landuse type in 1989 and 2001, but it was converted into oil palm plantation in 2010. The rice land continuously decreased during the periods. Regarding to the analysis, forest and rice lands were fragmented into smaller patches from 1989 to 2001. Indeed, the availability of milled rice in Langkat Regency have decreased; from 328,913.90 ton in 1989 to 19,436.74 ton in 2010.

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*Keywords:* landuse conversion; rice sufficiency; landscape metrics; Langkat Regency

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### 1. Introduction

Population growth (Livernash and Rodenburg [1]; Ningal *et al.* [2]), urbanization (Deng *et al.* [3]) and government policies (Sadewall *et al.* [4]) are the common driving factors of landuse conversion in the most developing countries. Urbanization and increasing population growth will accelerate landuse changes as related to the requirement of housing, industrial/commercial area and public infrastructures. Aspinall and Hill [5] defined landuse science as an inclusive, interdisciplinary subject that focuses on the nature of landuse and land cover, their

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changes over space and time, and the social, economic, cultural, political, decision-making, environmental and ecological processes that produce these patterns and changes.

Deng JS *et al.* [3] noted that one of the most rapidly growing applications of remotely sensed data is the derivation of landscape pattern metrics for the assessment of land cover condition and landscape change dynamics. Identifying and analyzing landuse change is required to understand the process of landuse pattern dynamics. Currently, the spatio-temporal dynamics of landuse change can be analyzed easier by using Geographical Information System (GIS) and remote sensing technology. As a software supporting GIS, FRAGSTATS can be used to compute several statistics in patch and class among a landscape or in a landscape scale, such as number of patches (NP), patch density (PD) and patch cohesion index (Cohesion) (McGarigal *et al.* [6]). Additionally, landuse transition matrix is a useful tool that has been widely accepted in landuse change analysis [7].

Transformations of spatial pattern of landuse have an impact on the change of landscape structure and function from ridge to reef. Kokove [8] stated that landuse change influences the declining of soil fertility and environmental damages. Irawan [9] mentioned many factors of agricultural land conversion, following external factors (urbanization and population growth), internal factors (socio and economic), and policy factor (regulation of local government). Regarding to a study of landuse change and food security planning in Thailand (Thongtap and Eiumnoh [10]), the problem of household food security is not as simple as agricultural output or sufficient rice as food, but also encompasses all factors affect a household's access to an adequate food continuously.

Langkat Regency is located in North Sumatera Province, Indonesia. Population growth, urbanization and agro-industrial development in the regency is increased, and it contributes to the increasing of landuse conversion. Landuse conversion occurred dominantly from forest and agricultural (rice field) to oil palm plantations as well as built up area. In addition, several policies of the local government are also contributed to the conversion of landuse either direct or indirectly affects.

The study aims to identify the main factors of landuse conversion and to assess their impact on rice sufficiency in Langkat Regency by using Geographic Information System (GIS), remote sensing, landscape metrics and socio – economic approaches. Moreover, the specific objectives of the study are:

- a. To identify and analyze the landuse conversions and landscape metric in Langkat Regency from 1989 to 2010,
- b. To identify and analyze the effect of population growth, urbanization, higher income opportunities from oil palm production and government policy on the landuse conversion and rice sufficiency in Langkat Regency.

## 2. Materials and Method

### 2.1. Description of the Study Area

Langkat Regency is located in North Sumatera Province, Indonesia ( $3^{\circ} 14' - 4^{\circ} 13' \text{ N}$ ,  $97^{\circ} 52' - 98^{\circ} 45' \text{ E}$  and 0 – 104 meters above sea level). The total area is 6,263.39 km<sup>2</sup> (626,329 ha) which consists of 23 sub regencies and 277 villages (Statistical Institution of Langkat Regency [11]).

### 2.2. Data Collection and Analysis

The study area is covered by two scenes of Landsat images; path/row: 129/57 and 129/58. In order to identify the landuse conversion, the Landsat images (TM and ETM+) were used at three time-series; they are acquired in 1989 (June 13 and March 17), 2001 (June 14 and February 22) and 2010 (Jan 30). Unsupervised classification method was applied landuse to classify the landuse types in the study area by using IDRISI KILIMANJARO Software Ver. 16.03 (Eastman [12]). The landuse types were classified into forest, mix vegetation, rice cultivation, oil palm, built up, fishpond and barren land. Overlaying with some composite bands; such as 123, 234, 345, 247 and 354, made the landuse classification process easier. Total area of each landuse was determined and compared from 1989, 2001 and 2010. Crosstab command in Idrisi was then used to identify the landuse conversion. Three landuse maps were created as the final outputs by using ArcMap 9.3.

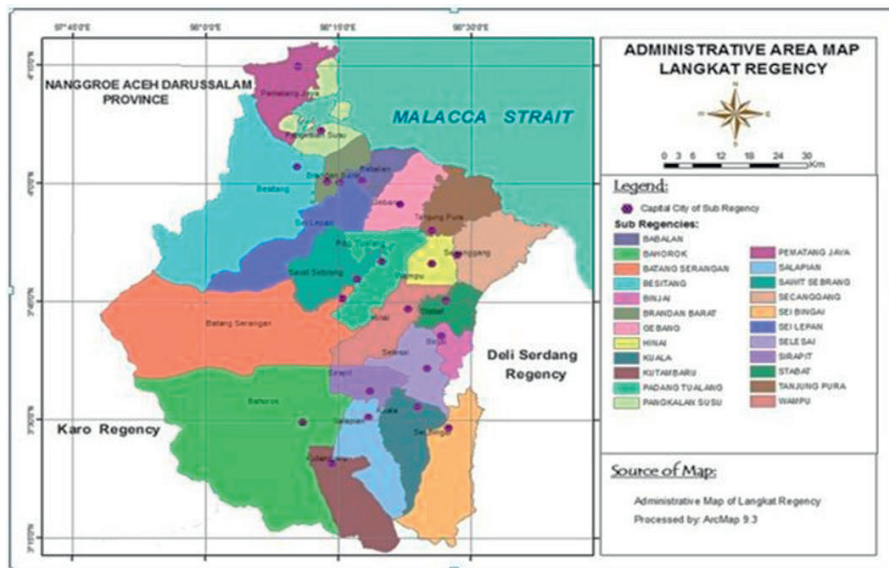


Fig 1. Administrative area of Langkat Regency

Two spatial metrics were evaluated to describe the composition and configuration of landscape pattern changes in Langkat Regency; they are Patch Density (PD), and Patch Cohesion Index (COHESION). These metrics were computed for each period at the class levels.

Secondary data of population growth and urbanization (e.g. total of built-up area, number of villages and road density) was collected from 1989 to 2010. The correlation of these datasets and landuse conversion was determined using SPSS Software. A survey interview was conducted following structured and unstructured questions on the key informant interviews. Focus Group Discussion (FGD) was also implemented in order to observe some driving factors of rice field conversion, and it was followed by 60 respondents.

Secondary data on milled rice production and consumption per capita were collected from the Statistical Institution of Langkat Regency. Quantification of total milled rice production in 1989, 2001 and 2010 were generated regarding total area of rice field on landuse map. Due to the comparison of milled rice production and consumption, rice sufficiency could be assessed [13].

### 3. Result and Discussions

#### 3.1. Spatial Pattern of Landuse

The changes of landuse pattern in Langkat Regency from 1989 to 2010 are presented in Table 1 and Figure 2. Forest, mix vegetation and rice field are the dominant landuse types in 1989, which covering 52.16%, 27.95% and 12.43% of area, respectively. In 2001, forest and mix vegetation were still the dominant landuses but the rice field was replaced by oil palm plantation. They covered 45.92%, 16.65% and 16.39% of area, respectively. Identification of landuse in 2010 indicated that oil palm was the most dominant landuse, which covered 38.13% of the total area and followed by forest and mix vegetation at 34.14% and 17.31%, respectively.

Table 1. Landuse statistics of Langkat Regency in 1989, 2001 and 2010 based on classification result

Time period	1989		2001		2010	
	Hectare	%	Hectare	%	Hectare	%
Landuse Type						
Forest	320,927.1	52.16	282,518.5	45.92	210,072.2	34.14
Mix Vegetation	171,944.6	27.95	102,454.7	16.65	106,505.3	17.31
Rice	76,473.7	12.43	63,125.6	10.26	22,854.8	3.71
Oil Palm	8,233.5	1.34	100,830.8	16.39	234,599.5	38.13
Fishpond	6,017.4	0.98	12,374.5	2.01	9,880.0	1.61
Built-up	3,936.3	0.64	17,649.1	2.87	18,838.8	3.06
Barren	27,757.4	4.51	36,337.1	5.91	12,539.6	2.04
Total	615,290.1	100.00	615,290.1	100.00	615,290.1	100.00

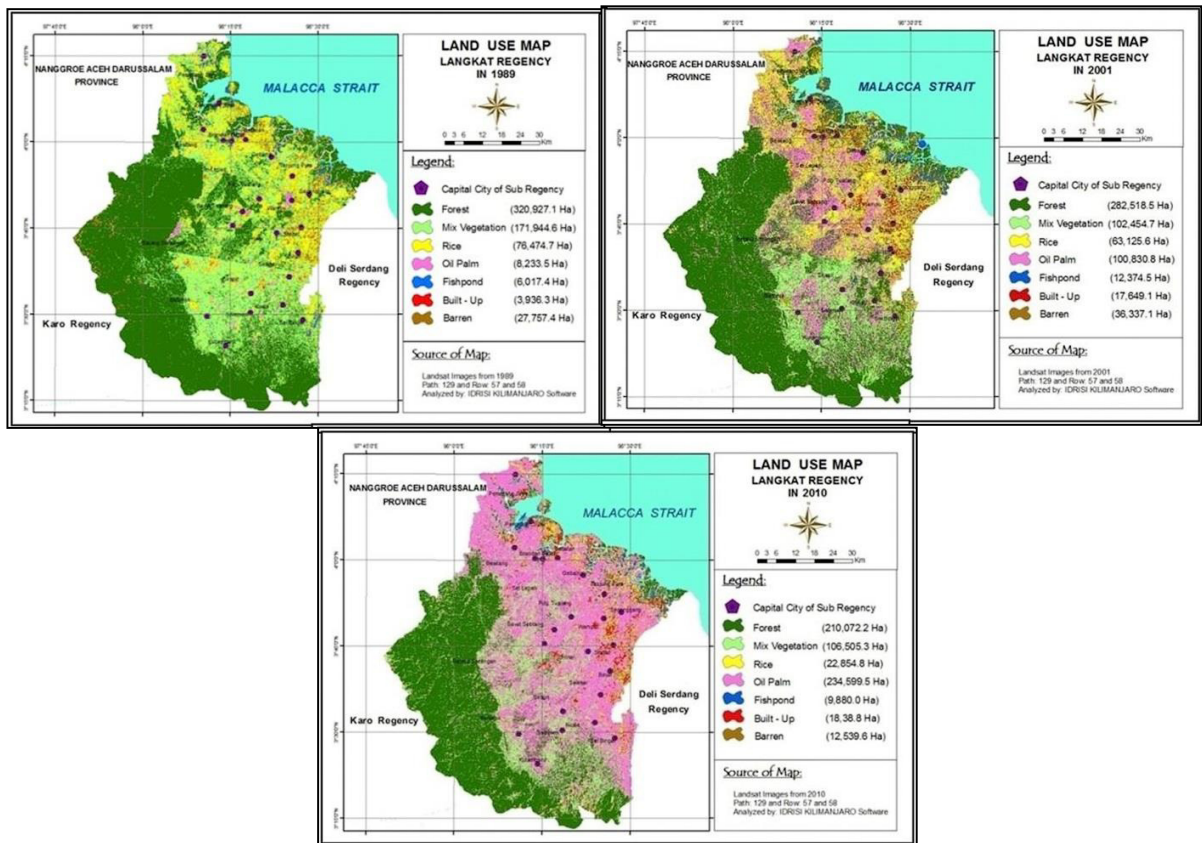


Fig. 2. Landuse map in (a) 1989; (b) 2001; (c) 2010

Forest had a significant negative correlation with oil palm plantation as showed in Table 2 and Figure 3. This result occurred because of the most of forest area was converted into oil palm plantation by the villagers.

Table 2. Correlation coefficient of population, built-up change, forest change, mix vegetation change, rice change and oil palm change

		Forest	Mix veg	Rice	Oil palm	Fishpond	Built-Up	Barren
Forest	Pearson Corr.	1						
	Sig. (2-tailed)							
Mix Veg	Pearson Corr.	.731 <sup>ns</sup>	1					
	Sig. (2-tailed)	.478						
Rice	Pearson Corr.	.994 <sup>ns</sup>	.654 <sup>ns</sup>	1				
	Sig. (2-tailed)	.068	.546					
Oil Palm	Pearson Corr.	-.997*	-.777 <sup>ns</sup>	-.984 <sup>ns</sup>	1			
	Sig. (2-tailed)	.045	.433	.113				
Fishpond	Pearson Corr.	-.454 <sup>ns</sup>	-.940 <sup>ns</sup>	-.357 <sup>ns</sup>	.516 <sup>ns</sup>	1		
	Sig. (2-tailed)	.700	.222	.768	.655			
Built-Up	Pearson Corr.	-.810 <sup>ns</sup>	-.992 <sup>ns</sup>	-.743 <sup>ns</sup>	.849 <sup>ns</sup>	.891 <sup>ns</sup>	1	
	Sig. (2-tailed)	.399	.079	.467	.354	.300		
Barren	Pearson Corr.	.757 <sup>ns</sup>	.108 <sup>ns</sup>	.822 <sup>ns</sup>	-.709 <sup>ns</sup>	.238 <sup>ns</sup>	-.229 <sup>ns</sup>	1
	Sig. (2-tailed)	.453	.931	.385	.498	.847	.853	

\* = Correlation is significant at the 0.05 level (2-tailed) if  $p \leq .05$

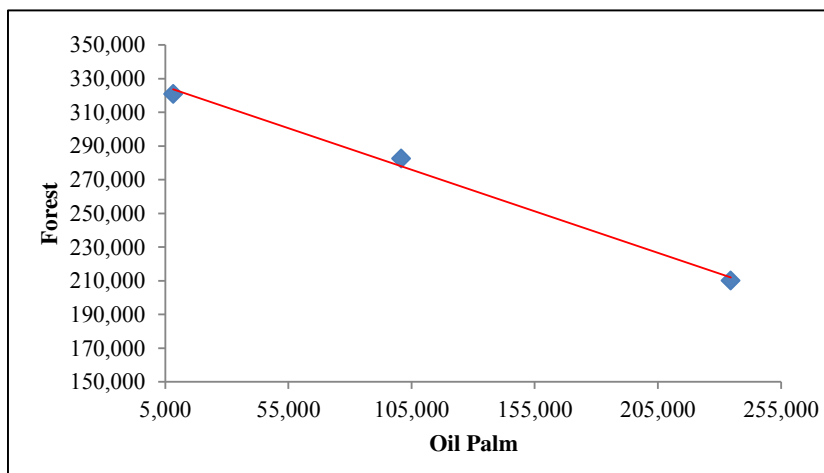


Fig. 3. Relationship of forest change and oil palm change

### 3.2. Landuse Conversion from 1989 to 2001

Mix vegetation had the highest landuse conversion from 1989 to 2001 (121,672.4 ha), and it was dominated by the conversion into oil palm plantation (45,136.4 ha). Forest had the second highest landuse conversion (91,518.3 ha), where was converted into oil palm plantation dominantly (35,667.1 ha). Rice field was the third with 54,961.3 ha of area. About 15,159.0 ha of rice field area was converted into mix vegetation, and 13,891.7 ha into oil palm plantation.

Nearly 97,539.5 ha of oil palm area has been developed from other landuse types since 1989 while most landuse conversion occurred from mix vegetation (45,136.4 ha). Forest was the second of newly formed-landuse (53,109.6 ha) and most of the new forest area landuse occurred from mix vegetation (35,644.5 ha). All the transition matrix of landuse conversion from 1989 to 2001 is shown in Table 3.

Table 3. Transition matrix of landuse conversion (ha) of Langkat Regency from 1989 to 2001

		2001								
Landuse type		Forest	Mix vegetation	Rice	Oil- palm	Fish-pond	Built- up	Barren	Total 1989	
									Area	%
1989	Forest	229,408.8	29,205.0	9,932.2	35,667.1	4,065.6	2,025.6	10,622.8	320,927.1	52.16
	Mix vegetation	35,644.5	50,272.3	24,946.7	45,136.4	1,913.5	5,116.8	8,914.5	171,944.6	27.95
	Rice	7,928.2	15,159.0	21,512.4	13,891.7	1,815.0	6,891.8	9,275.7	76,473.7	12.43
	Oilpalm	1,269.8	2,258.6	1,016.7	3,291.3	20.5	234.7	141.8	8,233.5	1.34
	Fishpond	1,664.0	625.3	271.4	154.9	1,497.7	113.6	1,690.5	6,017.4	0.98
	Built-up	1,037.2	584.0	746.8	263.4	239.5	563.3	502.1	3,936.3	0.64
	Barren	5,561.0	4,350.5	4,699.3	2,426.0	2,822.7	2,703.3	5,189.8	27,757.4	4.51
Total 2001	Area	282,518.5	102,454.7	63,125.6	100,830.8	12,374.5	17,649.1	36,337.1		
	%	45.92	16.65	10.26	16.39	2.01	2.87	5.91		

### 3.3. Landuse Conversion from 2001 to 2010

Forest had the highest landuse conversion (98,916.5 ha), and it converted into oil palm plantation dominantly (50,702.2 ha). Mix vegetation had the second highest landuse (70,176.3 ha) with the conversion into oil palm plantation about 52,768.1 ha of the area. Rice field had the third highest landuse conversion (58,740.9 ha) and it was converted into oil palm plantation and mix vegetation, about 41,941.0 ha and 11,534.2 ha, respectively.

About 170,011.0 ha of oil palm plantation has been developed from other landuses since 2001 and the most of area was occurred landuse from the mix vegetation (52,768.1 ha). Mix vegetation was the second of newly formed-landuse (74,226.9 ha) and the most converted-landuse occurred from forest (34,233.5 ha). All the transition matrix of landuse conversion from 2001 to 2010 is shown in Table 4.

Table 4. Transition matrix of landuse conversion (ha) of Langkat Regency from 2001 to 2010

		2010								
Landuse type		Forest	Mix vegetation	Rice	Oil- palm	Fish-pond	Built- up	Barren	Total 2001	
									Area	%
2001	Forest	183,602.0	34,233.5	3,989.6	50,702.2	2,814.8	3,953.1	3,223.4	282,518.5	45.92
	Mix vegetation	9,478.7	32,278.4	3,460.8	52,768.1	583.8	2,791.6	1,093.3	102,454.7	16.65
	Rice	683.9	11,534.2	4,384.6	41,941.0	285.6	3,406.8	889.5	63,125.6	10.26
	Oil palm	13,566.9	19,087.2	1,636.8	64,588.5	112.7	1,374.5	464.2	100,830.8	16.39
	Fishpond	628.8	1,421.2	1,579.2	1,654.3	2,462.0	1,400.0	3,228.9	12,374.5	2.01
	Built-up	322.5	2,236.1	2,955.8	8,498.5	143.4	2,929.4	563.5	17,649.1	2.87
	Barren	1,789.4	5,714.7	4,847.9	14,446.9	3,477.9	2,983.4	3,076.8	36,337.1	5.91
Total 2010	Area	210,072.2	106,505.3	22,854.8	234,599.5	9,880.0	18,838.8	12,539.6		
	%	34.14	17.31	3.71	38.13	1.61	3.06	2.04		



### 3.4. Landscape Metric at Class Level

Patch Density (PD) is the number of patches per 100 ha for a particular class of landuse or patch class. PD of rice field increased in 1989 to 2001, from 3.96 to 6.13 patches/100 ha. It was affected by oil palm and mix vegetation expansions. Fragmentation of rice area into smaller patches contributed to increase PD of rice field. Oil palm plantation and mix vegetation expansion continued and persisted to be converted into rice field in 2010. These phenomena decreased PD of rice field from 6.13 to 3.54 patches/100 ha (Table 5).

Patch Cohesion Index (COHESION) measures the physical connectedness of the corresponding patch type [14]. COHESION increases as the patch type becomes more clumped or aggregated in its distribution. Cohesion Indices of built-up area, oil palm and fishpond gradually increased during the periods. Barren Cohesion Index was not significant change (Table 6). Road development and urbanization contributed to the fusion among built-up and oil palm patches.

Table 5. Patch Density (PD) of different patch class in 1989, 2001 and 2010

Landuse/Land patch	Patch Density (PD)		
	1989	2001	2010
Forest	4.25	7.14	3.78
Mix vegetation	7.16	12.31	13.85
Rice	3.96	6.13	3.54
Oil palm	1.28	12.95	5.93
Fishpond	1.11	1.68	0.92
Built-up	1.23	3.44	1.72
Barren	4.86	7.03	2.35

Table 6. Patch Cohesion Index (Cohesion) of different patch class in 1989, 2001 and 2010

Landuse/ Patch class	Cohesion		
	1989	2001	2010
Forest	99.88	99.81	99.85
Mix vegetation	99.50	97.36	96.08
Rice	98.51	96.71	88.34
Oil palm	88.49	97.50	99.78
Fishpond	81.40	89.77	89.10
Built-up	65.01	86.51	89.02
Barren	85.12	88.31	85.54

### 3.5. Landscape Population Growth, Urbanization, Higher Income Opportunity and Landuse Policy

Population growth is an important determinant of landuse conversion. Based on the Statistics of Langkat Regency, there was a 12.88% population increased from 1989 (812,229 inhabitants) to 2001 (916,900 inhabitants), and followed by a 5.52% increase in 2010 (967,535). In 2010, Binjai Sub Regency had the highest population density (1,006.5 people/km<sup>2</sup>), followed by Stabat (753.1 people/km<sup>2</sup>) and Babalan Sub Regency (739.0 people/km<sup>2</sup>). Consequently, there is insignificant correlation between population growth and landuse change.

The road density increased by 49.00% from 1989 (0.16 km/km<sup>2</sup>) to 2001 (0.24 km/km<sup>2</sup>). However, road density decreased by only 6.72% in 2001 (0.24 km/km<sup>2</sup>) to 2010 (0.22 km/km<sup>2</sup>) due to declining of the road condition. Total number of villages increased by 11.11% and 20.43% from 1989 to 2001 and 2001 to 2010, respectively. There is significant correlation between number of village and forest change (Table 7).

Table 7. Correlation coefficient of road density, number of village, forest change, mix vegetation change, rice change and oil palm change

		Road Density	Number of Village
Road density	Pearson Corr.	1	
	Sig. (2-tailed)		
Number of village	Pearson Corr.	.611 <sup>ns</sup>	1
	Sig. (2-tailed)	.582	
Forest change	Pearson Corr.	-.626 <sup>ns</sup>	-.100*
	Sig. (2-tailed)	.569	.013
Mix vegetation change	Pearson Corr.	-.990 <sup>ns</sup>	-.717 <sup>ns</sup>
	Sig. (2-tailed)	.091	.491
Rice change	Pearson Corr.	-.540 <sup>ns</sup>	-.996 <sup>ns</sup>
	Sig. (2-tailed)	.637	.055
Oil palm change	Pearson Corr.	.680 <sup>ns</sup>	.996 <sup>ns</sup>
	Sig. (2-tailed)	.524	.058

\* = Correlation is significant at the 0.05 level (2-tailed) if  $p \leq .05$

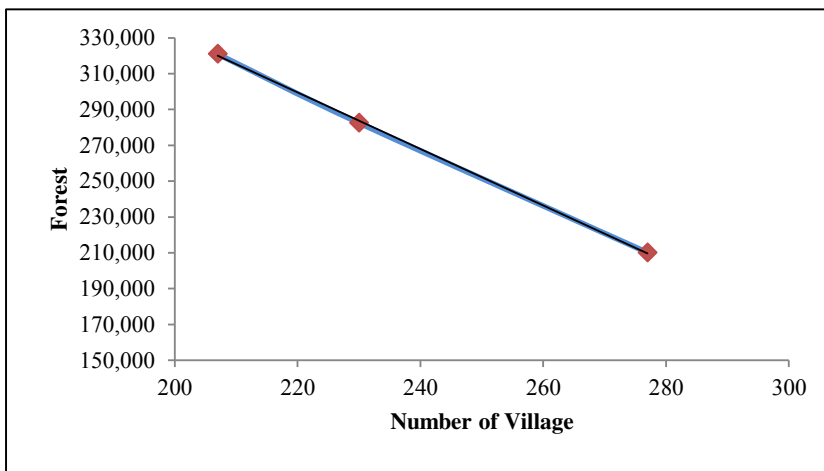


Fig. 4. Relationship of forest change and number of village change

Regarding to the survey results, most of the respondents converted their paddy field into other commodities (64.94%). There were eight respondents (10.38%) who sold their rice lands and only 19 respondents (24.68%) still maintained their rice land. Table 8 shows that higher income of substitute commodity (37.5 %) and uncertainty weather (20.31 %) are the main reasons why they changed their rice land into other commodities. In addition, for the comparison economically, the farmers will get US \$ 2,400 – 2,600/year for oil palm commodity and only US \$ 1,200 – 1,600/ year for rice.

Table 9 shows the loss of rice land to other landuses at Langkat Regency. Landuse conversion from rice to other landuses was the most important issue related to landscape provisioning service for rice sufficiency. The largest conversions occurred from rice to oil palm and mix vegetation.



Table 8. Respondents' reasons for changing the rice landuse

Reasons for changing the rice land	Frequency	Percentage
Uncertainty weather	24	20.31
Higher income of substitute commodity	48	37.5
Will have much relax time	5	3.90
Costly price of production input	1	0.78
Difficulty in accessible of production input	3	2.34
Need more labor compare substitute commodity labor	2	1.56
Simple technical cultivation of substitute commodity	16	12.5
Vulnerability to pest and disease	8	6.25
Follow others farmers' track	17	13.28
Saltwater intrusion	2	1.56
Total	128	100.00

Table 9. Rice land conversions to other landuses (ha) at Langkat Regency at different time periods

Landuse formed from rice land	1989 – 2001	2001 – 2010	1989 – 2010
Forest	7,928.19	683.91	2,079.09
Mix vegetation	15,158.97	11,534.22	10,819.17
Oil palm	13,891.68	41,940.99	49,219.38
Fishpond	1,815.03	285.57	544.95
Built-up	6,891.75	3,406.77	4,927.50
Barren	9,275.67	889.47	1,576.89

Table 10 presents the estimated milled rice production and consumption at Langkat Regency based on the total area of rice land in 1989, 2001 and 2010. It shows declining trend of the milled rice availability from 1989 to 2010 in Langkat Regency.

Table 10. Estimated milled rice production, consumption, and availability at Langkat Regency in 1989, 2001, and 2010

	1989	2001	2010
<b>A. Milled rice production</b>			
Area harvested (ha)	76,473.72	63,125.55	22,854.78
Average rice productivity (tons/ha)	5.23	5.30	5.96
Total rice production (tons)	799,915.11	669,130.83	272,428.98
Total milled rice production (tons)	437,752.58	366,181.04	149,086.43
<b>B. Milled rice consumption</b>			
Total of population	812,229	916,900	967,535
Total milled rice consumption (tons)	108,838.69	122,864.60	129,649.69
<b>C. Milled rice availability (ton)</b>			
	328,913.90	243,316.44	19,436.74

Note:

*Average rice productivity* = Based on data from Statistical Institution of Langkat Regency

*Total rice production* = Area harvested x average rice productivity x 2

*Dry grain harvesting (DGH)* = 86.59 % x Total rice production

*Total milled rice production* = 63.20 % x DGH

*Total milled rice consumption* = 0.134 x total of population

*Milled rice availability* = Total milled rice production – total milled rice consumption

There was high surplus of milled rice in 1989 (328,913.90 ton) and in 2001 (243,316.44 ton) but the situation was changed in 2010 (Table 10 and Figure 5). Although there was still a surplus of milled rice, but it was only 19,434.74 ton. The Local Government of Langkat Regency should secure the milled rice stock through importing from other sub regencies in order to fulfill their sufficiency; if the rice land conversion cannot be pressed.

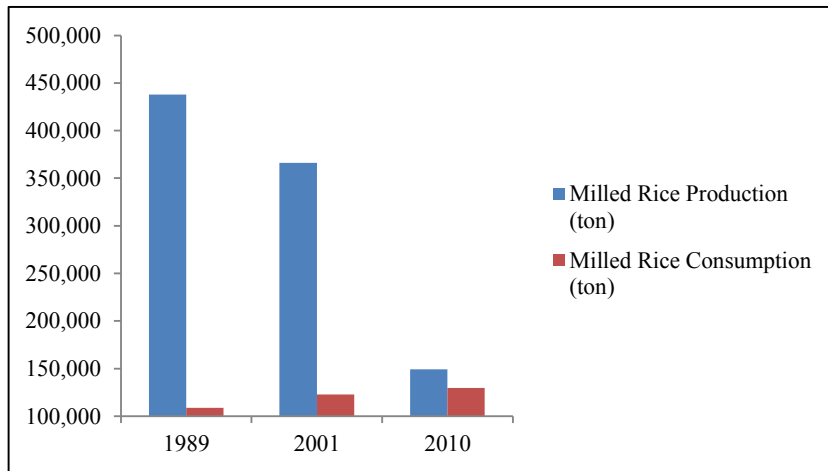


Fig. 5. Comparison between milled rice production and consumption in Langkat Regency since 1989 to 2010

Government's policies have also triggered land use conversion when those regulations cannot produce a favorable land use planning in a specific area. Many policies related land use planning in Indonesia, which was achieved by the national and local government seems to be conflicting each other about maintaining land use planning. Langkat Regency also has the Land use Planning Policy which is based on some previous policies. The latest Land use Planning for 2002 – 2011 is provided in the Local Regulation of Langkat Regency No. 15 in 2003. The purpose of policy is to identify protected areas and development zones for specific commodity, including production zone and residential zone, and some areas that will be developed.

There are many policies but land use conversions still occur, especially in Langkat Regency. Conversion of forest into oil palm and residential area; and rice area into built-up areas have been observed in the field as evidences that implementation of all the policies are still weak. The agricultural land use policies are difficult to implement because of some reasons:

a) Policy Coordination

The Central Government tries hard to avoid land use conversion in order to achieve the rice self-sufficiency, on the other hand, the Local Government pushes land use conversion through the agro-industrial development.

b) Policy Consistency

With territory autonomy, some planning might be changed because of the policy decision makers will give high priority for a specific sector that gives higher short-term advantages to increase their regional income such as by giving a permission letter for an expansion of oil palm plantation, permission to converting forest land into other land uses, and permission for housing development on agricultural/forest area, among others.

c) Planning Implementation

Most of land use conversion policies are directed to companies, but in reality most land use conversions (especially rice land) are implemented by individuals.

## 4. Conclusion and Recommendation

### 4.1. Conclusion

Landuse change assessment should include dynamics of the landscape structure and socio-cultural and ecological system to determine the consequences on rice sufficiency. The agricultural landuse policies to promote oil palm extensification from the natural forest and farmlands in Langkat Regency shall consider the impacts of landuse change on landscape services like sufficiency of rice supply, biodiversity and protection from flooding, drought and other natural disasters that could occur with climate change.

With ease access to remote sensing information in developing countries presently and supporting landscape analysis softwares should be part of the landuse assessment to predict the consequences of environmental scenarios on landscape services.

Integration of social, economic and environmental aspects with agricultural landuse management and policies are required to achieve the sustainable development in Langkat Regency. Strengthening landscape ecological management of natural resources from the ridge to reef would minimize the impacts on landscape provisioning for rice sufficiency in Langkat Regency.

### 4.2. Recommendation

Research and development are two main goals to achieve sustainable landscape services. Integration of these goals with government policies would have significant impact on human welfare. Some of research and development that could be applied in Langkat Regency are:

- a. Integrated landscape ecological assessment for retention of existing and suitable irrigated rice land to ensure rice sufficiency continuously;
- b. Assessment of mangrove forest to achieve sustainable mangrove services;
- c. Integrated landscape ecological approach to natural resource management (rice and fish sufficiency, biodiversity, water resources) to achieve sustainable landscape services;
- d. Institutional capability building on integrated landscape ecological management of natural resources.

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