Landscape-level evaluation of carbon and biodiversity in the tropical rain forests of Deramakot Forest Reserve, Sabah, Malaysia

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Abstract Site-based measurements of biomass (and carbon) are the accurate method but costly in time, budget and manpower. The application of remotely sensed data may achieve our goals in a large area in the shortest time. We investigated how remotely-sensed data could be applied to estimate above-ground biomass in the production forests of Deramakot Forest Reserve (reduced-impact logging site) and Tangkulap Forest Reserve (conventional logging site as of the analysis). We converted the tree census data from the research plots, which had been established by 2003, into above-ground biomass with the use of standard allometric equations. Altogether, we employed the data from 51 plots. We accurately measured the four corners of each plot with a GPS (Global Positioning System) equipment. We added three plots devoid of any tree cover as reference points. Subsequently, the location of each plot was determined on the LANDSAT ETM data taken in 2002. Among various combinations of LANDSAT bands, the normalized index of band 4 and 5 (called NDSI) demonstrated the highest correlation with the biomass values estimated from the ground data. However, the biomass estimates from this correlation model saturated at biomass 500 ton/ha or greater. This causes a considerable underestimate of biomass in high stock forests. We therefore numerically corrected the biomass values, where reflectance signals were saturated, using the canopy heterogeneity as guidance; in this algorithm we added proportionately greater correction values, with increasing canopy homogeneity, to the biomass values estimated from the correlation model. Application of this method to Deramakot and Tangkulap yielded the mean biomass density of 347 ton/ha in Deramakot, and 293 ton/ha in Tangkulap. These values were comparable to the mean values obtained from the ground survey, suggesting the adequacy of our methods. The difference of the two mean values (54 ton/ha) can be attributed to the difference in the logging methods. The cautious use of our methods can legitimately evaluate the above-ground biomass (and carbon) in a large area in the mixed dipterocarp tropical rain forests of this region.

Abstract for policy-makers

We investigated how effectively remotely-sensed satellite data could be used in the sustainable management of production forests in Deramakot Forest Reserve. We developed a new method to estimate above-ground biomass (equivalent to volume stock) in a large area using Landsat satellite data. The method and applications are described in this paper. With the use of this method, the mean biomass value was estimated to be 347 ton/ha in entire Deramakot (all compartments combined), and 293 ton/ha in Tangkulap. These values were comparable to the mean values obtained from our ground surveys, suggesting the adequacy of our method. The greater mean value by 54 ton/ha in Deramakot reflects the reduced impacts by RIL (reduced-impact logging) system. The use of our method can legitimately evaluate the above-ground biomass (and carbon) of the mixed dipterocarp tropical rain forests of this region on a landscape level, and therefore may be applicable to other Forest Management Units of similar forest types. Moreover, our method can rapidly evaluate canopy heterogeneity (which we consider as an index of the overall forest health) in a large area. As canopy

heterogeneity can become a surrogate for the abundance/richness of certain organisms (trees and mammals for instance), our method has a great potential to be used in the auditing system of forest certification to evaluate biodiversity in addition to the usefulness in stock and biomass estimation. As more forests are certified, timber prices are expected to fall. A new scheme to qualitatively and quantitatively ordinate certified forests is needed in order to differentiate better-managed forests from the rest. The amount of remaining carbon and biodiversity in logged-over forests are the two indicators to ordinate the forests and our method can evaluate these two indicators in a large area.

Keywords biodiversity, biomass, canopy heterogeneity, carbon, satellite data, tropical rain forests, reduced-impact logging

Introduction

Tropical rain forests are the reservoir of carbon. A web of organisms is maintained through carbon (energy) and mineral flows in a given rain forest ecosystem. Carbon (energy) and mineral flows include a grazing chain that starts from live plant parts (biomass) and a detritus chain that starts from dead plant parts (necromass). In either case, plants provide dependent organisms with carbon as food resource. Dependent organisms, on the other hand, maintain plant populations through pollination and mineral recycling. Biodiversity and carbon are thus intimately related to each other. It is logical to infer that biodiversity should maintain the long-term stability of tropical rain forests. This intuitive notion, however, is not well substantiated in the filed, particularly in tropical rain forests. One reason why we focus on the linkage between carbon and biodiversity lies in this academic challenge.

Secondly, carbon and biodiversity are the two major issues in the contemporary forestry (Scherr *et al.* 2004). Forests are expected to sequester carbon as biomass and thus to contribute to the reduction of green house gases. There are markets for carbon trading and, in this sense, forests have a new economic value. At the same time, forests are expected to contribute to the conservation of biodiversity. It is needless to say that the maintenance of natural forests can achieve both carbon sequestration and biodiversity conservation. However, the natural forests are fairly limited in extension in the modern landscapes. In the tropics, logged-over forests predominate the landscape and natural rain forests are confined to protected areas. In this context, logged-over forests are the key area to control the carbon budget and biodiversity conservation. Tropical foresters are expected to achieve the synergy between carbon sequestration and biodiversity conservation in production (largely logged-over) forests. This is the second reason why we are concerned with carbon and biodiversity.

The ultimate goals of the collaborative Malaysia-Japan project in Deramakot Forest Reserve, Sabah, Malaysia, are to establish techniques how to maintain carbon and biodiversity in production forests. Logging obviously reduces the amount of the carbon left in production forests by extracting timber. However, reduced-impact logging (RIL) can maintain a relatively high carbon stock while maximizing yields (either monetary or volumetric yield in a longer term). In this paper, we first describe the methods to evaluate carbon and biodiversity in a large area using satellite data. We, then, demonstrate how effectively RIL in Deramakot can maintain above-ground carbon at a landscape level by comparing with the carbon stock in the surrounding Tangkulap Forest Reserve where conventional logging has been applied. Site-based measurements of biomass (and carbon) are the accurate method but costly in time, budget and manpower. The application of remotely sensed data may achieve our goals in a broad area in the shortest time. This report describes some new algorithms to apply remotely sensed data in biomass/carbon estimate, and subsequently some conceptual frameworks to incorporate carbon and biodiversity into sustainable forest management.

Methods

Biomass estimation

New algorithms to estimate above-ground biomass were developed by Nakazno *et al.* (in prep. in Japanese), in which the authors coincide with those of the present paper. Herewith, we briefly describe the methods. We used ground-based data from 43 plots located in Deramakot and two plots in Tangkulap. The imagery of the study area is shown in Fig. 1. Those plots consisted of ten 0.2 ha quadrats (20 x 100m or 40 x 50m) and thirty-five 0.16 ha quadrats (20 x 80m). Tree censuses were conducted in these plots for those trees more than 10cm diameter at breast height (dbh) by the FRC team or the Japanese team. All trees more than 10cm dbh were identified to species with their dbh values measured. We converted dbh values into above-ground biomass values using the following standard allometric equations (Brown 1997):

$$Wt = \exp(-2.314 + 2.53 \times \ln(dbh)) \qquad (1)$$

Here, Wt (kg) is above-ground biomass inclusive of leaves and branches, and dbh (cm) is diameter at breast height.

In order to identify the locality of each plot, we measured the longitude and latitude of the four corners of each plot at the resolution of 0.001 minute using a global positioning system (GPS) (Magellan Meridian Platinum, USA). When we judged that the readings of GPS had some errors due to the interference from a thick canopy, we corrected the position readings based on the land survey data on the ground.

In addition to forest plots, we added two plots in grassland and one plot in bare land (each 0.09ha of 30x30 m) in order to get reference points for low-biomass signals. The positions of each plot were determined as above.

We used Landsat ETM data taken on May 28, 2002, for the analysis of remotely sensed data. Landsat ETM consists of eight multi-spectral sensors and has 30 x 30m resolutions. This means that one pixel on the data corresponds to the ground area of 30 x 30 m. Tropical rain forests are often covered by thick clouds and reflectance data captured by Landsat ETM thus cannot correctly reflect the canopy conditions. The data that we used also demonstrated cloud effects, but we judged that none of our plots are under the clouds.

In the vegetation analysis of the satellite data, normalized vegetation index (NDVI) is often used. This index is based on the nature of green plants on which chlorophyll absorbs red radiation (R), and reflects near-infrared radiation (IR). The difference of the strength of absorption of R and reflectance of IR is normalized by the total radiation of R and IR as follows:

$$NDVI = (IR - R) / (IR + R) \qquad (2)$$

In the Landsat ETM data, R corresponds to band 3 and IR to band 4. This index is useful for the ecosystems of low vegetation coverage. However, NDVI can quickly saturate above a certain threshold value of vegetation coverage. In order to resolve this problem, we used another index called "NDSI" as follows (Nakazono *et al.* in prep.):

$$NDSI = (band4 - band5) / (band4 + band5) \qquad (3)$$

NDSI is a normalized index of the reflectance from bands 4 and 5 of Landsat ETM. We compared the calculated NDSI indexes of the research plots and the biomass values estimated from the ground data using the allometric equations. NDSI indexes increased curvi-linearly with increasing above-ground biomass values estimated based on the allometric equations among 37 research plots (Fig. 2). The slope of NDSI values for initial biomass values was steep and NDSI quickly saturated at greater biomass values. We fitted biomass values to NDSI based on the following equation:

$$B = 1040.5 \times (NDSI)^{0.5} - 78.885 \qquad (4)$$

where B is above-ground biomass (ton/ha).

We predicted that the biomass values based on the reflectance data of Landsat ETM could be overestimated than those values based on the allometric equations. This overestimation can occur because the forests of a re-growth phase during a secondary succession are characterized by disproportionately greater foliar biomass (and thus greater leaf area index) than wood biomass leading to a disproportionately greater reflectance signal of biomass, i.e. overestimation of total above-ground biomass. In order to correct this overestimation effect, we identified the forests where the overestimation was likely to occur. Once again, such forests are at a re-growth phase and those forests are often characterized by heterogeneous canopy conditions because timber extractions cause patchy canopy openness, which is visible throughout the re-growth phase. On the other hand, the natural forests or the logged-over forests after reduced-impact logging may have more homogeneous canopies. We, therefore, categorized forests into several canopy-heterogeneity conditions following the methods of Nagatani *et al.* (2000). Firstly, we removed the pixels affected by clouds, open-water and bare soils, and then categorized the remaining pixels into 256 classes based on an unsupervised classification method. Subsequently, we calculated the number of classes included within a varying mesh size (n x n pixels from any one point; n was always odd number; one pixel corresponds to 30 x 30 m). We defined the number of classes in a n x n mesh as F(n), which reflected the canopy heterogeneity condition, i.e. greater the F(n) is, more heterogeneous the canopy is. We changed n from 3 to 15 and examined the changing pattern of F(n) in the following three training areas: Kuamut Forest Reserve where no sign of logging was visible; Deramakot Forest Reserve where timbers were mildly extracted by reduced-impact logging operation; and Tangkulap Forest Reserve where timbers were heavily extracted by conventional logging methods. We placed grids of 3000 x 3000 m in Tangkulap Forest Reserve and Deramakot Forest Reserve, and grids of 2000 x 2000 m in Kuamut Forest Reserve as demonstrated in Fig. 3.

When we changed n from 3 to 15 at each of the grid points in the three training areas, F(n) values changed rapidly as depicted in Fig. 4 (two sites only are shown). Notably, F(n) increased from Kuamut to Deramakot to Tangkulap at any n value, suggesting that canopy was more heterogeneous with increasing logging intensity. As explained earlier, biomass based on the equation (4) may be overestimated in heavily logged forests. We, therefore, categorized forests based on F(n) where n was set to 9 (pixels) and corrected biomass values as follows:

When $F(9) \geqq 25$, the forest was considered heavily logged; B(corrected)=B - 50.

When $F(9) < 25$, and $(NDSI)^{0.5} < 0.4$; B(corrected) = B.

When $(NDSI)^{0.5} \geqq 0.4$, B values were saturated. In this case, we assumed that lower the F(n) value was, greater the B(corrected) value was. Thus, when $F(9) \leqq 11$, B(corrected) = B + 200; when F(9) = 12, B(corrected) = B + 150; when $F(9) \leqq 14$, B(corrected) = B + 100; when F(9) = 15, B(corrected) = B + 50.

Subsequently, at each intersect of the grids in the three training areas, we calculated biomass value based on the equation (4) (see below) and corrected by F(n) values as explained in the above. The mean value of the estimated biomass in each training area was then compared with actually measured biomass on the ground to investigate the accuracy of our methods.

Analysis of canopy heterogeneity and biodiversity

As has been stated, the mode of logging operation may result in different canopy heterogeneity. In the above analysis, canopy heterogeneity is expressed by the number of vegetation classes per unit area (i.e. F(n) where n ranges from 3 to 15 pixels corresponding to 90 x 90 to 450 x 450 m mesh). F(n) value will increase as unit area increases because F(n) is a cumulative value. There is another aspect in canopy heterogeneity, that is the deviation from a mean. The same number of vegetation classes may not occur if the area of analysis is spatially shifted in the forest where canopy heterogeneity is great. On the other hand, a similar (or the same) number of vegetation classes always occurs regardless of the locality if the forest is homogeneous. This spatial repetition can be demonstrated by the coefficient of variation (CV) of F(n). We, therefore, calculated the CV of F(n) with varying pixel sizes in Deramakot and Tangkulap. We hypothesized that CV of F(n) is greater at small unit area in Deramakot due to natural gaps and/or small-scale operations of reduced-impact logging, but thereafter CV decreases with increasing unit area. On the other hand, CV of F(n) can be greater at any unit area in

Tangkulap than in Deramakot, and will increase with increasing unit area in Tangkulap due to the large-scale operation of heavy logging.

Results

The estimates of above-ground biomass at the intersections of the grids in Deramakot and Tangkulap are indicated in Fig. 5. With increasing area (i.e. increasing pixel sizes) at the intersections, mean values of biomass are merged to a constant value in each site (Fig. 5). The mean value eventually became 346 ± 40 ton/ha in the Deramakot training area, and 273 ±25 ton/ha in the Tangkulap training area. These values are closely comparable to the actually measured values by Seino *et al.* (see this volume); this correspondence suggests that our method is robust enough to evaluate above-ground biomass.

We applied the equation 4 with the corrections described above to all compartments of Deramakot Forest Reserve to estimate above-ground biomass of trees. Results are shown in Appendix 1. Above-ground biomass density (ton/ha) by compartment of Deramakot Forest Reserve ranges from 285 (Compartment 134) to 480 (Compartment 110) with the mean value of 347. The total above-ground biomass in entire Deramakot Forest Reserve is estimated to be 19,038,000 tons as of May 28, 2002, the date of the satellite data. By contrast, the mean value of above-ground biomass densities at the intersects of 3000 m grids in Tangkulap Forest Reserve is 273 (ton/ha).

CV of F(n) values, i.e. an index of canopy heterogeneity, peaked in an area equivalent of 3 x 3 pixels (90 x 90 m) in Deramakot and then decreased with increasing area (Fig. 6); this suggests that a mean patch size of the canopy is nearly 90 x 90 m. Contrary, CV increased monotonously with increasing area up to 15 x 15 pixels in Tangkulap, indicating that canopy condition at the scale of 450 x 450 m varied from place to place.

Discussion and application

Biomass estimation on a landscape level

We suggest that the method described here can adequately estimate the above-ground biomass of the mixed dipterocarp tropical rain forests of Deramakot and the adjacent areas. The difference of biomass density by 54 ton/ha (347-293=54) between the two forest reserves is striking. It is very obvious that this difference is caused by the difference in the logging methods. We conclude that reduced-impact logging (RIL) is effective to reserve above-ground biomass by 54 ton/ha on average. We estimate that the net additive effect of the implementation of reduced-impact logging for the total area of Deramakot is 2,978,034 tons of biomass (54 ton/ha x 55,149 ha). This translates to the net addition of 1,340,115 tons of carbon assuming the concentration of carbon is 45% in biomass.

We applied our method to the entire region of Deramakot and Tangkulap, and mapped the distribution of biomass density at the resolution of 30 x 30 m. The color map in Fig. 7 contrasts Deramakot with the surrounding regions in terms of biomass density. It is noteworthy that this map can be used as a base map for forestry operation planning.

Implications for biodiversity

Above-ground biomass is significantly correlated with the number of families per 0.2 ha ($r^2 = 0.55$, $P = 0.0138$; Seino *et al.* unpublished). This correlation does not imply that richness is functionally linked to biomass and that family-rich forests are more stocked. It simply means that more severely logged forests are impoverished in the number of families of canopy trees. Thus, this correlation is applicable only to the logged-over forests in this region. Based on this assumption, we extrapolated this correlation to the entire region of Deramakot and Tangkulap. The number of families of canopy trees was estimated from the above-ground biomass. Results are indicated in

Fig. 8 for the years 1985 and 2002. The family richness has drastically changed between the two years. A large tract of Tangkulap and the adjacent areas were converted, and lost family richness, while the Deramakot region reserves family richness reasonably well. A large area in the Deramakot region demonstrates the increase of family richness obviously due to the recovery of biomass. The summary of the comparison is demonstrated in the bar graph of Fig. 9, which depicts the number of pixels categorized in each family-richness class (number of families per 0.2ha). During the seven years from 1985 to 2002, the frequency of richest classes (≧28 families/0.2ha) greatly decreased, while the frequency of modestly rich classes (22 – 27 families/0.2ha) increased. During this period, reduced-impact logging was introduced to Deramakot. Therefore, the results imply that reduced-impact logging system can preserve modestly rich assemblages of canopy-tree families, and sustain highest richness in places. We are in the midst of analyzing the patterns of the richness of other organisms (flying insects, soil fauna and mammals) with the anticipation that some groups of organisms (either abundance or richness) may correlate with above-ground biomass. If so, we can correlate the richness or abundance of such organisms with satellite reflectance data, and extrapolate landscape-level patterns to a large region.

Implications for the sustainable management of the tropical rain forests

Our analysis demonstrated that reduced-impact logging (RIL) was effective to sustain carbon in above-ground biomass, and modestly rich assemblages of canopy species. As such, our analysis is applicable to understand landscape-level patterns and processes with some assumptions. With this analytical ability, remotely sensed data and the algorithms described here can be effectively utilized in the sustainable management of tropical rain forests. Particularly, it is useful for a rapid evaluation of volume stock, designing logging roads/feeder roads/skit trails, post-harvest planning, auditing purposes for forest certification, wildlife conservation, spotting encroachment, and designing a cohabitation scheme with traditional villages. We, however, have to be cautious because our algorithms are applicable only to the logged-over mixed dipterocarp tropical rain forests with biomass ranges similar to ours. They may not be applicable to the other types of tropical rain forest such as montane forests or lowland forests of different canopy composition because reflectance signals will be different in such forests.

One of the key issues in the sustainable forest management is the incorporation of biodiversity. There may be at least two ways to apply remote sensing in the use of biodiversity for sustainable forest management. Currently, biodiversity is one of the criteria for sustainable management, and any indicators for biodiversity criteria are under rigorous search (see other papers in this volume). Furthermore, such indicators must be easily measured without expert knowledge and practically used in an auditing system yet with solid scientific bases. In this regard, remote sensing may be a good tool for spatially elucidating such indicators. As we have demonstrated, if the richness of tree families were valuable indicators for the biodiversity criteria, then we can make use of our algorithms to demonstrate the patterns of tree families in production forests. A prerequisite for such application is that the richness of tree families has an indicator value for overall biodiversity and ecosystem health. Secondly, biodiversity may be more positively incorporated into the management of production forests in such a way to add economic values to produced timbers. We here suggest a novel approach in the application of remote sensing in the use of biodiversity for adding such economic values.

The foundation of the market mechanisms why forest certification and reduced-impact logging work is primarily the ethic value added to certified forests. Conscious consumers recognize green premium values in certified forests and drive away the products from uncertified forests. If biodiversity can add further values for the certification system, such a management system can become a strong economic incentive for foresters and other related stakeholders. We suggest that economic values be added to timbers as follows:

Additional economic value = net carbon reserve (additionality) by RIL * unit carbon price in the market + net biodiversity additionality by RIL * market price for biodiversity (or price for ecosystem services that biodiversity can bring about) (5)

In this concept, the most challenging task is to determine the market price for biodiversity; this cannot be readily determined for obvious reasons. On the other hand, net biodiversity increase (additionality) by RIL can be spatially estimated by remote sensing with cautious assumptions.

As has been demonstrated, different modes of logging operations resulted in different canopy conditions. Reduced-impact logging (RIL) has created small canopy patches in the scale of 90 x 90 m, more-or-less close to the canopy conditions of pristine forests where natural canopy gaps only are visible. By contrast, conventional heavy logging created highly heterogeneous canopy conditions as large as 450 x 450 m or larger. Homogeneous canopy conditions are known to maintain the abundance of certain mammal groups (Johns 1997). According to our algorithms, the CV (coefficient of variation) of F(n) can effectively demonstrate the canopy homogeneity. As the inverse of CV is proportional to canopy homogeneity, the equation (5) can be rewritten as:

Additional economic value = net carbon sequestration by RIL * unit carbon price + 1/CV * market price for biodiversity (6)

Once again, at this moment, we are far from actually using the equation (6) because the environmental-economics to determine market price for biodiversity are still premature. However, the equation (6) can be readily applied to the auditing system of forest certification. Moreover, this concept can be used to differentiate better-managed forests from the rest even among certified forests. As the number of certified forests increases drastically, we need to invent another system to ordinate certified forests. It is logical to assume that the price of timbers will eventually fall if the number of certified forests increases. For this purpose, our algorithms and the equation (6) are quite powerful to add another green-premium value to well-managed forests with rich biodiversity of the organisms, provided that such organisms are sensitive to canopy openness.

One of the remaining research tasks is to substantiate how effectively canopy homogeneity reflects the abundance and diversity of various organisms. In the next phase of the collaborative Malaysia-Japan project, we need to focus on this research question. Secondly, we suggest that our algorithms be actually applied in the auditing of forest certification in the near future.

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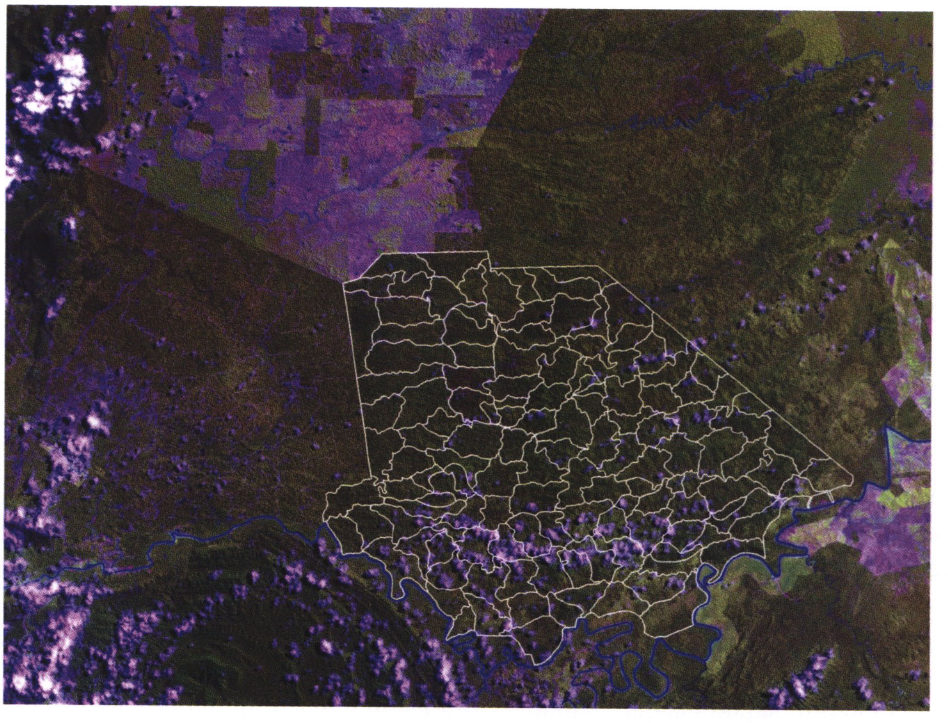

Figure 1. The aerial view of Deramakot Forest Reserve, Tangkulap Forest Reserve and the adjacent areas. The view is shown with Landsat ETM data as of May 28, 2002.

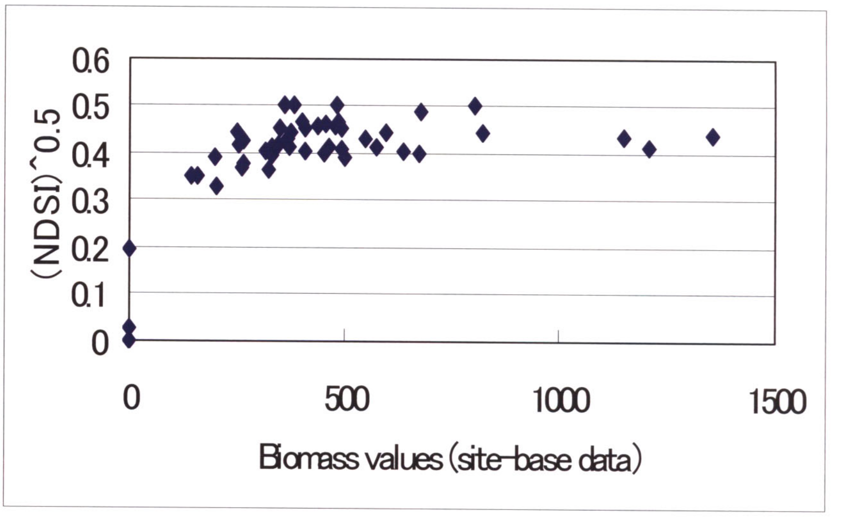

Figure 2. The relationships between NDSI and measured above-ground biomass among ground research plots.

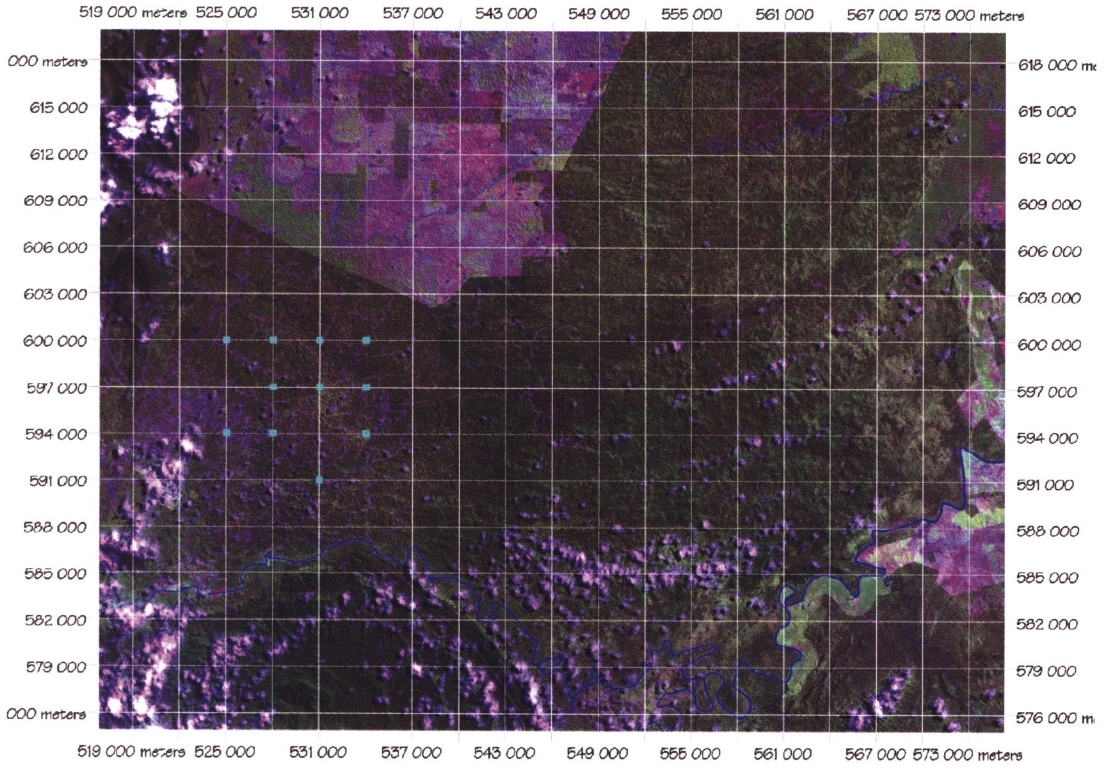

Figure 3. An example of the grids placed in the three training areas.

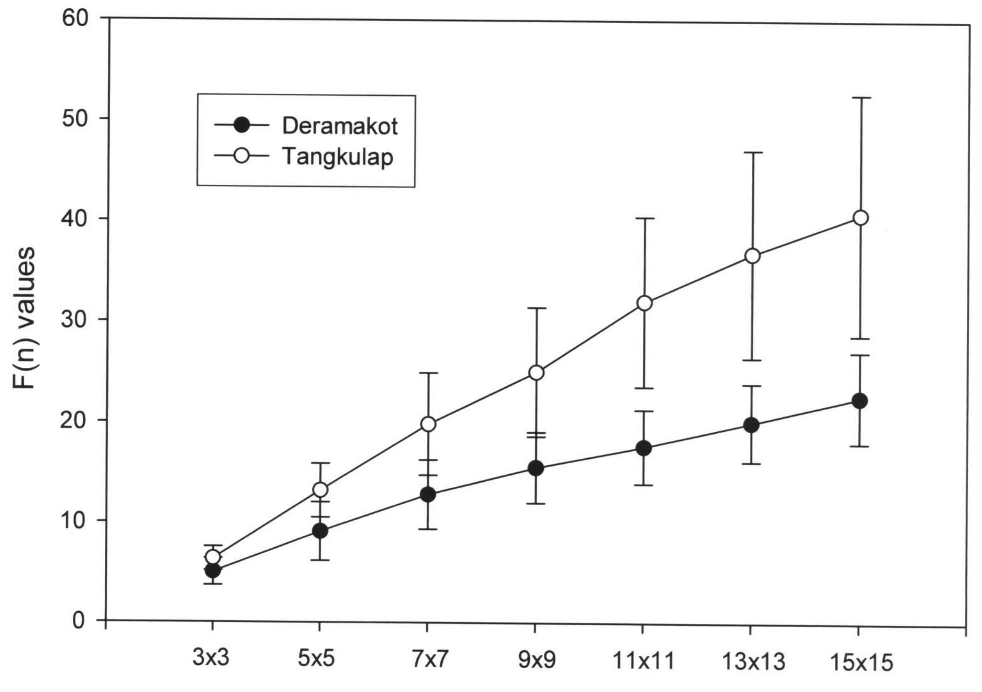

Figure 4. The number of classified vegetation classes per unit area, and increasing patterns with increasing unit area. The number of vegetation classes is expressed as F(n); see text for the details.

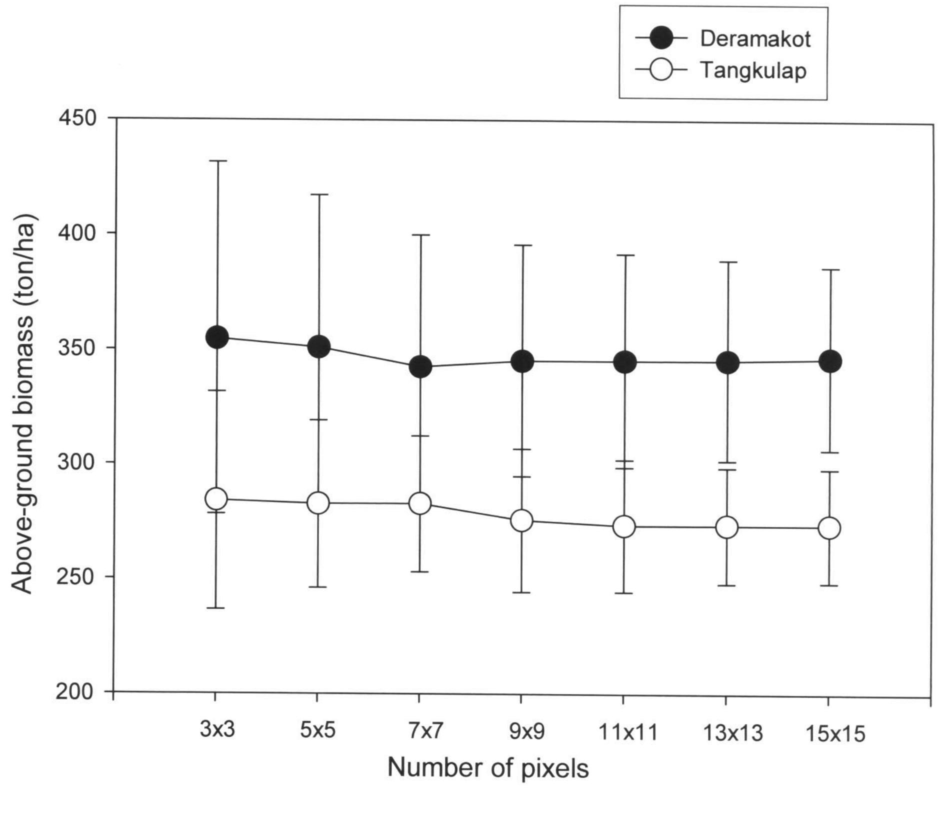

Figure 5. Mean ± SD of estimated above-ground biomass densities (ton/ha) based on NDSI with numerical corrections. Biomass densities are evaluated with increasing unit area at the intersections of the grids (see Fig. 3).

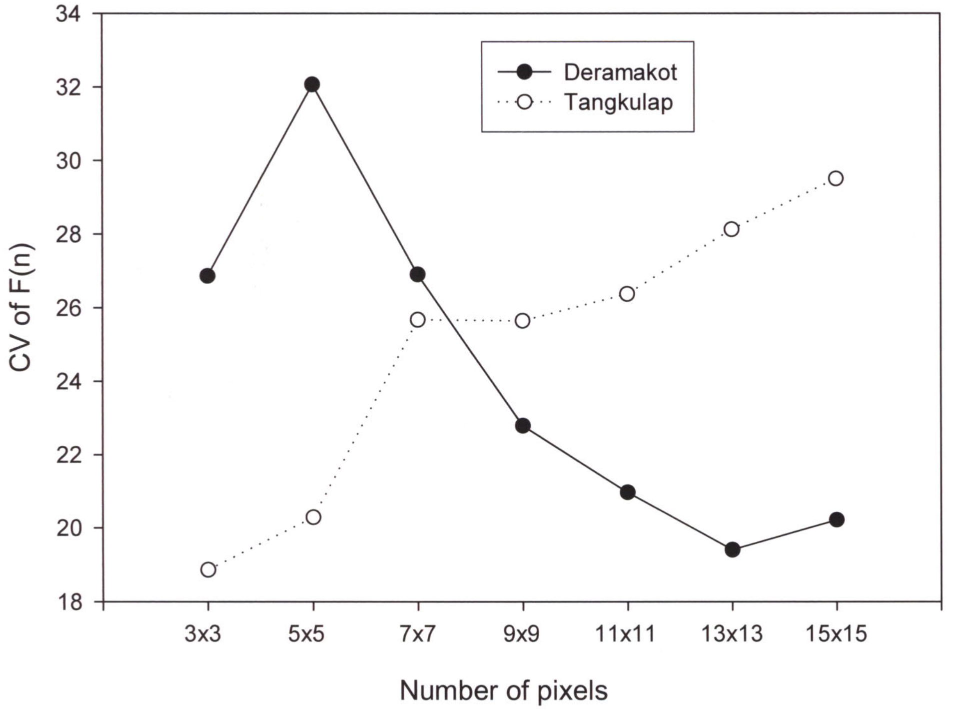

Figure 6. Coefficient of variations of F(n) with increasing unit area in Deramakot and Tangkulap.

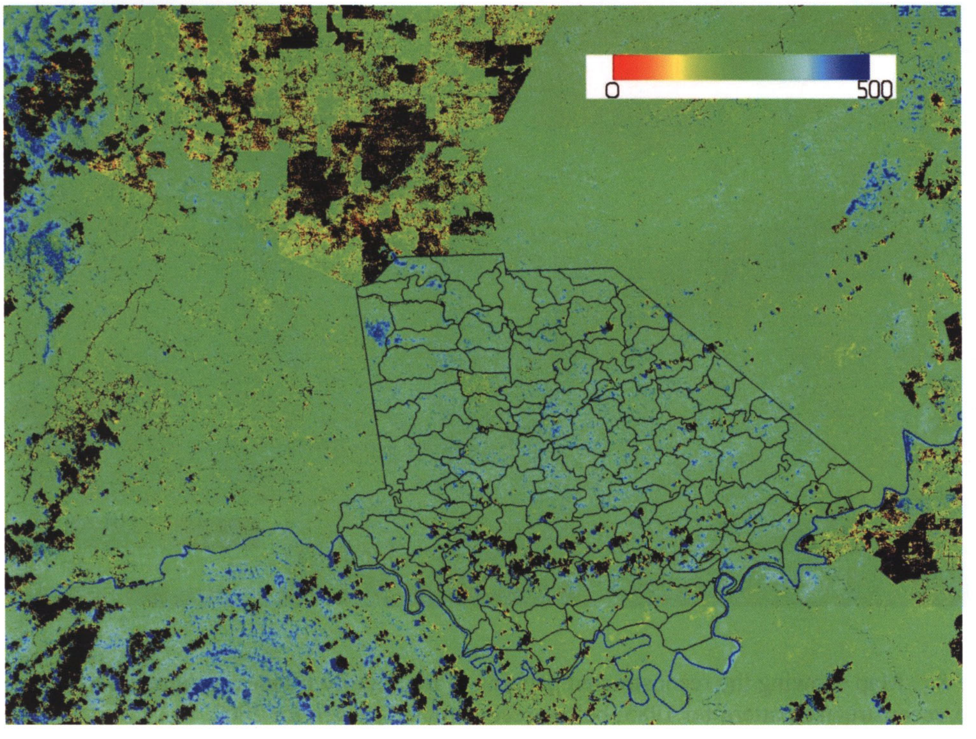

Figure 7. Map showing the spatial patterns of biomass densities (ton/ha) at the resolution of 30 x 30 m.

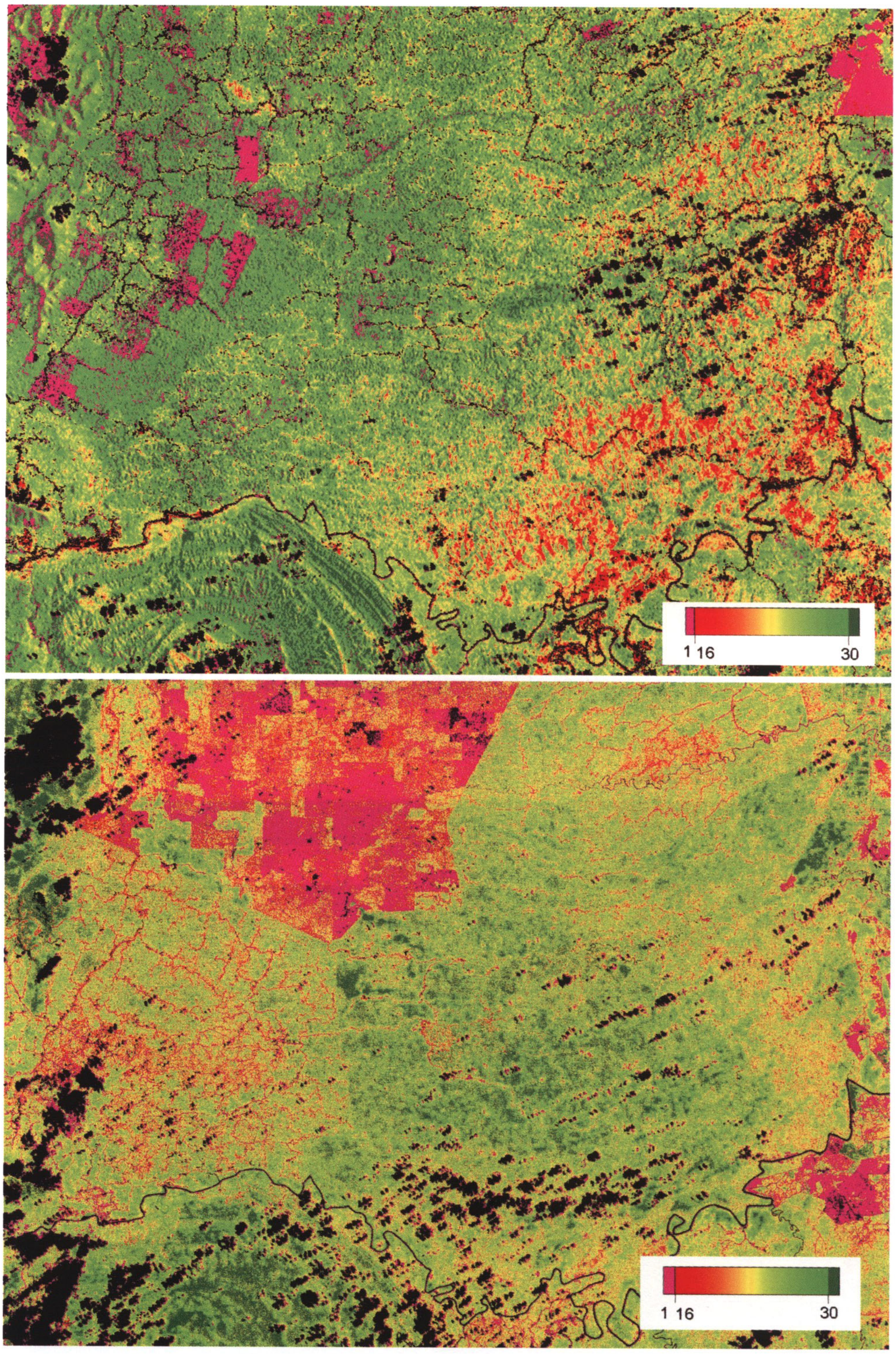

Figure 8. Map showing the reconstructed patterns of tree-family richness (number per 0.2 ha). Above, reconstructed pattern for 1985; below, reconstructed pattern for 2002.

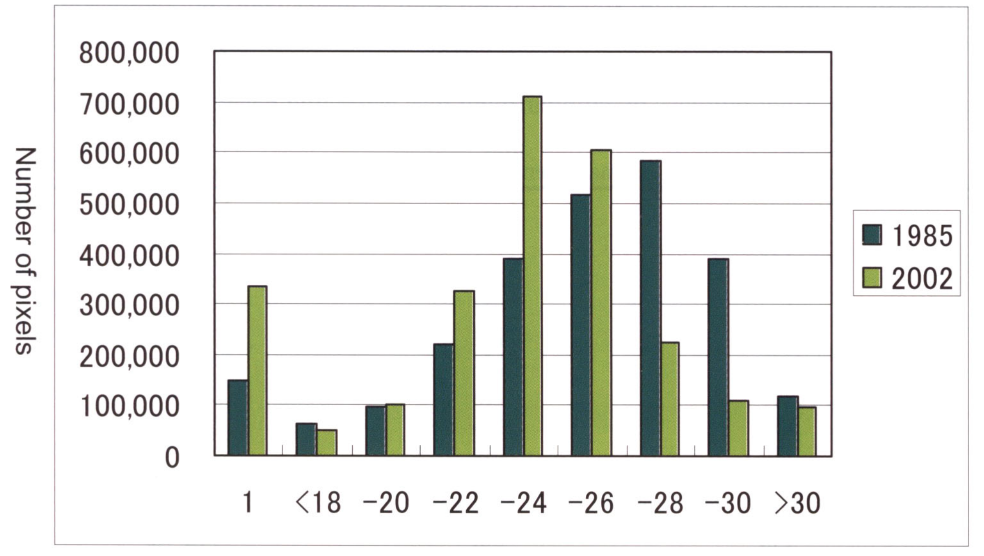

Figure 9. The number of pixels fallen in each tree-family richness class in the training area (the area shown in Fig. 7) for 1985 and 2002. Shifts due to land-use changes are shown.

Appendix 1. Estimated biomass density (ton/ha) and total biomass (ton) by compartment in Deramakot Forest Reserve. Biomass density was estimated according to two methods: (1) Pixels covered by clouds were removed, (2) Pixels covered by clouds were removed and further corrections were added according to Nakazono *et al.* (in prep.). Total biomass by compartment was estimated based on the method (2).

Compartment No.	Biomass density(ton/ha)(1)	Biomass density(ton/ha)(2)	Area of compartment (ha)	Total biomass (ton)
1	324	324	555.21	179918
2	333	327	496.93	162314
3	329	327	604.39	197725
4	327	327	309.03	100954
5	349	342	359.21	122689
6	357	351	567.06	199179
7	347	346	321.03	111017
8	336	336	329.19	110455
9	320	309	306.53	94670
10	338	338	467.51	157962
11	339	310	670.30	207625
12	358	356	774.28	275311
13	406	316	299.58	94681
14	350	327	607.39	198623
15	315	315	577.28	182097
16	342	333	402.06	133959
17	360	360	192.44	69200
18	352	346	552.30	190994
19	383	343	307.55	105513
20	355	355	547.22	194094
21	340	337	300.59	101295
22	350	349	383.90	133811
23	408	334	424.45	141707
24	329	324	336.52	108996
25	325	320	736.31	235480
26	387	355	450.62	160078
27	347	342	904.09	309283
28	347	347	368.86	127971
29	353	349	439.56	153338
30	387	346	474.34	163980
31	366	340	315.61	107203
32	354	354	168.14	59597
33	348	346	701.59	242503
34	292	286	431.54	123560
35	350	350	312.11	109234
35	384	345	328.48	113451
37	354	344	412.15	141612
38	412	371	93.37	34667
39	393	362	494.58	178915
40	363	361	766.95	276893
41	353	347	377.18	130930
42	448	411	96.58	39657
43	383	382	384.38	146644
44	326	304	432.93	131620
45	377	356	234.60	83541
46	362	362	254.73	92322
47	351	342	452.83	154763
48	345	345	117.83	40707
49	388	385	587.92	226418
50	413	341	497.28	169596
51	395	335	102.27	34215
52	378	354	488.40	172649
53	385	358	264.76	94815
54	381	361	175.77	63540
56	365	351	290.62	101906
57	341	339	704.14	238772

Compartment No.	Biomass density(ton/ha)(1)	Biomass density(ton/ha)(2)	Area of compartment (ha)	Total biomass (ton)
58	379	363	500.69	181723
59	405	357	392.36	140179
60	394	360	661.78	238132
61	357	348	338.96	118126
62	375	361	629.89	227322
63	374	367	328.44	120663
64	341	341	557.02	190032
65	396	360	414.53	149248
65	459	396	317.26	125678
66	390	361	516.87	186734
67	339	338	451.75	152560
68	384	383	503.29	192534
69	380	365	333.97	121846
70	359	343	503.67	172938
71	350	350	441.06	154216
72	362	347	498.29	172716
73	405	380	398.75	151695
74	371	353	584.56	206086
75	314	303	469.98	142264
76	371	359	500.07	179526
77	424	364	192.17	70046
78	348	347	151.21	52425
79	427	347	178.56	62013
80	409	362	231.45	83817
81	363	357	94.16	33634
82	371	310	266.03	82578
83	381	378	382.66	144536
84	364	342	548.81	187705
85	348	348	171.72	59727
86	354	354	581.59	205792
87	341	336	276.52	92894
88	343	341	315.77	107559
89	372	339	590.01	199782
90	381	353	413.94	145955
91	414	337	413.40	139238
92	463	364	163.01	59356
93	432	314	345.95	108580
94	438	343	133.03	45692
95	363	321	124.74	40083
96	350	316	343.12	108520
97	391	354	448.61	158682
98	397	326	354.82	115528
99	412	328	552.27	181380
100	433	356	466.99	166030
101	367	352	460.64	162300
102	447	325	340.56	110686
103	520	371	551.33	204603
104	424	315	319.27	100648
105	481	332	480.54	159568
106	358	356	362.44	129175
107	473	374	346.39	129465
108	399	338	206.39	69803
109	529	381	131.91	50311
110	724	480	360.64	173215
111	595	397	482.36	191427
112	396	317	370.01	117409
113	342	342	292.29	99932
113	597	422	218.33	92050
114	663	466	513.71	239455
115	458	336	449.81	151054
116	390	370	499.36	184856

Compartment No.	Biomass density(ton/ha)(1)	Biomass density(ton/ha)(2)	Area of compartment (ha)	Total biomass (ton)
117	461	360	638.06	229713
118	523	401	244.19	97959
119	441	339	539.00	182554
120	352	339	336.85	114234
121	508	361	354.36	127893
122	563	388	443.75	172138
123	500	358	477.28	170634
124	422	319	568.57	181557
125	310	303	873.66	264971
126	397	323	577.28	186292
127	366	326	374.64	122305
128	331	300	503.77	151325
129	352	339	334.56	113333
130	352	308	291.10	89753
131	325	287	454.33	130250
132	366	306	440.94	135070
134	353	285	674.21	192173
	Mean 388	Mean 347	Total 55148.77	Total 19038530