Agro-ecosystems, their population densities and land cover in Indonesia in the context of upland-lowland relationships

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Abstract

With increasing interest in landscape level interactions between land users in uplands and lowlands, basic data on the total area and the number of people involved in the various combinations of land use types are helpful in prioritising research. We combined four data sources: the FAO classification of agro-ecological zones ('agro-ecosystems' or 'farming systems'), district level human population data, the IGBP land cover classification and a coarse digital elevation model. Overlays were used to estimate the number of people and area involved in combinations such as 'lowland rice below forest', 'lowland rice below upland crop mosaics' or 'lowland rice below tree crops', as well as the actual forest cover fractions in each of the agro-ecological zones. Overall, 80% of Indonesia's population is directly linked to the potential downstream – upstream conflicts associated with the land use in upland crop mosaics. The data suggest that 50% of Indonesia's population live in lowland rice agro-ecosystems (> 700 persons km^{-2}) with 'upland crop mosaics' (~ 150 persons km^{-2}) as their upstream neighbours; 23% live in these mosaics and another 9% in tree crop systems downstream of the upland crop mosaics. Area-wise the lowland side of the rice - upland combination covers only 7.1% of the total land area and on Java involves 4.1 persons in the lowland per person in the uplands. Lowland rice agro-ecosystem downstream of the 'forest' agro-ecosystem cover only 3.1% of the area and involve 3.2% of the population, but they have a lowland: upland person ratio of 33 which offers better (per capita) prospects for effective 'rewards' in the uplands for maintaining watershed functions. From a biodiversity perspective the combination of 'tree crops' and 'forest' in the same watersheds may be of specific interest. This involves 18.5% of the land area and 4.8% of Indonesia's population. Actual forest cover within the various agro-ecosystems varies from 35 % in the lowland rice agro-ecosystem, via 46 % for the upland crop mosaic and 48% for the 'tree crop' zone to 75 % for what is classified as the 'forest farming system'. At the smaller scale, these remaining forest areas within the agriculturally used and productive landscape may be the focus of 'environmental service function' analyses, focussing on 'landscape agroforestry'.

1. Introduction

Southeast Asia and neighbouring parts of South and East Asia contain a major part of the world population, living in landscapes with some of the worlds' highest population densities. Yet as a region it still contains area of closed forest, as well as many land cover types that are intermediate between closed forest and open-field agriculture or urban domains. Insular Southeast Asia has probably the worlds' highest rate of land-ocean transfer of sediment per unit land area (Milliman et al. 1999). Thus the region as a whole offers many opportunities to explore the interactions between forest conversion, intensification of land use, biodiversity conservation (from local, national and/or international perspectives), and watershed functions that matter for people at a range of distances from the land units involved in the change.

At the start of the new millennium, the East Asia plus Pacific region contained 1 836 M people (just over one-third of all the inhabitants of developing countries), of which 62% (1 124 M people) directly involved in agriculture; 278 M people (15% of total regional population live in extreme poverty, with daily incomes less than 1 US$ day^{-1}; a quarter of the 'extremely poor' live in China; about 240 M people (13% of total population) are under nourished; rural poverty ranges from 4.6% in China to 57.2% in Vietnam (Dixon et al., 2001).

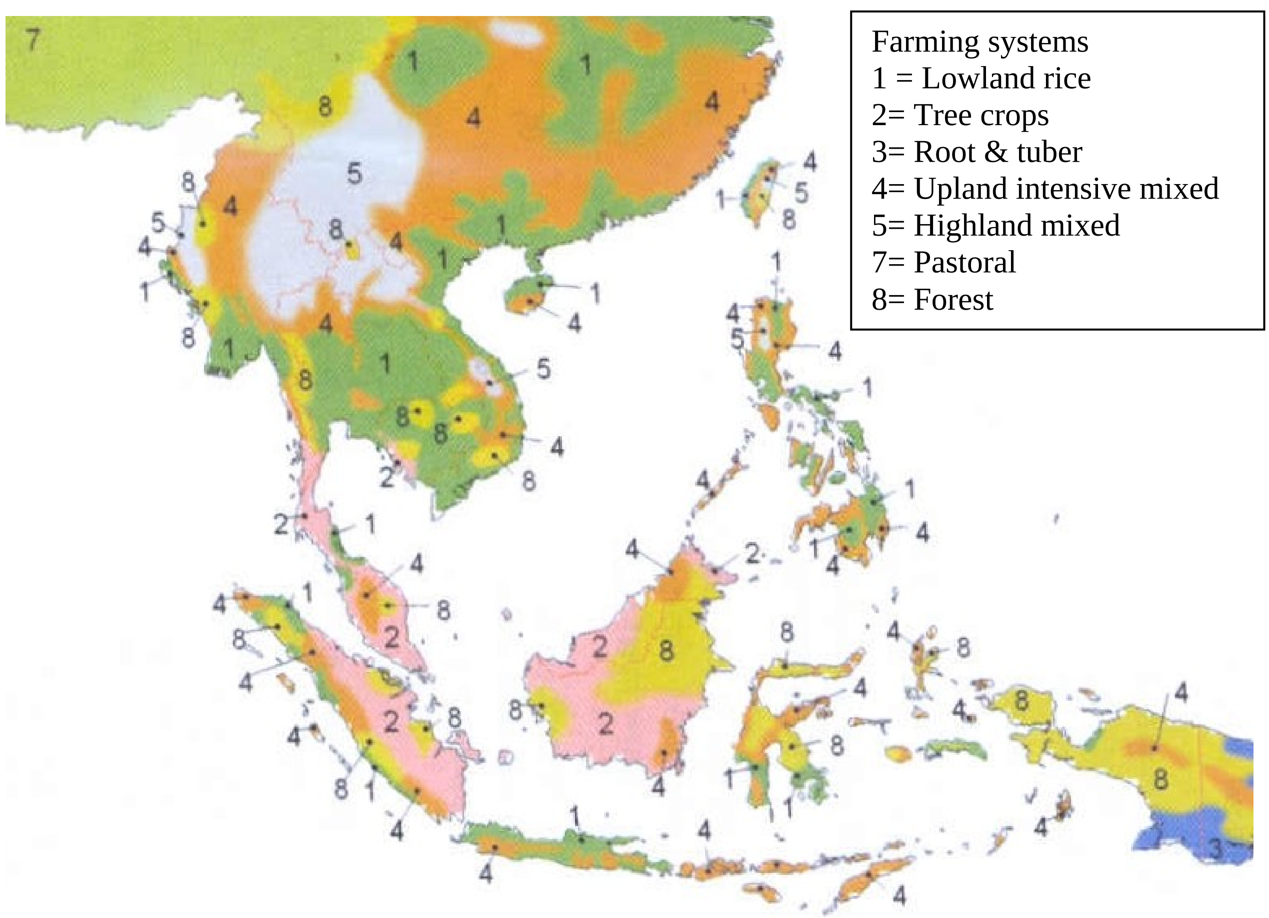

Figure 1. Major farming systems in East Asia and Pacific (source: Dixon et al., 2001)

The distribution of the rural population is very uneven: the lowland rice farming system maintains on average 240 persons km^{-2}, the intensive upland mosaics 100 persons km^{-2}, the tree crop systems 35 persons km^{-2} and the sparsely populated forest systems <15 persons km^{-2}.

Table 1. Major farming systems in East Asia and Pacific (source: Dixon et al. 2001); NB the data on area and population size include all of China and the Koreas

Farming system	**Areal extent (% of land area in region)**	**Rural population, population density (% of total)**	**Principal livelihoods**	**Prevalence of poverty**
1. Lowland rice/urban	197 M ha (12 %)	474 M 241 km^{-2} (42 %)	Rice, maize, pulses, sugarcane, oil seeds, vegetables, livestock, aquaculture, off-farm work	Moderate
4. Upland intensive mixed (***incl. major areas outside of the tropics***)	314 M ha (19 %)	310 M 99 km^{-2} (27 %)	Rice, pulses, maize, sugar cane, oil seeds, fruits, vegetables, livestock, off-farm work	Extensive
5. Highland extensive mixed	89 M ha (5 %)	47 M 53 km^{-2} (4 %)	Upland rice, pulses, maize, oil seeds, fruits, forest products, livestock, off-farm work	Moderate
2. Tree crop mixed	85 M Ha (5 %)	30 M 35 km^{-2} (3 %)	Rubber, oil palm, coconuts, coffee, tea, cocoa, spices, rice, livestock, off-farm work	Moderate
8. Sparse (forest)	172 M ha (10 %)	23 M 13 km^{-2} (1 %)	Hunting, gathering, off-farm work	Moderate
3. Root – tuber (PNG)	25 M ha (2 %)	1.5 M 6 km^{-2} (< 1%)	Root crops (yam, taro, sweet potato), vegetable, fruits, livestock, off-farm work	Limited
***Others* (mostly non-tropical China)**				
6. Temperate mixed	6 %	14		Moderate
7. Pastoral	20 %	4		Extensive
9. Sparse (dry)	20 %	2		Extensive

In the discussion on ***rural poverty*** and ***environment*** a two-way relationship is often distinguished, where environmental degradation enhances poverty through the loss of 'environmental services' such as the provision of clean water, while environmental degradation is at least partially related to local population densities. On the other hand, the current interest in 'environmental service rewards' suggests that maintaining critical environmental service functions can become a relevant sources of 'livelihoods' through ES payment and reward schemes. The nature of the environmental services will differ with the agro ecological zone, while the potential per capita benefit of such payments and rewards will depend on the number of people involved as beneficiaries as well as suppliers (the higher this ratio, the better the chances for effective benefit transfers…).

From the map (Fig. 1) we can distinguish a number of combinations (with examples of where they occur):

Key combinations for concerns on watershed functions:

- 1 (lowland rice) downstream of 4 (upland mosaics), as fore example in Java, west coast of Sumatra, S Sulawesi, N. Thailand, N Vietnam, Mindanao, Luzon
- 1 (lowland rice) downstream of 8 (forest**)** , as fore example in Thailand, N Sumatra, SE Sulawesi, Laos, Cambodja, Vietnam
- 1 (lowland rice) adjacent to 2 (tree crops) , remarkably scarce at this mapping scale

Key combinations for concerns on biodiversity functions:

- 2 (tree crops) next to 8 (forest), , as fore example in Jambi, E Kalimantan, Peninsular Malaysia
- 2 (tree crops) next to 4 (upland mosaics) , , as fore example in Sumatra (lowland/piedmont/mountain zone), W & E Kalimantan, Malaysia
- 4 (upland mosaics) next to 8 (forest) – the typical 'forest margin' of popular discourse: patches in Sumatra, Peninsular Malaysia, Sabah, Vietnam, Papua

As a pilot for an analysis of these issues at the Southeast Asia scale, we initiated a study for Indonesia to explore the quantitative relationships between land, people and landscape-level relationships between agro-ecosystems. We acknowledged the shortcomings of any such classification system, but aimed at deriving the 'big picture' that sets the stage for a more detailed analysis on the basis of more refined data.

Objectives

- To distinguish upland-lowland linkages between agro-ecosystems in Indonesia
- To estimate the area, population density and total number of people involved in the various landscape combinations of agro-ecosystems at district and island level in Indonesia
- To estimate the fraction of actual forest cover in the various 'agro-ecosystems' in Indonesia, in relation to the number of people involved

2. Methods and data sets

Data sets

Four digital maps were used for the analysis: a Farming Systems map, an Elevation map, a Population and the IGBP-Land cover map.

A map of the Major Farming systems in East Asia and Pacific came from an FAO and World Bank study (Dixon et al., 2001) that originally is un geo-referenced and stored in a digital raster file format (jpeg file) contained 9 farming system categories. The classes of major farming systems map are

Farming systems in East Asia and Pacific * indicates prevalence in Indonesia
1* = Lowland rice
2* = Tree crop mixed
3* = Root & tuber
4* = Upland intensive mixed
5 = Highland extensive mixed
6 = Temperate mixed
7 = Pastoral
8* = Sparse (Forest)
9 = Sparse (Arid)

A population map came from GIS data sets by Uwe Deichmann and the Center for International Earth Science Information Network (CIESIN), Columbia University and World Resources Institute. This map contains population counts and administrative unit boundaries at the district level using 1995 data of the national bureau of statistics.

A digital elevation map (in meters above sea level) was obtained from the GTOPO30 Global 30 Arc Second Elevation Data Set. This map has resolution at 30 Arc second or approximately has resolution at 1 km^2 in a pixel.

Land cover map was obtained from Global Land Cover Characterization from USGS EROS Data Center, International Geosphere Biosphere Programme (IGBP) Land cover map. This map has 1-km nominal spatial resolution, and is based on 1-km AVHRR data spanning April 1992 through March 1993. The classes of IGBP land cover map of Indonesia region are as follows:

2 = Evergreen Broadleaf Forest
8 = Woody Savannas
9 = Savannas
10 = Grasslands
12 = Croplands
13 = Urban and Built-Up
14 = Cropland/Natural Vegetation Mosaic
17 = Water Body

Methods

The procedure used for this analysis was first to create a geo-referenced farming system (agro-ecosystems) map and then to digitize the boundaries of agro-ecosystems by on-screen digitizing using GIS software. For objective 1, the subcategory of agro-ecosystems map was digitized on screen by overlaying the agro-ecosystems map with the elevation map to distinguish a number of combinations, specified below.

The digital maps in vector data structure were converted into a grid data structure with a pixel size of 1 km^2. Both the combination of agro-ecosystem map and the population map at the district level in the grid data structure were overlaid using GIS tools to obtain the areas of agro-ecosystem combinations within each district.

For objective 2, the population estimate of agro-ecosystem combinations in each District was calculated using formula (assuming proportionality between the relative population densities per farming system in the district with that in Asia as a whole) as follows:

$$Pop_{(1)} = Pop_{(tot)} \times \left[\frac{Area_{(1)} \times AvgPDens_{(1)}}{(Area_{(1)} \times AvgPDens_{(1)}) + (Area_{(2)} \times AvgPDens_{(2)} + ... + (Area_{(n)} \times AvgPDens_{(n)}} \right] \quad (1)$$

where $Pop_{(1)}$ is the population estimate of agro-ecosystem combinations in each District, $Pop_{(tot)}$ is the population year 1995 in each District, $Area_{(1)}$ is the percentage of area of agro-ecosystem combination in each District, $AvgPDens_{(1)}$ is the average of rural population density in each agro-ecosystem combination. The lowland rice agro-ecosystem has population density on average 241 persons km^{-2}, the tree crop mixed 35 persons km^{-2}, the root-tuber 6 persons km^{-2}, the intensive upland mosaics 99 persons km^{-2} and the sparsely populated forest systems 13 persons km^{-2} (Dixon et al., 2001).

For objective 3, the population density of agro-ecosystem combination in each District was calculated using formula as follows:

$$Popdens_{(1)} = \left[\frac{Pop_{(1)}}{AreaKm_{(1)}} \right] \quad (2)$$

where $Popdens_{(1)}$ is the population density of agro-ecosystem combination in each District, $Pop_{(1)}$ is the population estimate of agro-ecosystem combination in each District, $AreaKm_{(1)}$ is the total area of agro-ecosystem combination in each District.

The method in the estimation of the fraction of actual forest cover in the various agro-ecosystems was carried out using geographic information systems (GIS). The digital agro-ecosystems map in vector data structure was converted into grid data structure with a pixel size of 1 km^2. Both the agro-ecosystems map and IGBP land cover map in the grid data structure were overlaid using GIS tools to obtain the fraction of actual forest cover in the various agro-ecosystems.

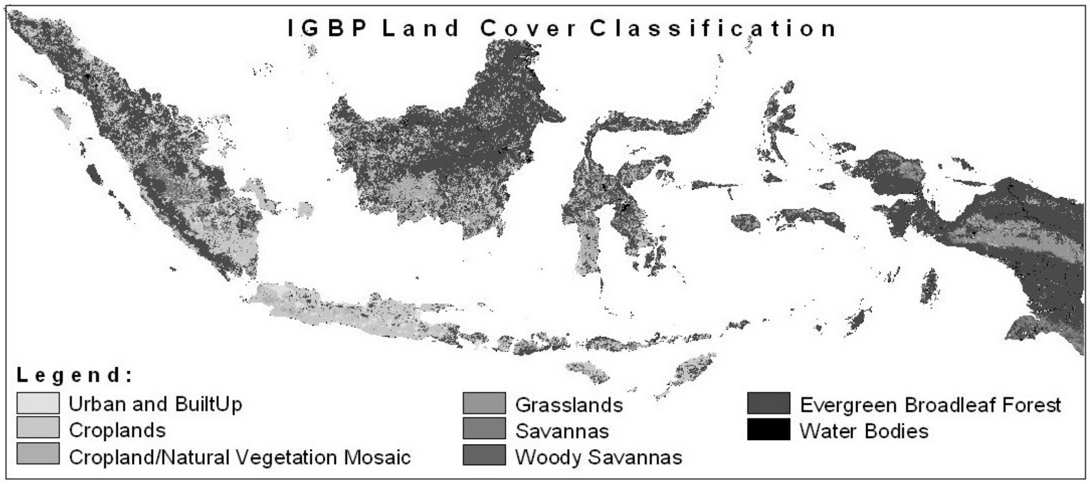

Figure 2. Land cover classification at 1-km nominal spatial resolution for Indonesia according to the IGBP legend based on imagery of the 1992-1993 period

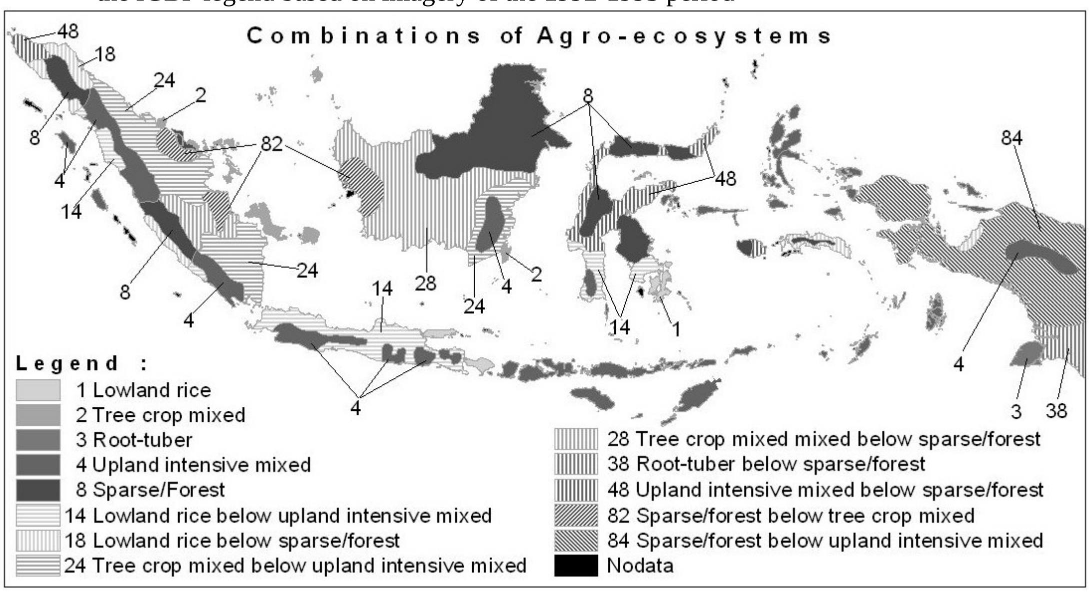

Figure 3. Agro-ecosystems of Indonesia in fig. 1 split by subcategory according to upland-lowland links

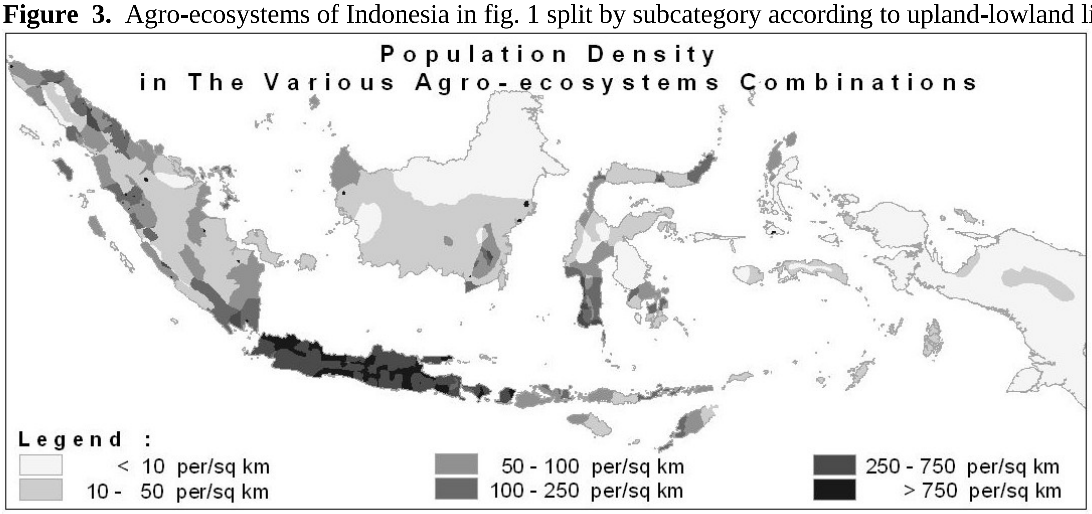

Figure 4. Human population density in Indonesia in 1995, ranging from < 10 persons km^{-2} in parts of Kalimantan, Sulawesi and Papua, to more than 750 persons km^{-2} in Java/Bali/Lombok.

3. Results

3.1 Agro-ecosystems, area and population

The result of distinguishing agro-ecosystems in a number of combinations is presented in fig. 3. Due to the rather small-scale resolution of the map, some agro-ecosystems in categories as well as in subcategories could not be delineated with sufficient accuracy, and even some of them could not be distinguished in some small islands.

Table 2 shows the estimation of population in the various combinations of agro-ecosystems at the six island groups in Indonesia resulted from the analysis. From the result of analysis shows that the most people in Java/Bali live on the 1 (lowland rice) downstream of 4 (upland mosaics), approximately 90 millions people live in that subcategories. This is also showed in Sulawesi that the most people live on the 1 (lowland rice) downstream of 4 (upland mosaics), approximately 5.8 millions people live in that subcategories. For completing result of the estimation of population in the various combinations of agro-ecosystems at the district level is showed in Appendix 1.

1 = Lowland rice/urban
2 = Tree crop mixed
3 = Root-tuber
4 = Upland intensive mixed
8 = Forest
14 = Lowland rice/urban below Upland intensive mixed
18 = Lowland rice/urban below Forest
24 = Tree crop mixed below Upland intensive mixed
28 = Tree crop mixed below Forest
38 = Root-tuber below Forest
48 = Upland intensive mixed below Forest
82 = Sparse / Forest below Tree crop mixed
84 = Sparse / Forest below Upland intensive mixed

Table 3 shows the estimation of population density in the various combinations of agro-ecosystems at the six island groups in Indonesia resulted from the analysis. The most densely populated agro-ecosystem is the lowland rice/urban system in Java /Bali downstream of the upland mosaics (combination 14), with approximately 1,084 persons km^{-2}. In Sulawesi this same combination accounts for approximately 192 person km^{-2}. In Sumatra the most densely populated subsystem is the lowland rice/urban downstream of forest**,** with approximately 147 persons km^{-2}. Complete result of the estimation of population density in the various combinations of agro-ecosystems at the district level is presented in Appendix 2.

In table 4 the fraction of the total population of Indonesia and the six island groups is categorized by the combination of agro-ecosystem: 50% of Indonesia's 1995 population lived in 'rice systems downhill of upland crop mosaics', 23% lived in these 'upland crop mosaics' and another 9% in 'tree crop systems downhill of upland crop mosaics'. Overall, 80% of Indonesia's population is thus directly linked to the potential downstream – upstream conflicts associated with the land use in upland crop mosaics.

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Table 2. Population (number of people, M) in the various combinations of agro-ecosystems

	1	14	18	2	24	28	3	38	4	48	8	82	84	Total
Jawa/Bali	6.281	90.027							21.803					118
Kalimantan			0.000	0.175	2.062	5.407			1.814		1.024	1.064		12
NTT/NTB/MAL			0.552						8.768	0.070	0.017			9
Papua			0.163				0.021	0.070	0.614		0.005		1.083	2
Sulawesi	0.600	5.799							0.993	4.828	0.880			13
Sumatra		1.567	5.550	1.424	15.270	2.320			11.474	1.244	1.245	0.525		41
Total (M)	6.881	97.393	6.265	1.598	17.332	7.727	0.021	0.070	45.466	6.142	3.170	1.589	1.083	**195**

Table 3. Population density per km^2 in the various combinations of agro-ecosystems

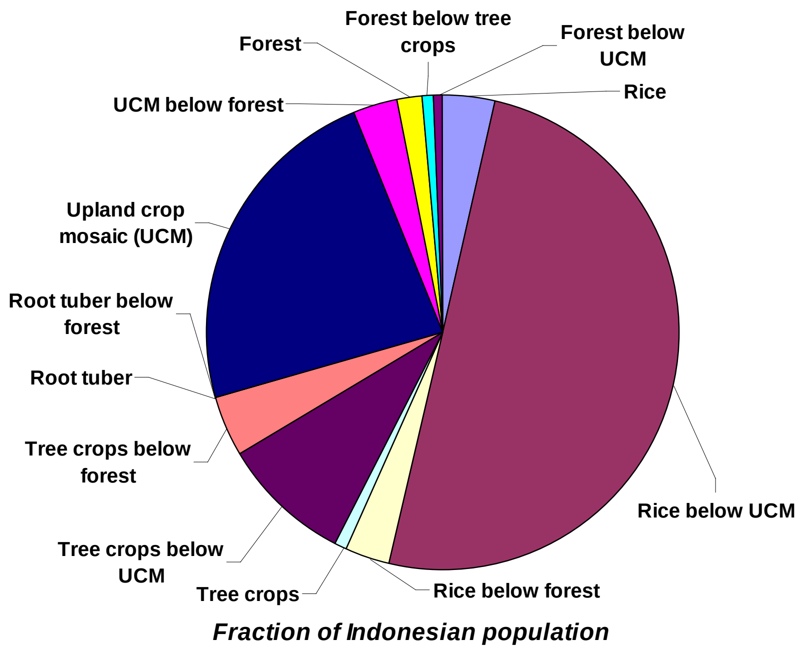
	1	14	18	2	24	28	3	38	4	48	8	82	84
Jawa/Bali	610	1,084							485				
Kalimantan				34	49	23			82	29	5	30	
NTT/NTB/MAL			40						72	16	2		
Papua			27				2	2	19		4		4
Sulawesi	73	192							104	76	12		
Sumatra		88	147	62	91	58			137	86	23	17	

Table 4. Fraction of Indonesia's population by combination of agro-ecosystem (sorted by the number of people involved)

	14	4	24	28	1	18	48	8	2	82	84	38	3	Total
Total	***0.500***	***0.233***	***0.089***	*0.040*	*0.035*	*0.032*	*0.032*	*0.016*	*0.008*	*0.008*	*0.006*	*0.000*	*0.000*	1
Jawa/Bali	0.762	0.185			0.053									
Sumatra	0.039	0.282	0.376	0.057		0.137	0.031	0.031	0.035	0.013				1
Sulawesi	0.443	0.076			0.046		0.369	0.067						1
Kalimantan		0.157	0.179	0.468			0.000	0.089	0.015	0.092				1
NTT/NTB/MAL		0.932				0.059	0.007	0.002						1
Papua		0.314				0.083		0.002			0.554	0.036	0.011	1

In figure 5 and 6 the distribution of people and land over the various subsystems is presented graphically, supporting the substantial difference in people versus area based classification of importance.

A.



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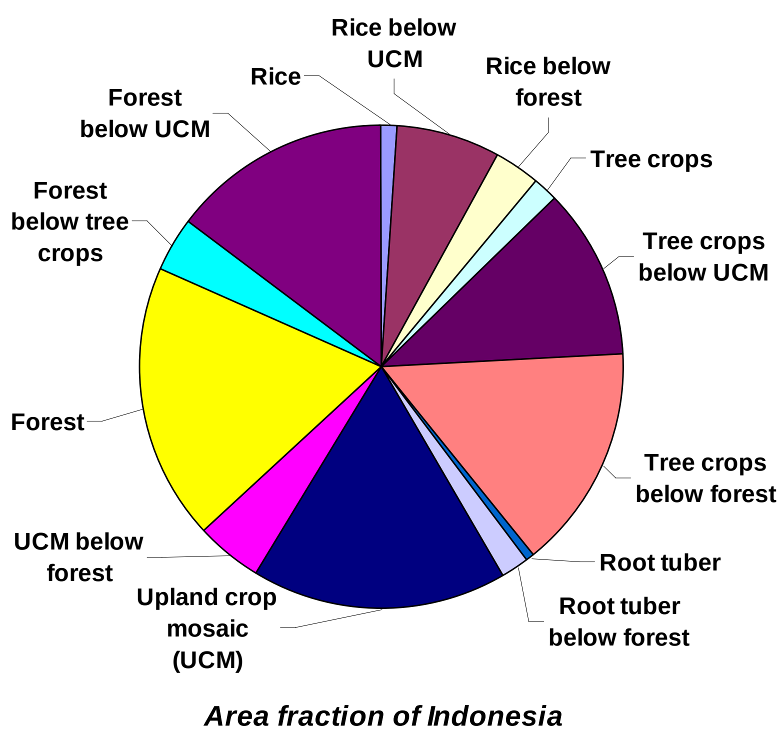

Figure 5. A. Fractions of Indonesia's 195 M people (in 1995 – 2005 estimates are 230M) living in the various agro-ecosystems, defined with respect to their upland neighbour **B.** *Idem* for area.

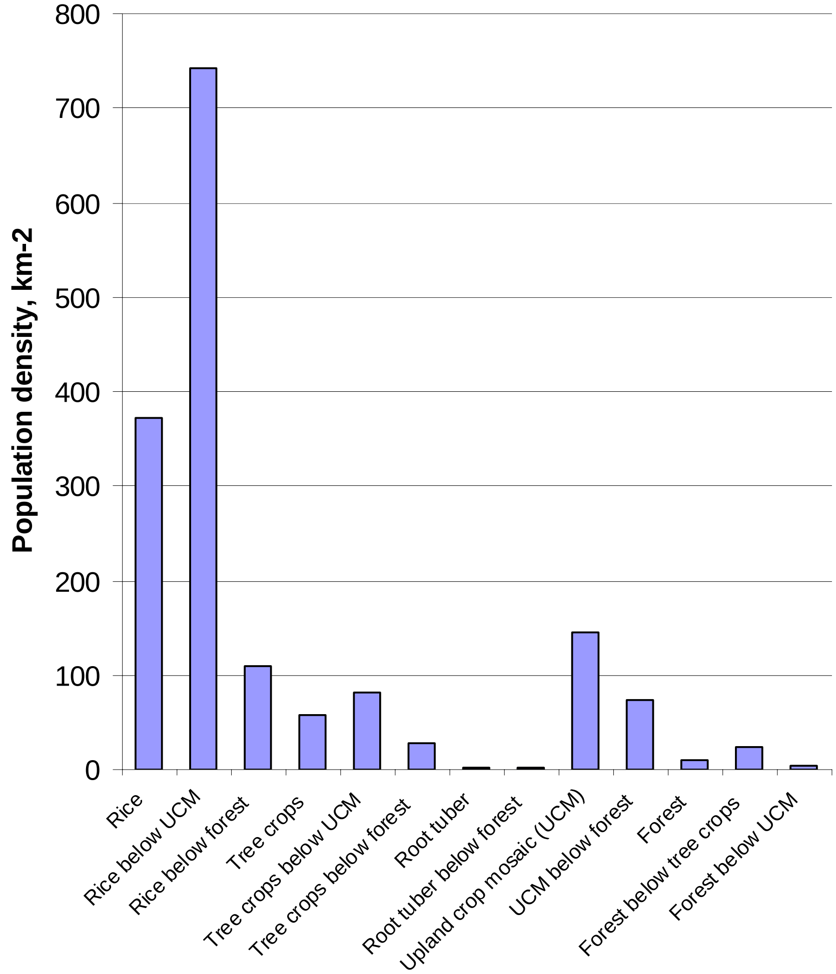

Figure 6. Average population densities in the various landscape-level combinations of agro-ecosystems

3.2 Land cover per 'agro-ecosystem'

The AVHRR land cover data at 1-km^2 grid scale classified by the IGBP legend allow us to consider the differences between islands in the same 'agro-ecosystem' category. A first impression of the data (Fig. 7 upper part) suggests that 'evergreen broad leafed forest' and 'crop land' cover dominate, with 56 and 23 percent of the total area, respectively (105 and 44 M ha, respectively). Approximately 8% of Indonesia was classified as savanna or grassland, and another 7% as mosaic of natural vegetation and cropland. The remaining 5% is classified as urban area or open water.

Substantial between the islands in forest cover (Fig. 7 lower part) suggest essentially 5 patterns, as Sulawesi and the NTB-NTT-Moluccan group correspond and can be tentatively labeled as 'eastern islands group': Java/Bali, Sumatra, Eastern islands, Kalimantan, Papua. The differences in forest cover are linked to (the logarithm of) population density, as is a tentative index of C stocks (Fig. 8).

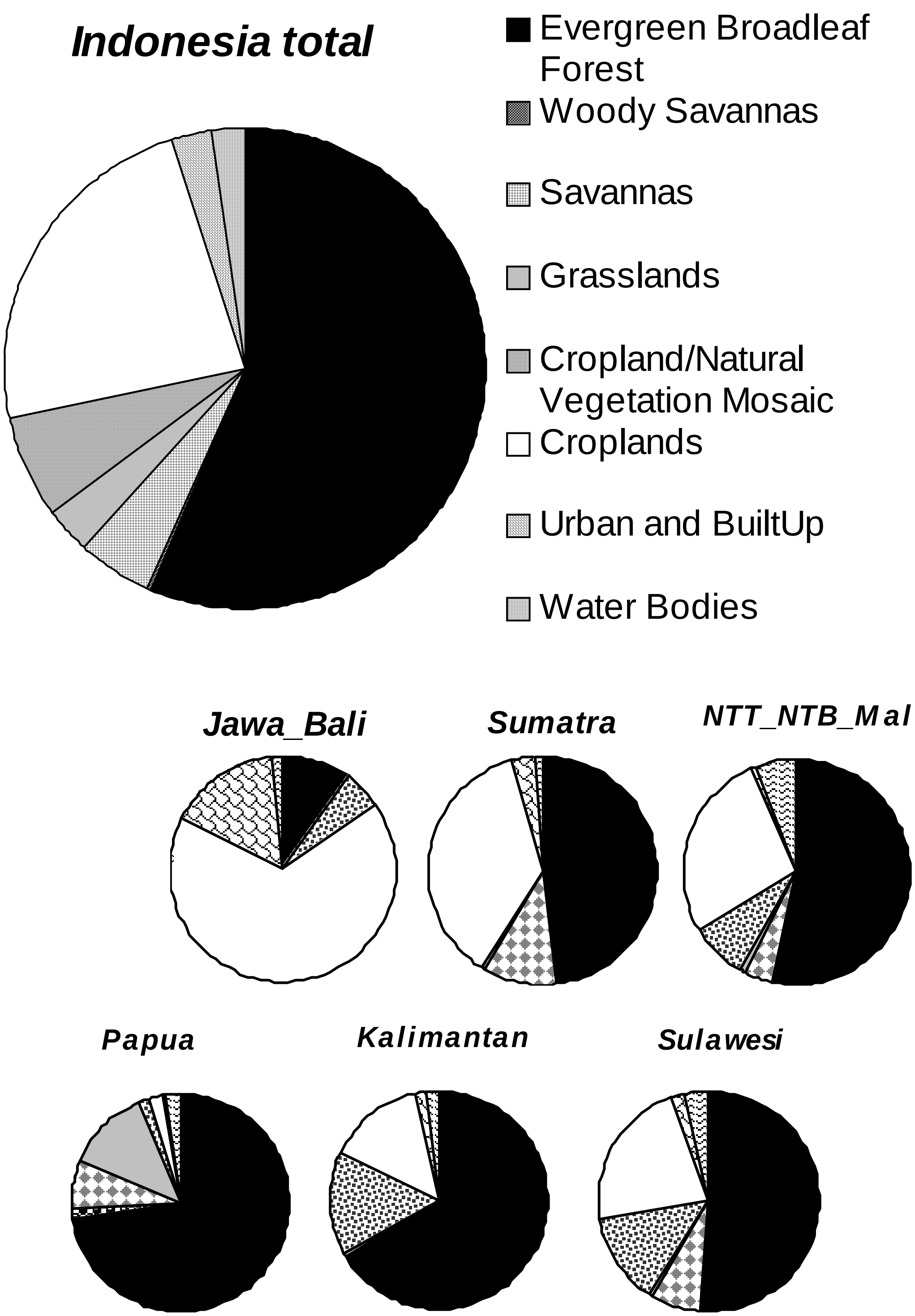

Figure 7. Land cover classification for Indonesia's islands (excluding the seas) according to the IGBP legend in fig. 2. (source: Global Land Cover Characterization from USGS EROS Data Center, International Geosphere Biosphere Programme (IGBP) Land cover map; based on imagery of the 1992-1993 period.

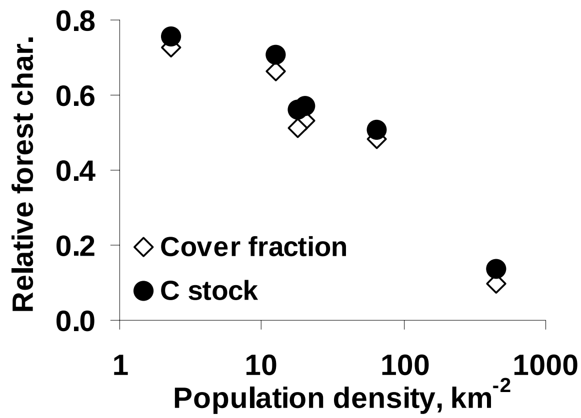

Figure 8. Relationship between forest cover (IGBP classification) and population density (NB logarithmic scale); a tentative relative C-stock value is added, assuming above-ground C stocks of 200, 100, 30, 10, 50, 5, 10 and 0 Mg ha^{-1}, for forest, woody savanna, savanna, grassland, crop/veg. Mosaic, cropland, urban areas and water bodies, respectively)

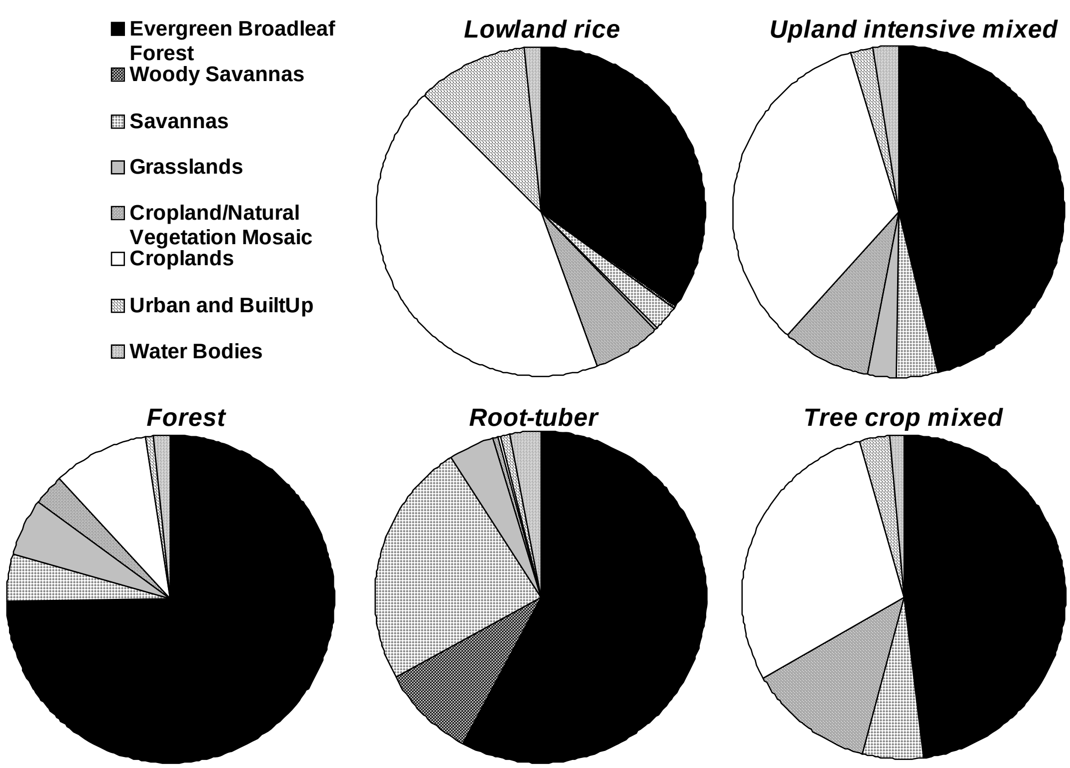

Figure 9. Classification at km^2 pixel scale according top the IGBP legend for the five agro-ecosystems recognized in Indonesia based on imagery of the 1992-1993 period

Overlaying this classification with the 'agro-ecosystems' classification by Dixon *et al.* (2001) (Fig. 9), suggests that at least one of these two classification systems is less straight-forward than the names suggest: the differences in recorded land cover between the 'agro-ecosystems' are much smaller than one might have expected. More than a third of the pixels in the lowland rice 'agro-ecosystem' are recorded as 'Evergreen Broadleaf Forest' at pixel scale, while only 75% of the 'Forest agro-ecosystem' belongs to this class. Analyzing the data per island group (Table 7) suggests that the overall difference in land cover between the island groups are reflected in the differences within each of the 'agro-ecosystem' categories.

For most of the 'agro-ecosystems' the degree of forest cover as well as the estimated relative C-stock is linked to the island-level average population density (Fig. 10). The upland crop mosaic for all islands other than Java appears to have an approximately equal degree of forest cover, and this 'agro-ecosystem' type may thus be used as substitute for a land cover indication. But the forest cover in the 'lowland rice agro-ecosystem' is clearly related to overall population density.

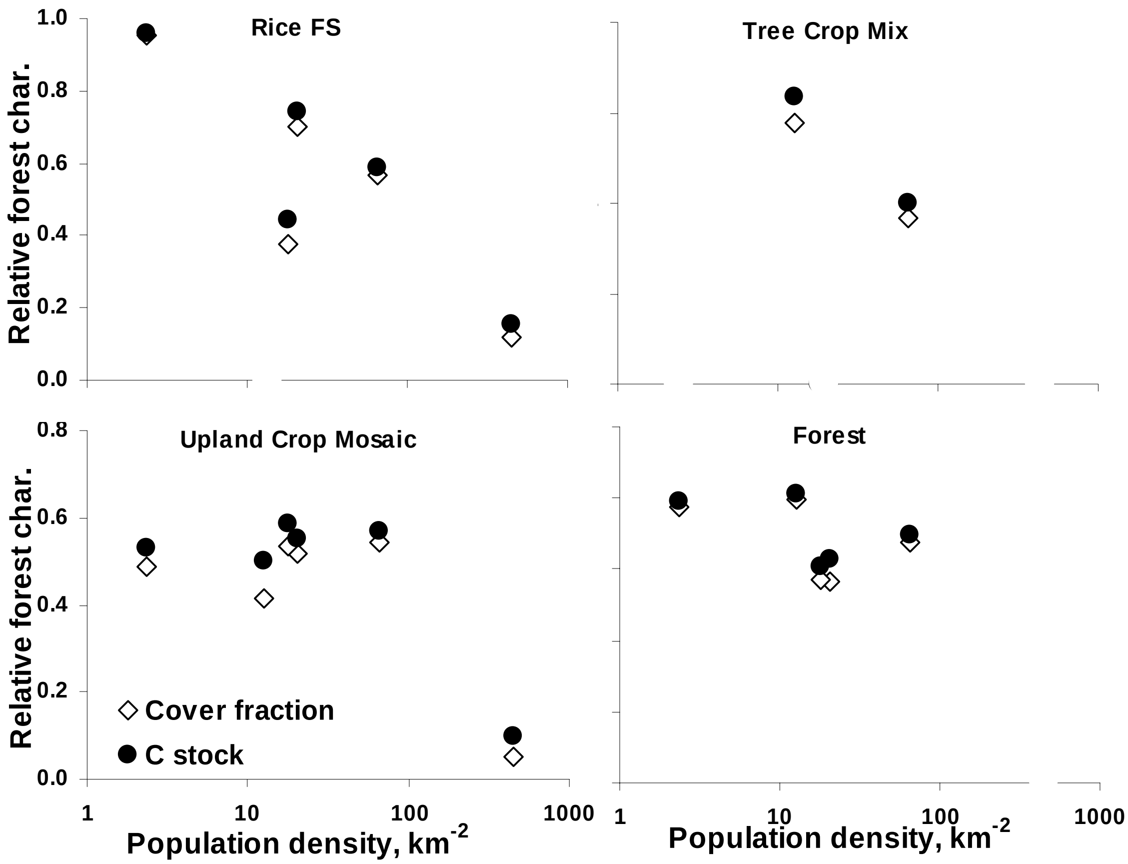

Figure 10 Relationship between population density at the level of island (group)s and the relative forest cover and C-stocks for the four major 'agro-ecosystems' of Dixon et al. (2001) (compare fig. 8)

Table 5. Land cover (IGBP legend) per 'agro-ecosystem' for six island groups in Indonesia

Lowland rice/urban	**Evergreen Broadleaf Forest**	**Woody Savannas**	**Savannas**	**Grasslands**	**Cropland/ Natural Veg. Mosaic**	**Croplands**	**Urban and BuiltUp**	**Water Bodies**
Indonesia_average	0.349	0.000	0.027	0.002	0.065	0.432	0.107	0.018
Jawa_Bali	0.116		0.001		0.042	0.625	0.199	0.016
Sumatra	0.567		0.060			0.329	0.038	0.006
NTT_NTB_Mal	0.703		0.088	0.022	0.089	0.052	0.005	0.041
Kalimantan	0.000		0.000					
Sulawesi	0.377		0.023	0.001	0.218	0.310	0.036	0.034
Papua	0.954	0.001	0.015	0.006	0.001	0.016	0.000	0.007
Tree crop mixed								
Indonesia_average	0.482	0.000	0.060	0.002	0.124	0.289	0.030	0.013
Jawa_Bali								
Sumatra	0.365		0.131		0.003	0.453	0.042	0.007
NTT_NTB_Mal								
Kalimantan	0.576		0.001	0.003	0.223	0.156	0.021	0.019
Sulawesi								
Papua								
Root-tuber								
Indonesia_average	0.577	0.092	0.239	0.045	0.006	0.003	0.008	0.031
Papua	0.577	0.092	0.239	0.045	0.006	0.003	0.008	0.031
Upland intensive mixed								
Indonesia_average	0.461	0.001	0.040	0.028	0.086	0.336	0.021	0.026
Jawa_Bali	0.053		0.001		0.093	0.768	0.078	0.007
Sumatra	0.544	0.000	0.068		0.014	0.347	0.013	0.013
NTT_NTB_Mal	0.517	0.003	0.023	0.002	0.081	0.318	0.008	0.049
Kalimantan	0.416		0.012	0.001	0.301	0.239	0.030	0.001
Sulawesi	0.535		0.068	0.012	0.145	0.192	0.022	0.027
Papua	0.486	0.002	0.053	0.318	0.063	0.041	0.014	0.022
Forest								
Indonesia_average	0.747	0.001	0.047	0.055	0.030	0.096	0.008	0.017
Jawa_Bali								
Sumatra	0.675		0.095			0.200	0.027	0.003
NTT_NTB_Mal	0.563	0.002	0.228	0.057	0.096	0.047		0.007
Kalimantan	0.796		0.006		0.052	0.126	0.007	0.013
Sulawesi	0.570		0.103	0.012	0.071	0.206	0.011	0.028
Papua	0.776	0.002	0.047	0.120	0.011	0.020	0.003	0.021

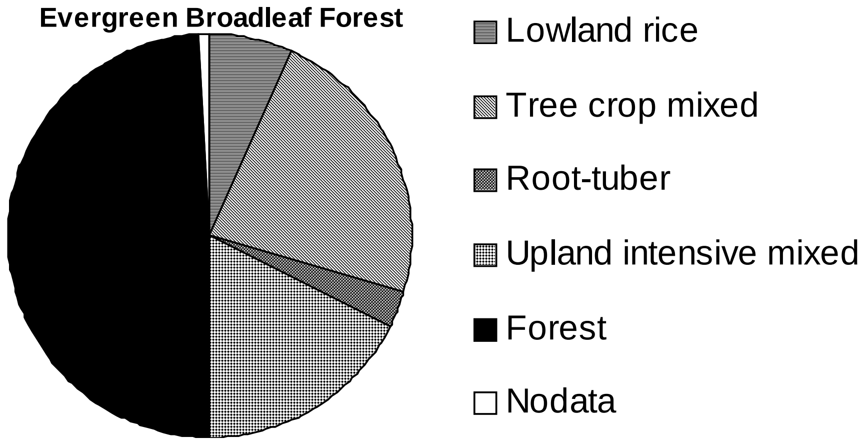

Figure 11. Distribution of 'evergreen broadleaf forest' pixels in Indonesia over the 5 'agro-ecosystems' of Dixon et al. (2001)

A further comparison with some relevance in current debates is the relative distribution of the 'evergreen broadleaf forest' pixels in Indonesia over the 5 'agro-ecosystems' (Fig. 11). Only half of the remaining forest vegetation is found in the 'extensive forest agro-ecosystem' of Dixon et al. (2001) and nearly a quarter in the 'tree crops mixed' system and nearly a fifth in the 'upland intensive mixed cropping systems'.

4. Discussion

The analyses presented here are clearly constrained by the type and quality of the underlying data sets. The analysis has pointed to a number of 'inconsistencies' that may help to (more) carefully interpret the data of the 'agro-ecosystems' classification by Dixon *et al.* (2001): the variation between the islands in land cover characteristics of the various systems is at least as large as the differences between the systems. Some of the IGBP land cover seem to be suspect as well – especially the high values for 'evergreen broad-leaf forest' in what are known to be 'rice agro-ecosystems' may in part be based on errors of interpretation.

The overriding conclusion may be, however, that a forest – agriculture dichotomy (as conventionally hinted at in discussions of '*deforestation*') has little relevance at the scale studied here. The major part of Indonesia's land area is 'in between': there is substantial tree cover within the agricultural zone (both the lowland rice and the upland crop mosaic system), while there is on average 25% non-forest in what are considered to be the last stretches of continuous forest systems with low population densities. Overall, this may give the impression of Indonesia as a country of agroforestry…

Combining these maps, acknowledging their weaknesses, with available population data (not without trouble themselves), suggests that a stunning 80% of Indonesia's population is directly linked to the areas of 'upland crop mosaics': 25% of the people live there, 50 + 9% live in lowland rice or tree crop systems downstream of these uplands. The sheer number of people involved suggests on one hand that improvements of local environmental conditions in the uplands will have local benefits for large number of people (and according to the Dixon analysis this system is the most prone to poverty). At the other hand, it suggests that the ratio of downstream to upland stakeholders will limit the total per capita benefits in the uplands of any transfer mechanism: in the absence of transaction costs, the per capita benefits in the uplands will only be 3 to 4 times the per capita costs in the lowlands. As the majority of people in the lowland and urban systems is only just above the poverty line, transfers to upland communities linked to broad concerns over watershed functions can be beneficial for large numbers, but at a modest *per capita* value.

References

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