Approach to Estimation of Mangrove Resources using Remote Sensing and a Trial in Okinawa

Kazuhiro Sato
College of Agriculture
University of the Ryukyus
Okinawa 903-01 JAPAN

Takashi Hoshi
Science Information Processing Center
University of Tsukuba
Ibaraki 305 JAPAN

Abstract

Remote sensing data has been used to examine and classify the mixture state of a mangrove forest in Okinawa, so it is possible with some degree of accuracy to classify a mangrove forest composed of two species into at least three mixture states. Thus, the area of each classified item can be easily obtained. In this paper, the construction of estimation methods of forest resources using remote sensing was discussed. This paper also presents a description of a practical trial of one method which combines the area of each classified mangrove forest through the processing of remote sensing data and the quantity of growing stock per ha. of some sample plots through the ground survey. In addition, the direction in which to look for a new index was examined. This new index would be expected to relate the conditions of mangrove resources.

1. Introduction

For a long period in the past, forest aerial photogrammetry has been increasing the quantity and quality of information with the advance from monochrome to color and then to infrared color photography, but it appears that its development has about reached its limit. In the present state of research on remote sensing in forestry, it seems that many trials are performed to join this accumulation with the new technology and develop practical applications of the results in this field. Until now there has been almost no examination of the use of remote sensing in the narrow sense for estimating forest resources and because of that, forest aerial photogrammetry has been made practicable for such a purpose. Furthermore, low resolution has been a problem in remote sensing. In countries or regions like Japan where intensive forestry has been developed, the relations among tree height, diameter at breast height and stem volume have been determined for each locality, species or forest type and productivity class; moreover, such information as the data on forest age and stand density has been collected extensively. Therefore, aerial photogrammetry has functioned effectively for the estimation of growing stock. If the utility of remote sensing for the estimation of forest resources were proved, it would certainly have a great significance for many regions where information on local forests has not yet been collected. Additionally, in the case of mangrove forests it would have a greater effectiveness for these main reasons: it is very difficult to survey in a forest because of complicated aerial roots and deep muddy sediments; survey activity is restricted by tides; the transportation and sanitation conditions are poor.

From such a view point as the above, the construction of estimation methods of mangrove resources by remote sensing was described and a trial for the estimation of resources of a mangrove forest in Okinawa, and the fundamental examinations for the realization of more automatic processing was presented. The mangrove forest in Okinawa is small in scale and consists of few species, but the forest does includes the Yaeyamahirugi(*Rhizophora stylosa*), Ohirugi(*Bruguiera gymnorrhiza*), Hirugidamashi (*Avicennia marina*) and Mayapushiki(*Sonneratia alba*), which come under the same genuses as the major genuses of mangroves in the world. Therefore, examinations of a typical Okinawan mangrove forest should also provide applicable fundamental knowledge for other mangrove forests in the world.

2. Estimation of Forest Resources

(1) Construction of Estimation Methods

We examined the construction of estimation methods for forest resources using remote sensing by comparing three estimation methods: forest aerial photogrammetry, forest inventory based on field works and remote sensing in the narrow sense. The new index assumed in that paper[4] has not yet been found. In this paragraph, the way of thinking is briefly described.

At present, aerial photography is used widely and the aerial volume table has been put to practical use. In addition, studies on the estimation of stand structure, which is necessary for forest management planning, are being pushed forward. Here, the "double sampling method " is adopted, utilizing the relationships among stand factors determined through ground survey and photo-interpretation. It has been made clear that such mutual relationships involve factors, which express tree size such as diameter at breast height (D), diameter for mean cross-sectional area (DM), tree height (H), crown area (CA), crown diameter (CD), and volume (V). Relations among these factors have been expressed with equations of slightly different types for each field in forestry.

Satellite remote sensing is suitable for the analysis of large target areas but there is a difficulty in estimating resources concerning its roughness which depends on the pixel size. In this paper, the estimation of forest resources using airborne remote sensing was described. It is not possible in all likelihood to estimate forest resources only through remote

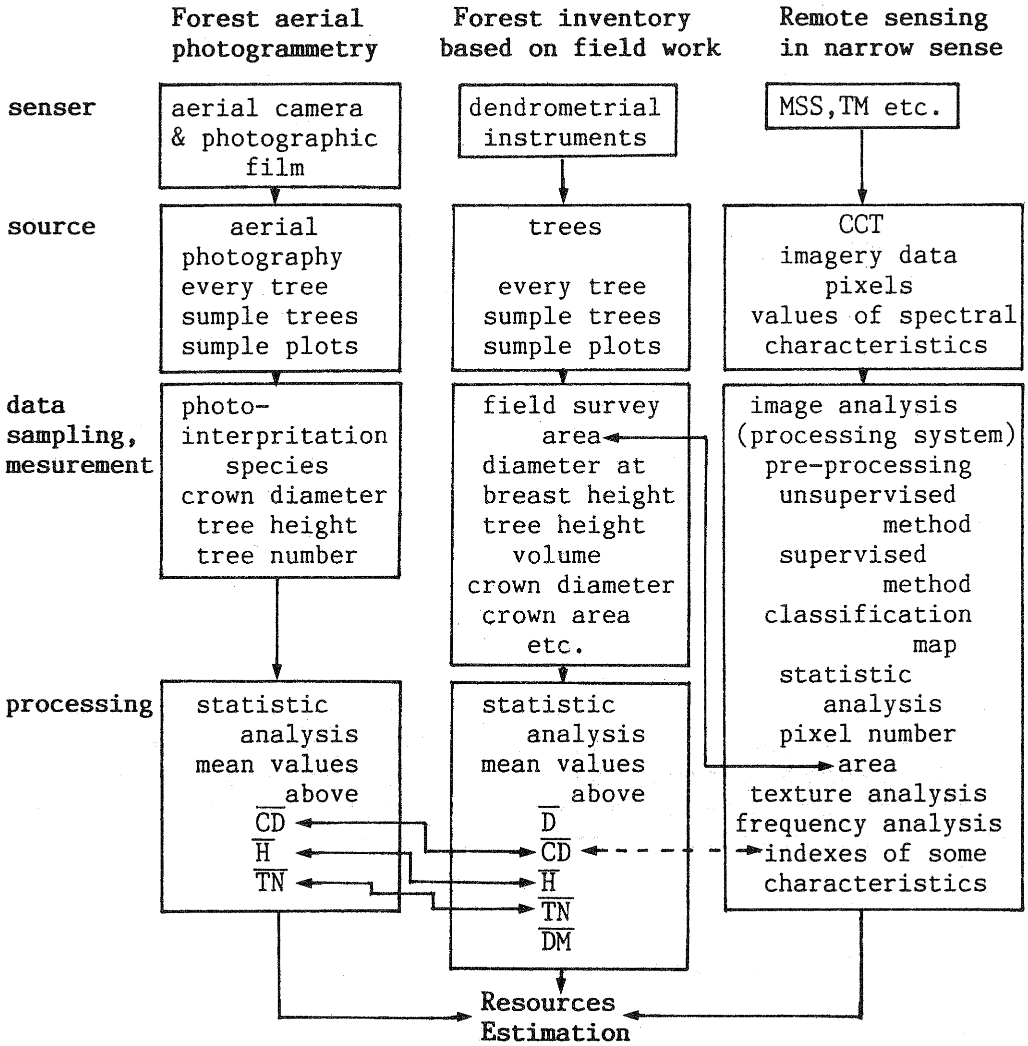


Fig. 1 Comparison of three estimation methods for forest resources and relationships among them

sensing without any information about an object forest obtained through ground survey. But, when there is some information on the regional forest and a minimum of information on the stand concerned, then a rough estimate is probably possible. Fig. 1 shows the construction of such an estimation.

First, the forest type classification and extraction of distribution are performed with an appropriate method such as the maximum likelihood method, the linear discriminate function and the Euclidean distance method. Actually, several such studies[2,4] on forest type classification have already been reported. Once this is done, the area of classified stands and the whole forest can be calculated easily. If the growing stock per unit area for an average sub-stand is known for each classified stand, the stand stock of each and the total stock of the whole forest can also be easily obtained as the product of each stand stock and stand area, and the sum of each product. The stock per unit area for an average sub-stand is not the same as the mean stock per unit area for a stand in the strict sense. If the mean stock per unit area is a known quantity, the problem of estimation using remote sensing cannot arise. The method above is described here assuming that the stock of the sample plot can be obtained after appropriately determining an average sample plot in the stand concerned. As there are many actual results on the way to the determination of sample plots in forest inventory, there should not be any difficulty in putting some methods into practice if classification using remote sensing is properly carried out. A trial which will be discussed below comes under this case. When even a rough estimation without a ground survey is needed, it will be possible to estimate forest resources by quoting from the results of forest inventorial surveys in the neighboring or surrounding forests or using regional rough standards of growing stock per unit area. The rough estimation should be premised on the combination with forest type classification using remote sensing.

Next, the following is a discussion of the mode of determining an average growing stock per unit area for each stand using remote sensing. Although practical examination has been scarcely made of this problem, remote sensing will gain a wider application if it is made possible. As mentioned above, a variety of investigations have been made in forestry on the relationships involving tree factors of individual trees with each other and stand factors. In a report[5] on the stand structure of a mangrove forest in Okinawa, the relationships among such tree factors as D, H, CA and V were shown as follows:

$$V = a\,(D^2)^b,$$

$$V = a\,(D^2 H)^b,$$

$$1/V = 1/(a \cdot CA^c) + 1/b,$$

$$CA = a \cdot e^{bD},$$

$$1/H = 1/(a \cdot D^h) + 1/b,$$

where : a, b, c, h = coefficients.

Among the factors above to be connected with V, probably only CA can be handled through remote sensing. It is considered that the state of crown size distribution and crown density of each stand must relate to the fineness and uniformity of imagery texture. Therefore, if an index related to those characteristics for texture can be found in appropriate ways such as various kinds of texture analysis and frequency analysis, some possibilities become apparent. For example, with such a index it will become possible to obtain each stand area in the forest type classification made with a combination of species or a mixture ratio. Further, if the relationship between crown size and the index can be made clear, it will become possible to estimate growing stock, through the computer processing of remote sensing data.

Through these examinations, if the index (IDX) that reflects CA is found, it is considered that IDX has a relation with D and H through CA. As D and H closely relate with V, there is an appropriate regression equation between IDX and growing stock per ha. (GSH). On these assumptions the construction to

IDX ⟶ GSH
} GSH×SA= SS, TSS=ΣSS=Σ(GSH×SA)
SA

IDX: new index obtained in future,
GSH: growing stock per ha.,
SA: stand area, SS: stand growing stock,
TSS: total of stand growing stock,
⟶ : corelation.

Fig. 2 Construction of a estimation method using remote sensing

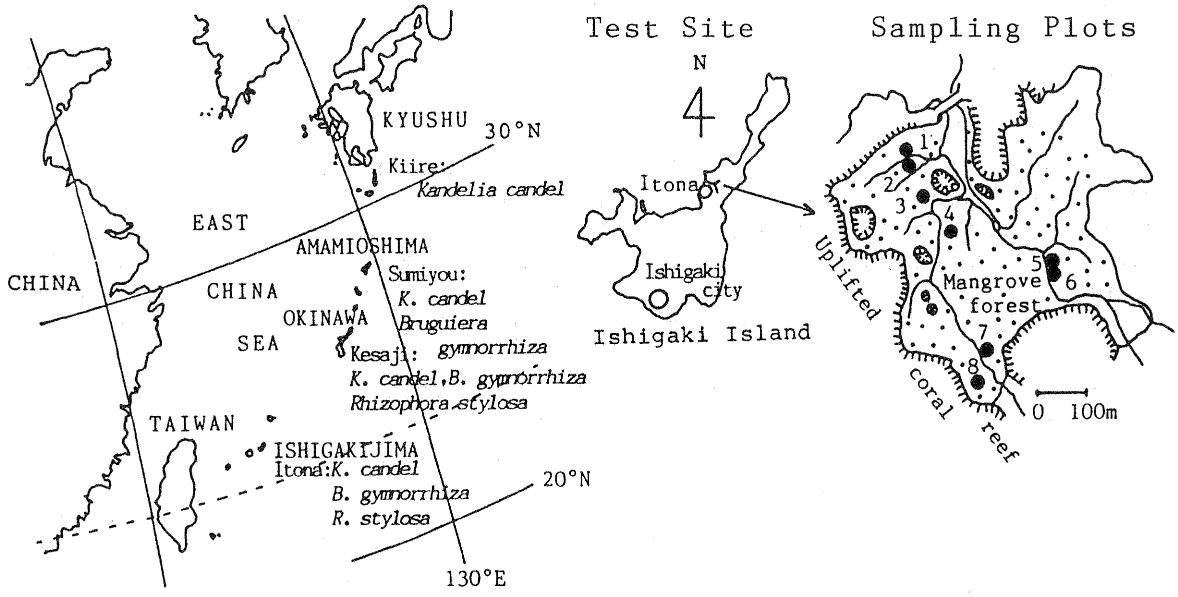


Fig. 3 Mangrove forests, distributed species in Japan and location of test site and sampling plots

estimate forest resources is shown in Fig. 2. GSH is estimated from IDX for each stand and stand growing stock is obtained as the product of GSH and stand area, and finally the resource quantity of the whole forest concerned is found by totaling the stand growing stock (SS) for the whole forest.

(2)Estimation of Mangrove Resources

In this paragraph, a trial will be described which follows the construction mentioned above. The subject forest of this study is a mangrove forest on Ishigaki Island located in the southwestern part of the Ryukyu Islands. The mangrove forest has grown into a forest of about 20 ha. at the mouth of the Fukido River. The data used in this paper was measured and calculated for two reports[3,5] on the mixture ratio of an Okinawan mangrove forest using remote sensing and the stand structure in the same forest. So, setting sample plots was not the ideal way to estimate forest resources. However, it might be adequate in the sense of "an average" mentioned above because the sample plots were set in typical plots of dominant stands of *R. stylosa* or *B. gymnorrhiza* or a medium mixed stand after reconnoitering the whole forest. These eight plots were squares of 400 m^2 (20 m × 20 m). In all plots the diameter measurement of every tree was done and D, H, CA and diameter at intervals of 1 m or 2 m for the calculation of stem volume were measured on each sample tree. From various examinations in the report mentioned above, for the stem volume, a regression equation of $V=a(D^2)^b$ was obtained for each plot and V was estimated by substituting D into this equation. In the case of *R. stylosa*, the volume of upper stem from the point of 80 cm above ground level was calculated considering the lower ramified prop roots thinned down. This part has not been usually used and the cutting height of mangroves having prop roots was above this section in Southeast Asia. The growing stock per ha.obtained in such a way is shown separately for species and mixture state in Table 2.

Airborne MSS data, collected at an altitude of 3,000 m,

Table 1 Percentage of calculated area of each item by pixel number within each area

Item	Whole forest		Area Ⅰ		Area Ⅱ		Area Ⅲ		Area Ⅳ		Area Ⅴ	
	PⅠ	PⅡ	PⅠ	PⅡ	PⅠ	PⅡ	PⅠ	PⅡ	PⅠ	PⅡ	PⅠ	PⅡ
Mangrove Ⅰ		29.1		47.1		23.6		11.2		23.6		24.2
Mangrove Ⅱ	80.3	32.3	89.0	38.4	96.0	43.7	87.2	16.8	78.2	26.4	77.3	33.2
Mangrove Ⅲ		38.6		14.5		32.7		72.0		50.0		42.6
Other forests	9.6		2.6		2.3		12.2		13.2		11.0	
Grass & farm	5.5		1.2		1.6		0.6		7.2		11.2	
Red soils	0.1		0.2									
Sands & road	2.4		3.6		0.1				1.4		0.5	
Water	2.1		3.4		0.0							
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

PⅠ : percent against total pixel number in the area, PⅡ : percent against total pixel number as mangrove, Mangrove Ⅰ : dominant plot of *R. stylosa*, Mangrove Ⅱ : medium mixed plot of both species, Mangrove Ⅲ: dominant plot of *B. gymnorrhiza*.

was used for the forest type classification and the measurement of the area of each classified item. While processing this MSS data, image analysis was performed using a remote sensing image data processing system called the "Tsukusys" developed by the University of Tsukuba.[2)] This forest was classified into three kinds by applying the maximum likelihood method as the supervised classification analysis. The three categories were the dominant forest of *R. styrosa*, the dominant forest of *B. gymnorrhiza* and the medium mixed forest of both species. It was comparable to results which were reached in an actual field survey within the mangrove forest area. Then, the whole mangrove forest was bordered in a classified image on color CRT and the pixel number on each classified item within the mangrove area was counted using the sub-routine for the above purpose in the Tsukusys. The three areas of different mixture states were handled in the same way as the whole forest. The result

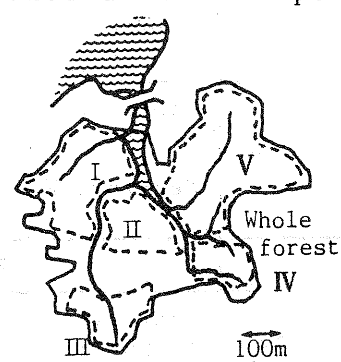


Fig. 4 Sketch map of each area examined

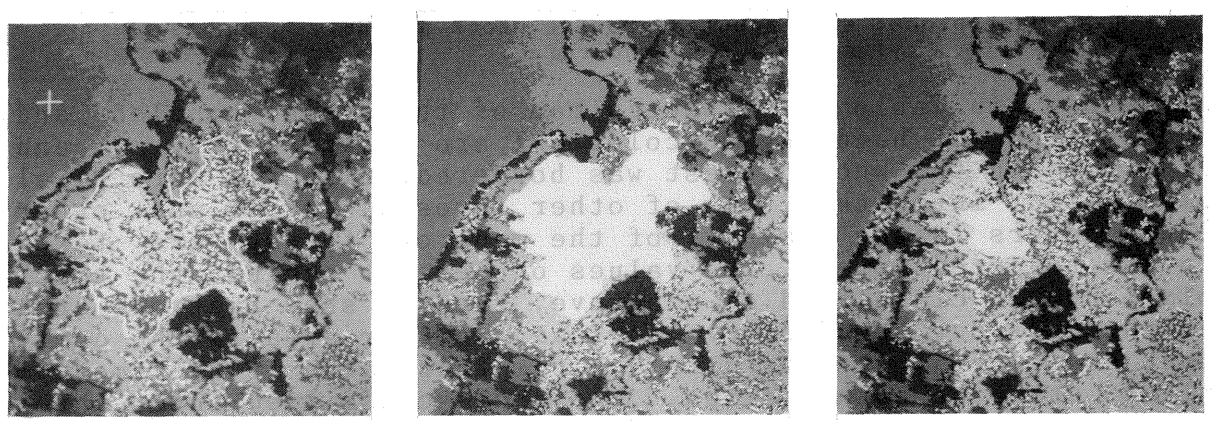


Fig. 5 Photos of the bordered area, whole forest and area Ⅱ on CRT

Table 2 Estimated growing stock and constituents of each area

Area	Item	area (ha.)	unit stock (m^3/ha.)	stand stock & constituent (m^3)	stock per ha.(m^3)
Whole forest	Mangrove I Mangrove II Mangrove III	5.669 6.282 7.525	R. 64.50 R. 149.50 B. 5.98 R. 0.22 B. 100.25	R. 365.65 R. 939.16 R.1306.48 B. 37.57 R. 1.67 B. 791.95 B. 754.38	107.75
		19.476		2098.48	
Area I	Mangrove I Mangrove II Mangrove III	1.879 1.533 0.620	ditto	R. 121.20 R. 229.18 R. 350.52 B. 9.17 R. 0.14 B. 71.33 B. 62.16	104.63
		4.032		421.85	
Area II	Mangrove I Mangrove II Mangrove III	0.613 1.138 0.848	ditto	R. 39.54 R. 170.13 R. 209.86 B. 6.81 R. 0.19 B. 91.82 B. 85.01	116.08
		2.599		301.68	
Area III	Mangrove I Mangrove II Mangrove III	0.221 0.332 1.419	ditto	R. 14.25 R. 49.63 R. 64.19 B. 1.99 R. 0.31 B. 144.24 B. 142.25	105.69
		1.972		208.43	
Area IV	Mangrove I Mangrove II Mangrove III	0.540 0.602 1.142	ditto	R. 34.83 R. 90.00 R. 125.08 B. 3.60 R. 0.25 B. 118.09 B. 114.49	106.47
		2.284		243.17	
Area V	Mangrove I Mangrove II Mangrove III	1.358 1.859 2.387	ditto	R. 87.59 R. 277.92 R. 366.04 B. 11.12 R. 0.53 B. 250.42 B. 239.30	110.00
		5.604		616.46	

unit stock: each species growing stock per ha.,
R.: *R. stylosa*, B.: *B. gymnorrhiza*.

is shown in Table 1, a sketch map of the areas handled and photographs of handling on color CRT are shown as Fig. 4 and Fig. 5. When the whole forest was bordered, slightly more pixel classified into the items of other forests, grass and other land covers in the vicinity of the mangrove forest were taken in the bordered forest. The values of percent against the total pixel number classified as mangrove, clearly show that one area is the dominant stand of *R. stylosa*, another area is the dominant stand of *B. gymnorrhiza* and the third area is the medium mixed stand of both species. The areas classified into three mixture states in each area were calculated depending on the pixel number. Therefore, the growing stock of an area can be obtained as the product of the value of stock per ha. through a ground survey and the area through the treatment above. The result of these calculations is shown in Table 2.

3. Direction of Examination of the new Index

The new index related to CA or CD must be obtained from remote sensing data for the realization of more automatic processing. We have not yet succeeded in finding the index, but some possibilities were suggested in the results of many fundamental examinations.

Several ideas were proposed as the indexes to represent the mixture state of a forest. We examined the relationships among remote sensing data and the following points[2,3]. 1) Mixture ratio with the tree number of *R. stylosa* against the number of all trees in a plot. 2) Mixture ratio with the total cross-sectional area at breast height of *R. stylosa* compared to all trees in a plot. 3) Mixture ratio with the tree number of *R. stylosa* composing the crown layer against the tree number composing the same layer in a plot. 4) Mixture ratio with the total of crown area of *R. stylosa* against the total of crown area of all trees in a plot. 5) Mixture ratio with the total crown area of *R. stylosa* composing the crown layer against the total of crown area of all trees composing the same layer in a plot. The results show that mixture ratio of 5) relates most closely with remote sensing data. An example of the correlation matrix of mixture ratios and means of CCT count calculated from aerial images and airborne MSS data sets is shown in Table 3. It should be reasonable because the crown layer is direct source of remote sensing data.

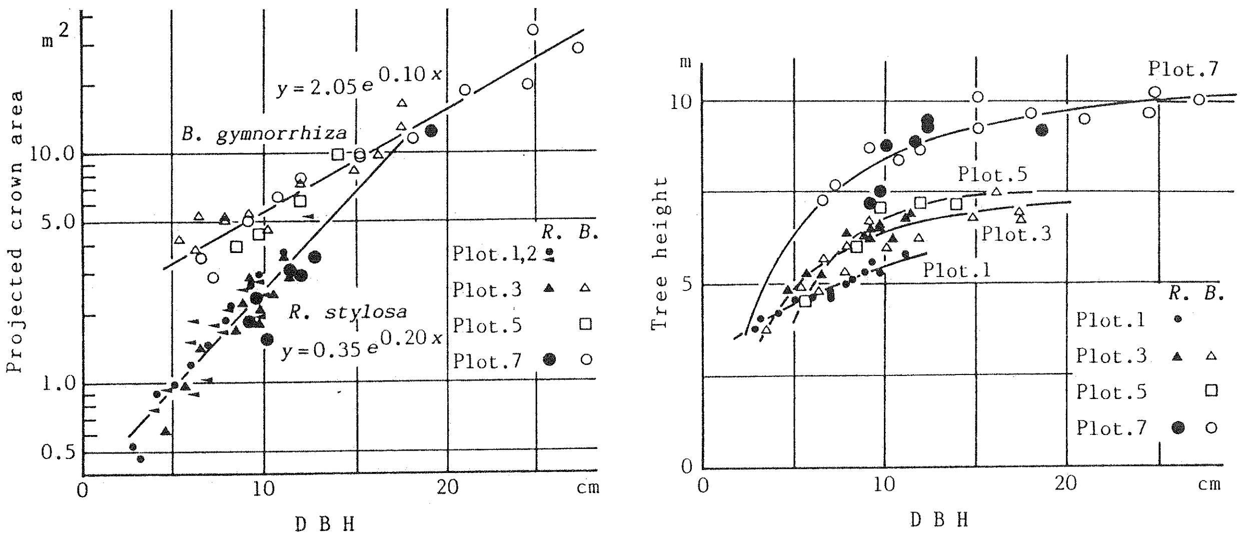
Table 3 Correlation matrix of four mixture ratios and mean CCT count from aerial image and airborne MSS data

N(I)	N(II)	S(I)	S(II)	R.	G.	B.	R/G	R/B	B/G	ch.2	ch.9	ch.11	2/9	2/11	11/9
——	0.997*	0.986*	0.988*	0.753	0.679	0.731	0.785	0.749	-0.568	0.796	-0.878*	0.203	0.863*	0.751	0.895*
	——	0.976*	0.979*	0.743	0.659	0.711	0.799*	0.747	-0.550	0.785	-0.860*	0.249	0.846*	0.733	0.883*
		——	0.999*	0.766	0.696	0.752	0.783	0.754	-0.577	0.833*	-0.936*	0.139	0.918*	0.797	0.946*
			——	0.768	0.700	0.754	0.781	0.757	-0.584	0.834*	-0.932*	0.151	0.917*	0.797	0.945*
				——	0.978*	0.983*	0.864*	0.988*	-0.925*	0.540	-0.674	0.506	0.616	0.451	0.735
					——	0.991*	0.741	0.942*	-0.971*	0.517	-0.617	0.442	0.580	0.438	0.675
						——	0.776	0.942*	-0.929*	0.576	-0.683	0.383	0.640	0.506	0.724
							——	0.913*	-0.647	0.486	-0.677	0.593	0.578	0.385	0.741
								——	-0.901*	0.494	-0.646	0.607	0.577	0.389	0.724
									——	-0.398	0.487	-0.526	-0.461	-0.307	-0.571
										——	-0.818*	-0.012	0.950*	0.987*	0.814*
											——	0.036	-0.952*	-0.812*	0.985*
												——	-0.045	-0.169	0.116
													——	0.943*	0.945*
														——	0.785
															——

N(I): mixture ratio of (1) in the text
N(II): mixture ratio of (3) in the text
S(I): mixture ratio of (4) in the text
S(II): mixture ratio of (5) in the text
R.: Red, G.: Green, B.: Blue
ch.2: 0.42–0.45 nm, ch.9: 0.80–0.89 nm, ch.11: 8.00–14.00 nm
/ : by band ratio
* : significant with 1% level

Fig. 6 show that the space occupation characteristics of crowns are different depending on the species. These characteristics explain the difference of degree of relationships among the mixture ratios mentioned above and remote sensing data. As a point of view contrary to this, it seems that remote sensing data includes factors to reflect the difference of crown between *R. stylosa* and *B. gymnorrhiza*.

Two belts examined for horizontal planar distribution of

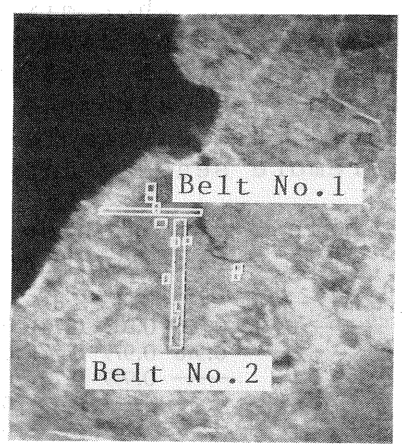


Plot.1: $\frac{1}{H}=\frac{1}{0.034DBH^{0.002}}-\frac{1}{0.034}$ (ρ =0.976) , Plot.3 : $\frac{1}{H}=\frac{1}{1.112DBH^{1.535}}+\frac{1}{7.696}$ (ρ =0.945)

Plot.5 : $\frac{1}{H}=\frac{1}{0.093DBH^{2.771}}+\frac{1}{7.731}$ (ρ =0.987) , Plot.7 : $\frac{1}{H}=\frac{1}{1.817DBH^{1.316}}+\frac{1}{10.823}$ (ρ =0.855)

Fig. 6 Relationships between CA, H and DBH(above)

Fig. 7 Belts examined for horizontal planar distribution of remote sensing data(right)



remote sensing data are shown in Fig. 7. The pixel data of each channel from the belts were taken out of examination for this study and the distribution of both untreated data and treated data(like by band ratio) were drawn in a figure looking like an aeroview. Some examples are shown in Fig. 8. In the figure from the data of ch.9, good correspondence with the field is noticeable. The mountainous part at the left can be matched to the maritime forest, the plateau-like part on the middle can be matched to the mangrove, and the valley-like part on the right is matched to the river. The higher parts in the plateau-like part are where *B. gymnorrhiza* is dominant. In the figure of ch.2, rough correspondence can be noticed but it is not clear. In the figure of by band ratio, high correspondence is noticed. The higher parts in the mangrove forest are where *R. stylosa* is dominant. In Fig. 9 the belt from north to south is shown and the valley-like part is probably matched to a creek's muddy bed exposed by a low tide. From those examinations, more preferable data should be found. For instance, the treated data of (ch.2 × ch.11)/ch.9 is proposed based on examination of those figures.

After the examination above, several proposed data will be processed by the texture analysis or frequency analysis. If the new index is discovered through such processing, a more automatic estimation method of mangrove resources will be established.

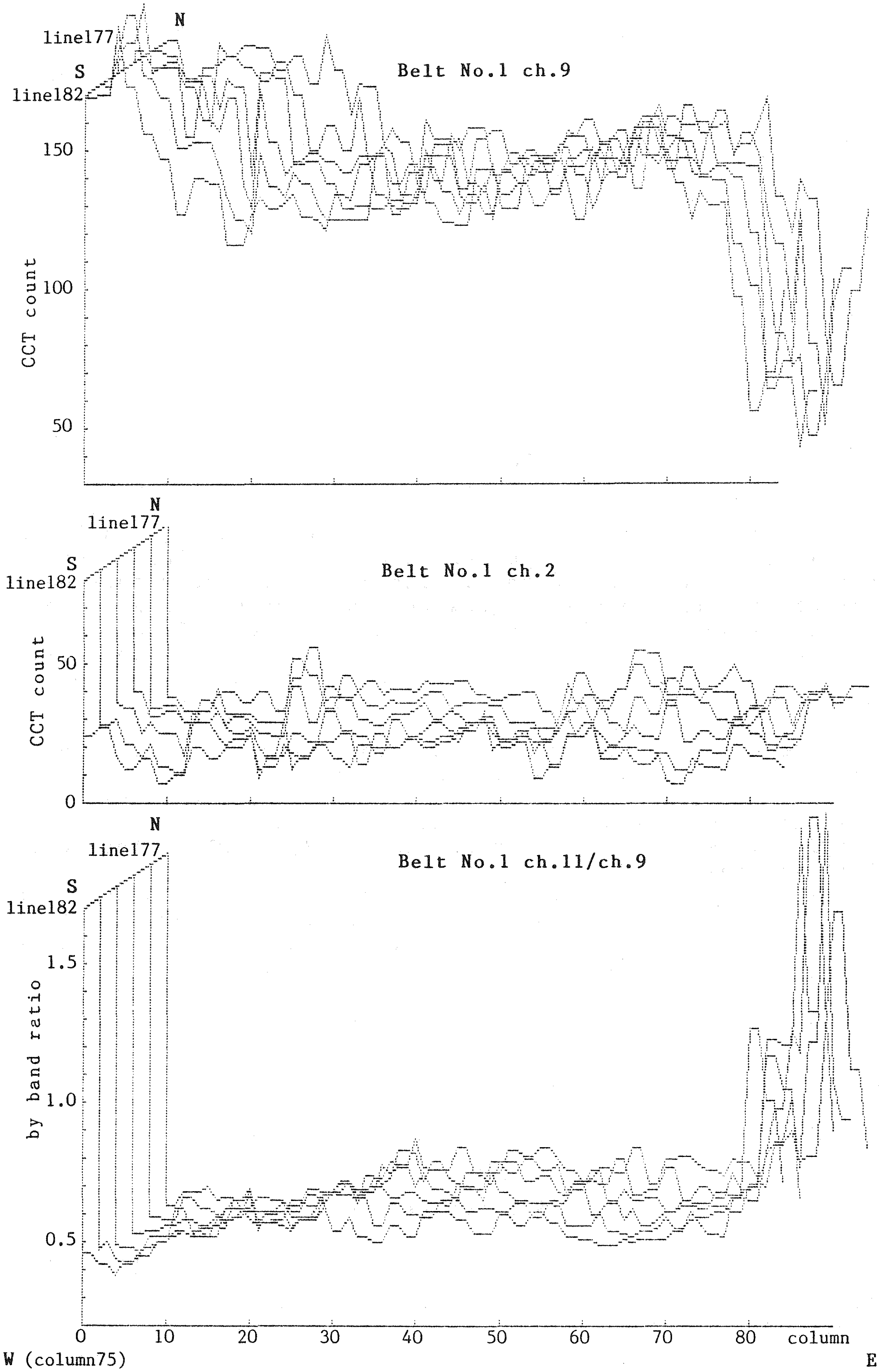


Fig. 8 Distribution of data in examined Belt No.1

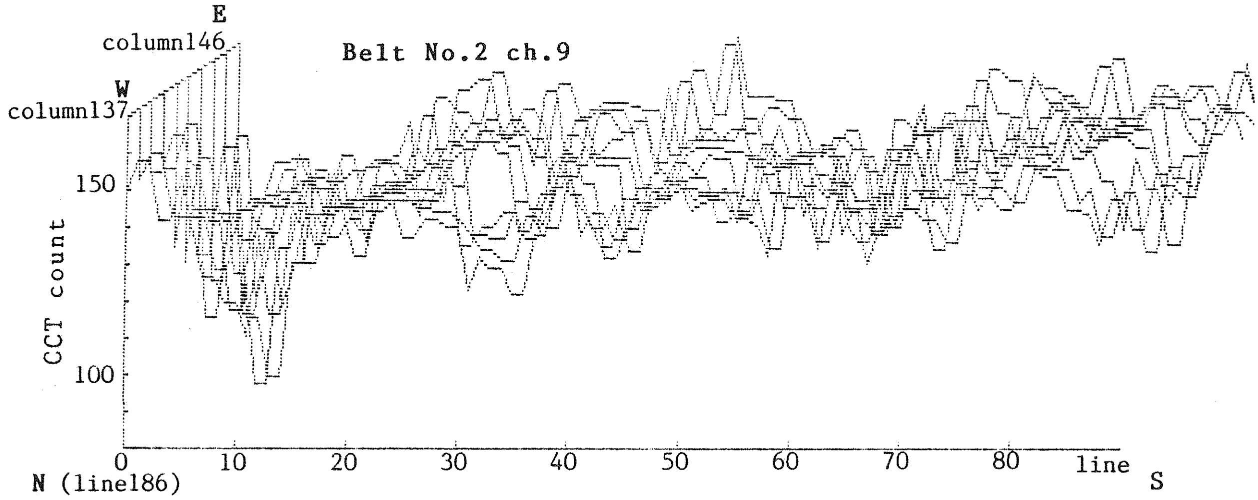


Fig. 9 Distribution of data in wxamined Belt No.2

4. Conclusions

There are few reports on the mangrove resources in Okinawa except Sunakawa's report[6] on forest resources which included the estimation of mangrove resources on Iriomote Island, which is near the island studied here, Ishigaki. In the report mentioned above, the values of growing stock per ha. of six field survey plots were estimated at a maximum of 110.5 m^3, a minimum of 36.8 m^3 and a mean of 91.8 m^3. It is considered, depending on the mean tree height and stand density, that these plots were young and middle-aged stands. On the other Okinawan natural broad leaved trees, the values from 100 m^3/ha. to 200 m^3/ha. were generally reported.[1] Thus, the estimated values shown in Table 2 seem to be adequate in comparison with the values mentioned above. For the resources of this mangrove forest, the values of growing stock were finally estimated as 1,306 m^3 on *R. stylosa*, 792 m^3 on *B. gymnorrhiza* and 2,098 m^3 of the total on both species.

Through a trial by the method examined in this paper for the estimation an unknown quantity of the resources of a mangrove forest, it became clear that the mangrove forest composed of two species can be classified into at least three forest types for mixture state and the mangrove resources can be estimated. The accuracy of the results with this method depends on whether the classification of forest type using remote sensing and the setting of sample plots for the field survey, are performed appropriately.

It remains in the future that the new index to relate with the growing stock of a stand through the crown size must be made clear.

References

1) Hirata, E. (1977): Studies on the weight yield of principal broad-leaved forests in Okinawa District, Sci. Bull. Agric. Univ. Ryukyus, Vol.24, pp.621-743. (in Japanese with English summary)
2) Hoshi, T. and Sato, K. (1985): Analysis of Mangrove Forest in Okinawa Using Airborne Remote sensing Data, Proc. 6th Asian

Confe. on Remote Sensing,pp.381-390.
3) Sato, K. and Hoshi, T.(1985): Examination of Mangrove Forest Factors using Airborne Remote Sensing, Proc. Anual Confe. of JSPRS,pp135-138. (in Japanese)
4) Sato, K. and Hoshi, T. (1986): Construction of Estimation Methods for Mangrove Resources using Remote Sensing, Proc. 7th Asian Confe. on Remote Sensing,pp.C-11-1-C-11-6.
5) Sato, K.: Stand structure of the Fukido Rive Mangrove Forest in Okinawa, Jour. Jpn. For. Soc., in press
6) Sunakawa, S. et al.(1983): Forest resources in Okinawa, Report on Developing Utilization of Forest Resources in Okinawa, Okinawa Administrative Authorities, pp.1-45. (in Japanese)