E75-10234
CR142420

III

01

SR No. 0580 - 1

DEMONSTRATION OF THE APPLICABILITY OF SATELLITE DATA TO FORESTRY

Kullervo Kuusela
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI 17, Finland

April 1974
Type III Report

(E75-10234) DEMONSTRATION OF THE APPLICABILITY OF SATELLITE DATA TO FORESTRY Final Report, Dec. 1972 - Apr. 1974 (Forest Research Inst., Helsinki (Finland).) 31 p HC $3.75 CSCL 20F G3/43

N75-21759
Unclas
00234

ORIGINAL PAGE IS OF POOR QUALITY

T.M.

1580A

ORIGINAL PAGE IS
OF POOR QUALITY

1. SR No.
0580 - 1

2. Type of Report
III

3. Recipient´s Catalog No.
-

4. Title
Demonstration of the applicability of satellite data to forestry

5. Report Date
April, 1974

6. Period Covered
Dec. 1972 - April 1974

7. Principal Investigator
Kullervo Kuusela

8. No. of Pages

9. Name and Address of Principal Investigators Organization
Forest Research Institute
Unioninkatu 40 A
00170 HELSINKI 17, Finland

10. Principal Investiga. Rept. No.
-

11. GSFC Technical Monitor
George Ensor

12. Sponsoring Agency Name and Address
-

13. Key Words (Selected by Principal Investigator)
Regression for forest characteristics

14. Supplementary Notes
-

15. Abstract

812 plots of 60 x 60 metres were measured in the field, interpreted from aerial photographs at scale 1 : 60000 or 1 : 50000 and measured by microdensitometric means for the four MSS tonal values. The material was located on two study areas of 16 x 96 km and on 4 tracts of 8 x 16 km in each study area in North Finland.

The tests showed that tehre existed a distinct correlation between tonal MSS values and many forestry characteristics. However, the standard deviations of tonal values within homogeneous strata proved to be too large to be used in estimating forestry characteristics directly from tonal values.

When satellite data were used as a supplement to photo interpretation for stratification, the variance of volume of growing stock on relascope plots within strata could be decreased by about 15...20 %. The possibility of improving stratification as a first phase of double sampling is regarded as the most promising procedure for utilize ERTS imagery in Finnish forest inventory. However, this would require some easy way of locating the plots from maps to satellite pictures or vice versa.

PREFACE

Remote sensing is extensively applied in Finnish forestry, primarily for forest mapping through conventional aerial photography. Recently more interest has been aroused by the possibility of utilizing aerial photography also for forest volume inventory, especially on the national level. The sixth national inventory of North Finland has begun with a double sampling method: aerial photo interpretation is the first phase, followed by ground measurements.

The ERTS program stimulated consideration of the prospects for including satellite imagery in an experimental program for forest inventory in North Finland. Broadly stated, the purpose of this project is to determine whether the satellite pictures can be used beneficially to cut down the total cost of forest inventory by reducing the field work requirement. The more specific objective is to analyze the regression of forest growing stock characteristics on the tonal images of satellite pictures.

The study was conducted in the Department of Forest Inventory and Yield, of the Finnish Forest Research Institute. Aerial photographs were interpreted in the spring of 1973 by Mr. Tarmo Uusitalo and Mr. Pertti Virtanen. Three groups of three men each made field measurements during three months in 1973 under the leadership of Mr. Matti Myllyniemi, Mr. Simo Poso and Mr. Pekka Tamminen. The measurements on satellite pictures were made by Mrs. Tuula Aalto and Mr. Timo Nyrhinen using a microdensitometric device in the winter of 1973-1974. The numerical data were prepared by Mrs. Tuula Aalto and computer processing was done by Mr. Matti Kujala and Mr. Simo Poso. The entire study was led and completed by Mr. Simo Poso under control of the principal investigator.

Helsinki, September 6, 1974

Kullervo Kuusela

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TEST MATERIAL

Two test sites were taken, 16 x 96 km each, in Finnish Lapland (Fig. 2). Each test site was divided into two parts, and further into 4 tracts of 8 x 16 km (Fig. 3). In each tract 192 points were located on aerial photographs of 1 : 60000 or 1 : 50000 according to the scheme of Fig. 4. Each of the points established a photo plot, for which forest characteristics such as land use class, mineral soil or bog, volume of growing stock, main tree species, treatment class, and site were interpreted from aerial photographs. The plot was defined by a relascope procedure: if the relation of tree diameter at breast height and the distance of tree from the plot center was larger than 1 : 50, the tree was included in the plot. "Variable plot" is a synonym for "relascope plot" because its size is not fixed but dependent on the size of the trees.

A number of the plots interpreted from aerial photos were also measured in the field. The field plots were drawn on the basis of either systematic sampling (tracts 2, 4, 6, and 8) or stratified random sampling (tracts 1, 3, 5, and 7). The definition of a field plot was the same as that of a photo plot. A tree tallied in the field represented 1 m^2/ha in basal area.

The relascope plots described above were not considered large anough to be used in connection with satellite pictures. Therefore, field measurements were also made for larger plots of 60 x 60 meters in size. The field estimations for those plots were made by a cluster of 9 relascope plots. They were 20 meters apart and each tree tallied represented 4 m^2/ha in basal area (Fig. 5). (In those cluster plots the relation of tree diameter and distance of tree to plot center $\geq$ 1 : 25.)

Most of the sample plots of 60 x 60 meters were drawn either systematically or randomly from each tract. Some were taken subjectively on the basis of easy access. The total number of the plots was about 1000. The number of those consisting of more than one compartment was about 200 and they were eliminated from the later study. (A compartment is defined as a relatively homogeneous piece of land as regards site and tree characteristics.) This means that the study was restricted to the plots falling entirely in one compartment.

ERTS PICTURES

The imagery used in the tests consisted of the two sets of pictures 1039-09315 and 1039-09322. Both sets comprised all four MSS bands. Thus the number of pictures was eight. They were taken on August 31, 1972.

The positive transparencies 1 : 1 million were enlarged and rectified to 1 : 400000. In order to make the location of test plots easier, the pictures were supplied with a grid and dots (Fig. 1). The grid was fixed to the official uniform coordinate system of Finland.

·Fig. 1. Part of satellite picture overlaid by a grid.

The pictures were bulk product, i.e. they were not given any special treatment by NASA. For this reason they were not very good with respect to radiometric accuracy. One set of scanning lines often differed distinctly from another. Furthermore the density curve of the pictures seemed to be nonlinear. The processing of positive transparencies 1 : 400000 from bulk product was performed by conventional photographic processing in the National Board of Land Survey in Finland.

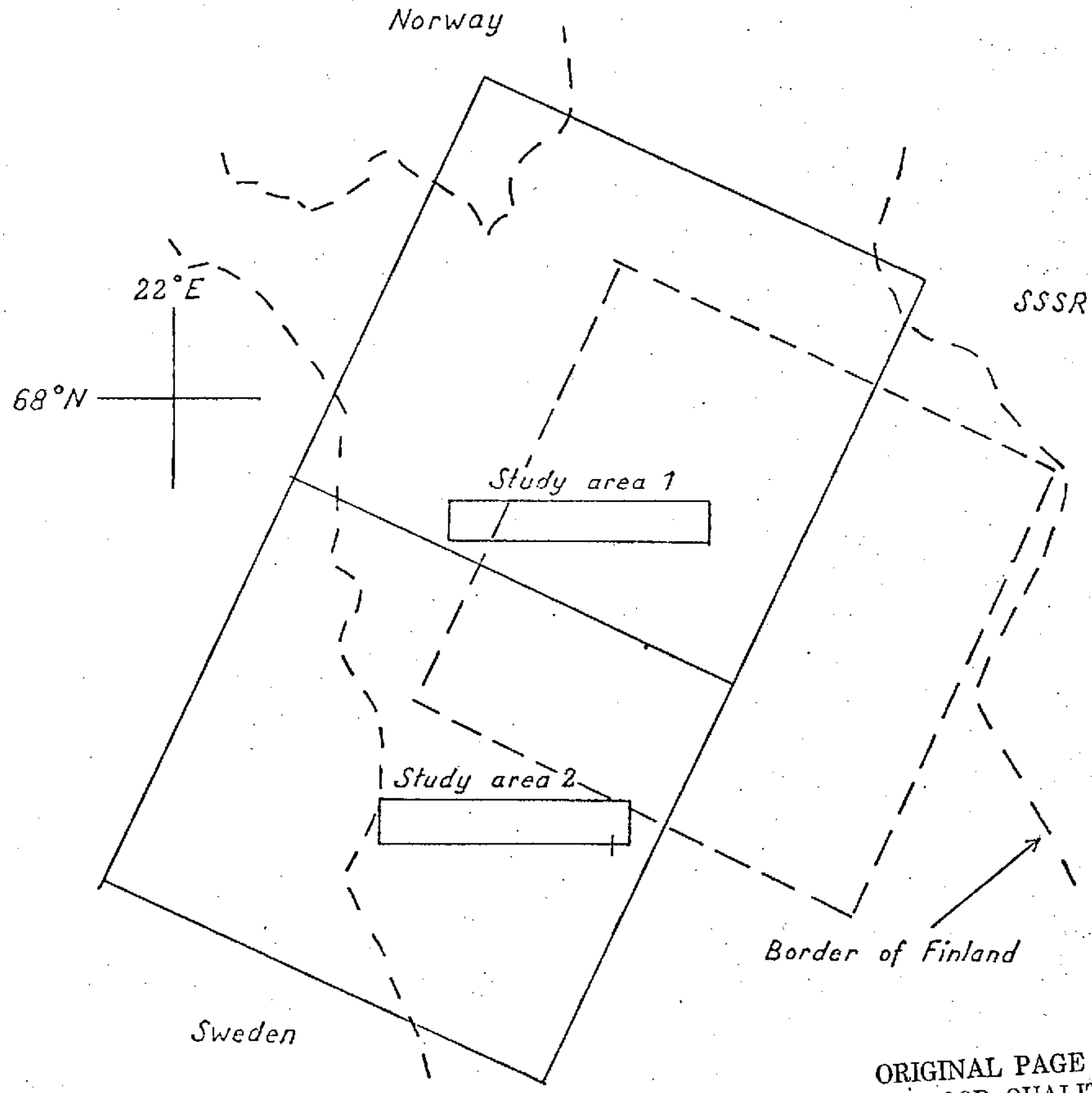


Fig. 2. Location of the ERTS imagery, area originally suggested, and the areas of more intensive study.

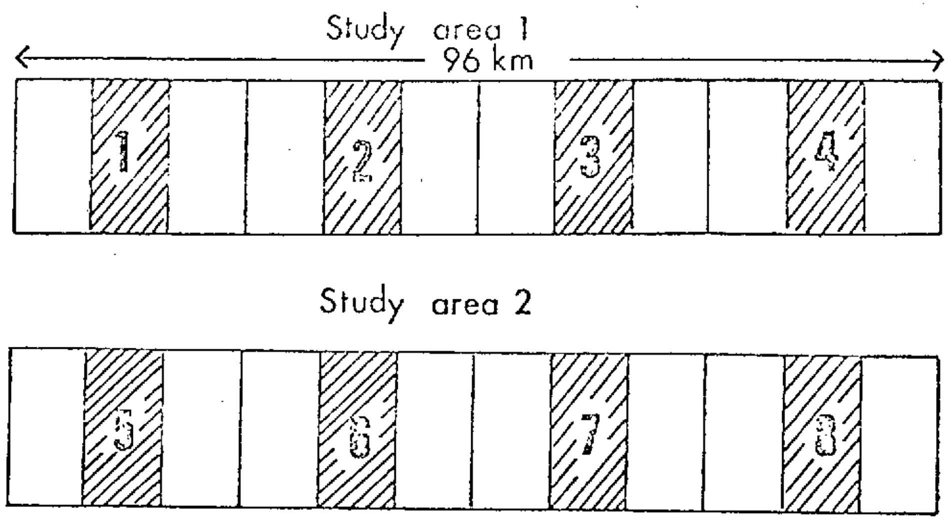


Fig. 3. Tracts on the study areas.

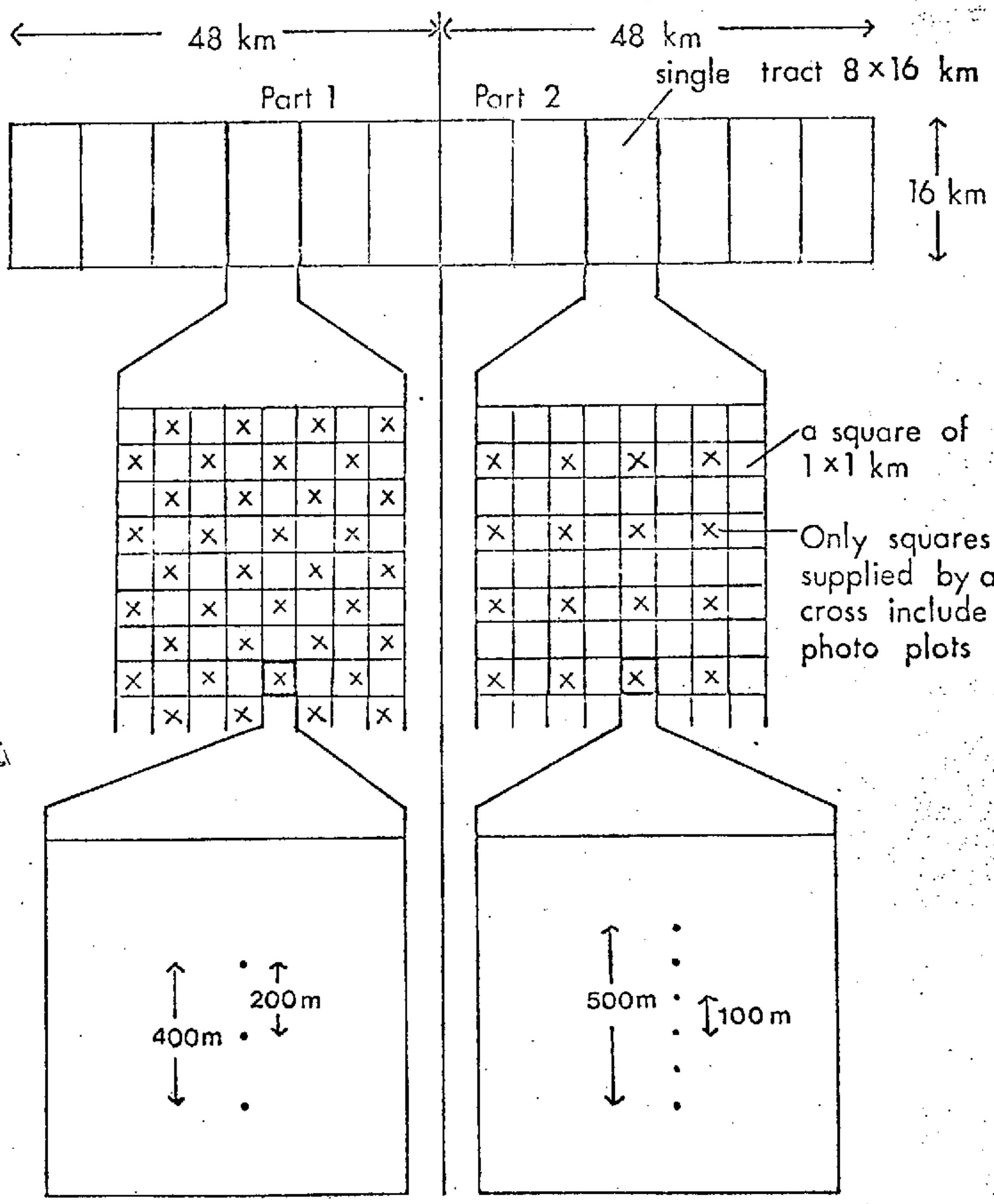
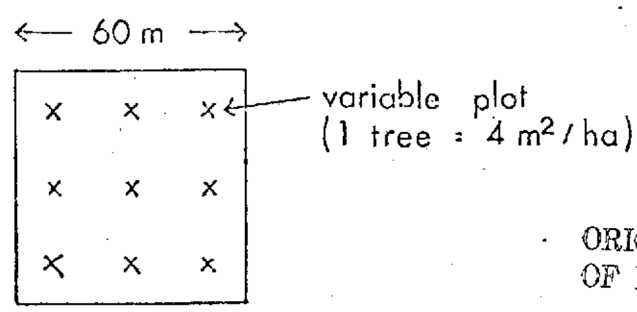


Fig. 4. Location of plots interpreted from aerial photographs.



ORIGINAL PAGE IS
OF POOR QUALITY

Fig. 5. Square plot sampled by 9 relascope plots.

The measurements from satellite pictures resulted in "tone values". These were obtained by microdensitometry. They are defined as follows:

1) tone value refers to the quantity of transmitted light
2) tone values are not absolute but relative figures
3) reference level corresponds to the tone value of a white line of the square grid on a positive transparency (cf. Fig. 1 and Fig. 5). The tone value of this level is taken as zero
4) tone value has been measured as the distance of a point on a graph from reference level in millimeters (see Fig. 6 and note the scale smaller than in the original)
5) the differences in tone values are proportional to the density of the corresponding plot on a positive transparency (D = log (I÷T), where $T = I \div I_o$, I = transmitted and I_o = incident light.).

The tone values for each of the 812 plots were measured by a microdensitometer from each MSS positive transparency. The aperture in the device represented exactly 60 x 60 m in the field. The measurements were made along a line which passed through many plots. The tone values of lines were transferred automatically to graphs (Fig. 6). Each graph was supplied with a reference level (zero level) by which the tone values were measured for each plot. In determining the reference level the grid superimposed on the satellite pictures was of great help.

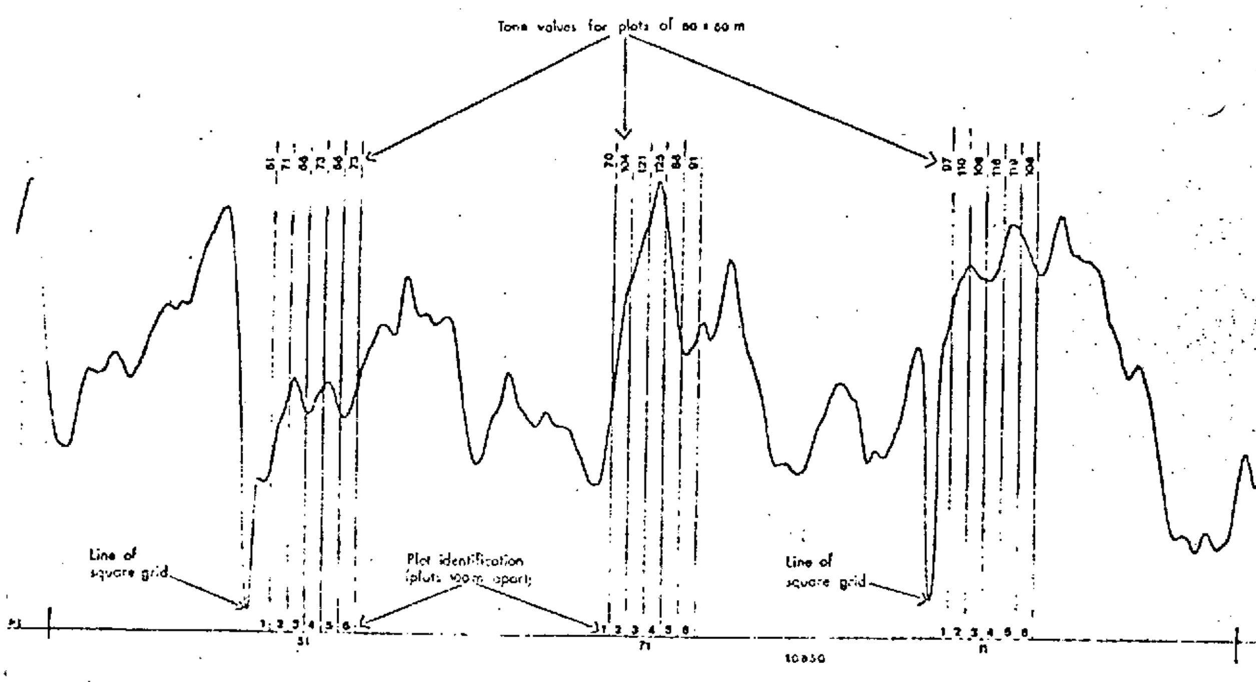


Fig. 6. Example of microdensitometric graph.

ORIGINAL PAGE IS
OF POOR QUALITY

TEST PROCEDURES

Tests were made for two purposes: The first was to study the regression between forest characrestics and MSS tonal values. Another aim was to derive criteria for evaluating the usefulness of the satellite pictures for forest inventory in given conditions.

First, the total number of plots was reduced from 1000 to 812 by eliminating those divided into two or more compartments as seen from aerial photographs. The 812 plots were then stratified into 23 classes according to field measurements. The means and standard deviations were calculated for each stratum by tracts (Table 1).

The stratification according to land use and site is common in Finnish forestry. Forest land refers to sites capable of producing timber more than 1 m^3/ha/year on average during a rotation of 100 years. The corresponding definition of poor forest land is .1 - 1.0

Stratum	Land use class	Site-class	Tree species	Volume of forest growing stock
1	forest land	mineral soil	any	0 - 10 m^3/ha
2	-"-	-"-	pine	11 - 55 "
3	-"-	-"-	"	56 + "
4	-"-	-"-	spruce	11 - 55 "
5	-"-	-"-	"	56 + "
6	-"-	-"-	bdlf.	11 - 55 "
7	-"-	-"-	"	56 + "
8	-"-	swamp	any	0 - 10 "
9	-"-	-"-	pine	11 - 55 "
10	-"-	-"-	"	56 + "
11	-"-	-"-	spruce	11 - 55 "
12	-"-	-"-	"	56 + "
13	-"-	-"-	bdlf.	11 - 55 "
14	-"-	-"-	"	56 + "
15	poor forest	mostly swamp	any	0 - 10 "
16	-"-	-"-	pine	11 - 55 "
17	-"-	-"-	spruce	11 - 55 "
18	-"-	-"-	bdlf.	11 - 55 "
19	waste land	swamp		
20	forest roads			
21	agricultural land			
22	roads, power lines, etc.			
23	water			

Table 1. Definition of strata.

m^3/ha/year, and waste land produces less than .1 m^3/ha/year. As this stratification is important in forestry planning it is also applied here. It was expected that the undergrowth of poor forest land will differ from that of forest land even when the standing tree volumes are equal.

Another procedure to study the regression was restricted to the plots which fell on mineral soil. Here the study dealt only with the regression between volume of forest growing stock and MSS tonal values. The study was made separately for total volume, and volume by three tree species: pine, spruce, and broad leaves, the last being almost totally birch. The number of plots in this analysis was 374.

The test to apply MSS tonal values for forest inventory was made on the basis of plots on mineral forest land, the number of which was 374. The study was concentrated on volumes of forest trees in total and by tree species. The inventory method used in the tests was a double sampling in which plots of the first phase are placed on aerial photographs of 1 : 60000 or 1 : 50000. These plots are then interpreted for all relevant forest characteristics.

In addition MSS tonal values are measured from satellite pictures for all the photo plots. Stratification of the first-phase plots is made primarily on the basis of photo interpretations. However, stratification is improved by the use of MSS tonal values. The hypothesis to be tested is that the use of satellite pictures makes the stratification significantly better.

For the test the 374 plots were divided into strata of three plots by tracts. Four kinds of stratification were applied, based on:

1. photo interpretation of total volume
2. MSS tonal values
3. photo interpretation of total volume supplemented by MSS tonal values
4. field measurements.

The variances within strata were calculated, making it possible to compare these variances with the total variances and thereby to come to relevant conclusions.

RESULTS

Regression for strata

The mean tonal values of strata 1...23 (see Table 1) by MSS bands have been illustrated for four tracts in Fig. 7. It shows that there exist distinct differences among the tonal values of many strata. This figure also reveals that the tracts seem to have systematic differences in tonal values.

The systematic differences in tonal values between the tracts were tested for strata 2 and 3. The basis for the selection was that the number of plots in those strata was highest. The means of the respective values of the two strata for the eight tracts are shown in Table 2. These values are used for eliminating the systematic differences between tracts and they are called "reference tonal values".

Tract	MSS			
	4	5	6	7
1	55	95	87	89
2	56	84	68	67
3	68	74	73	76
4	77	102	87	94
5	78	107	105	107
6	66	98	86	72
7	58	92	84	87
8	58	90	95	92
Total	67	94	87	89

Table 2. Reference tonal values of tracts.

The differences in reference tonal values of separate tracts may be remarkably large. For example, the mean of strata 2 and 3 in MSS 5 of tract 5 is 107. The respective value of tract 2 is only 84, and the difference is highly significant.

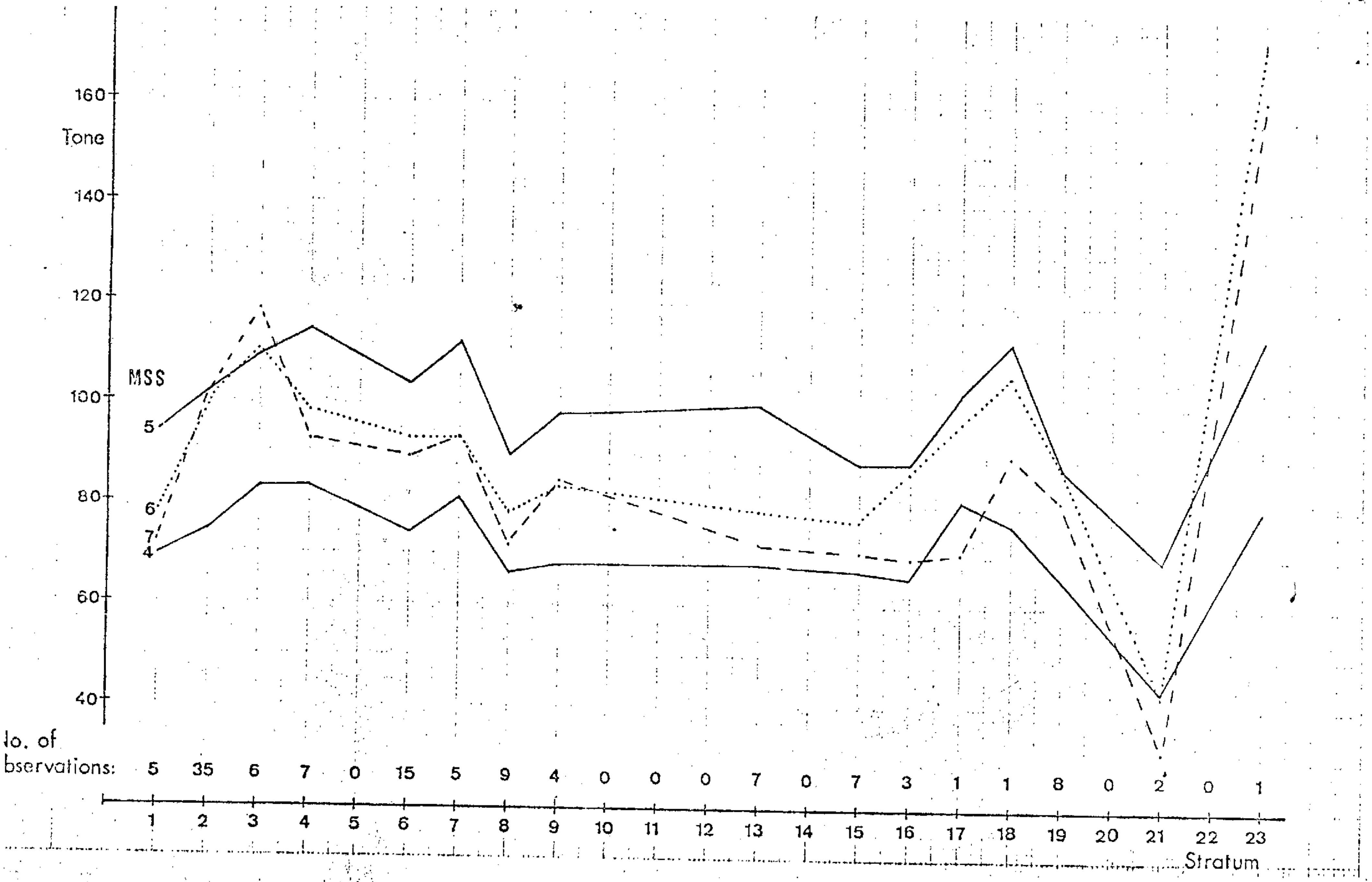
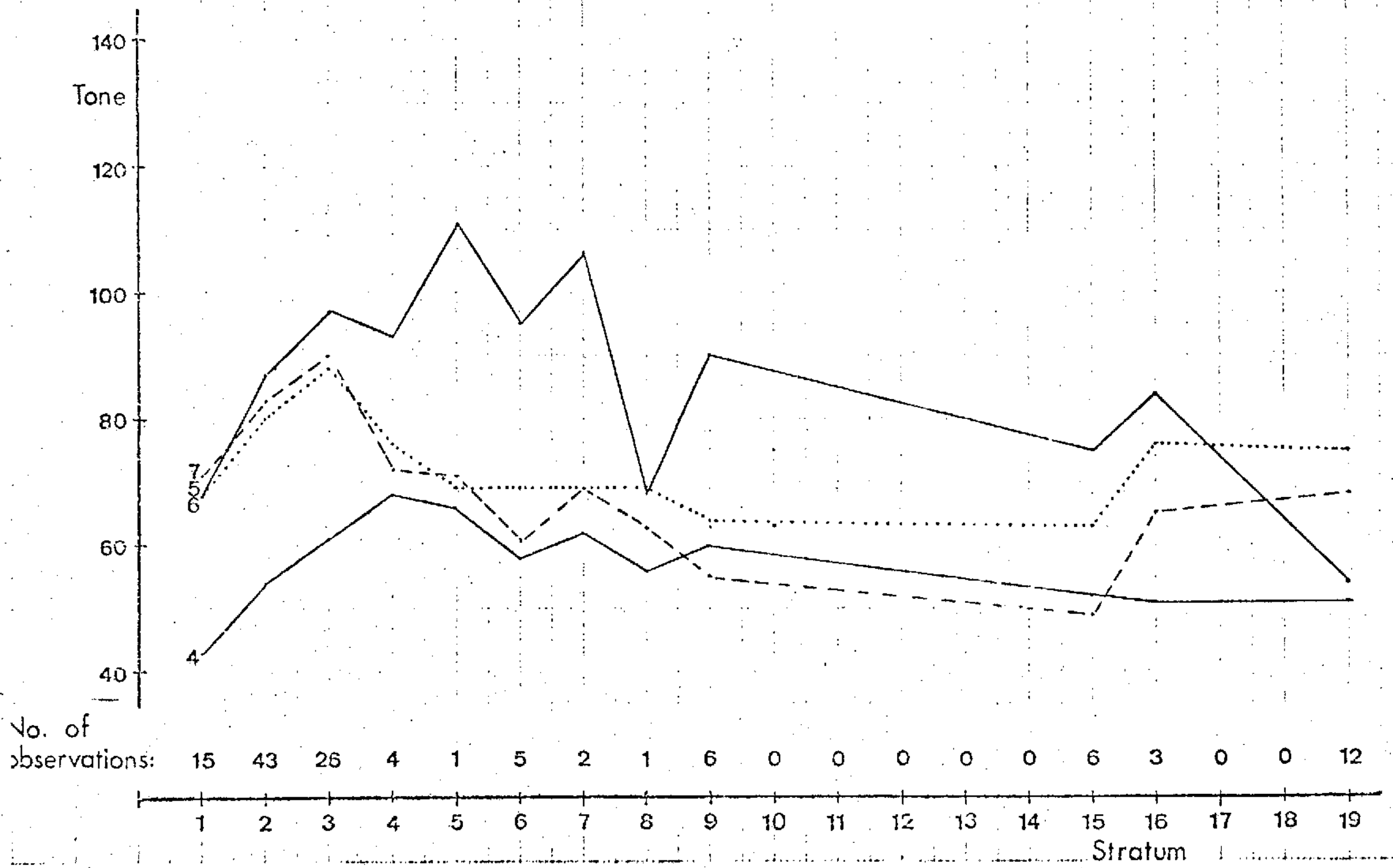
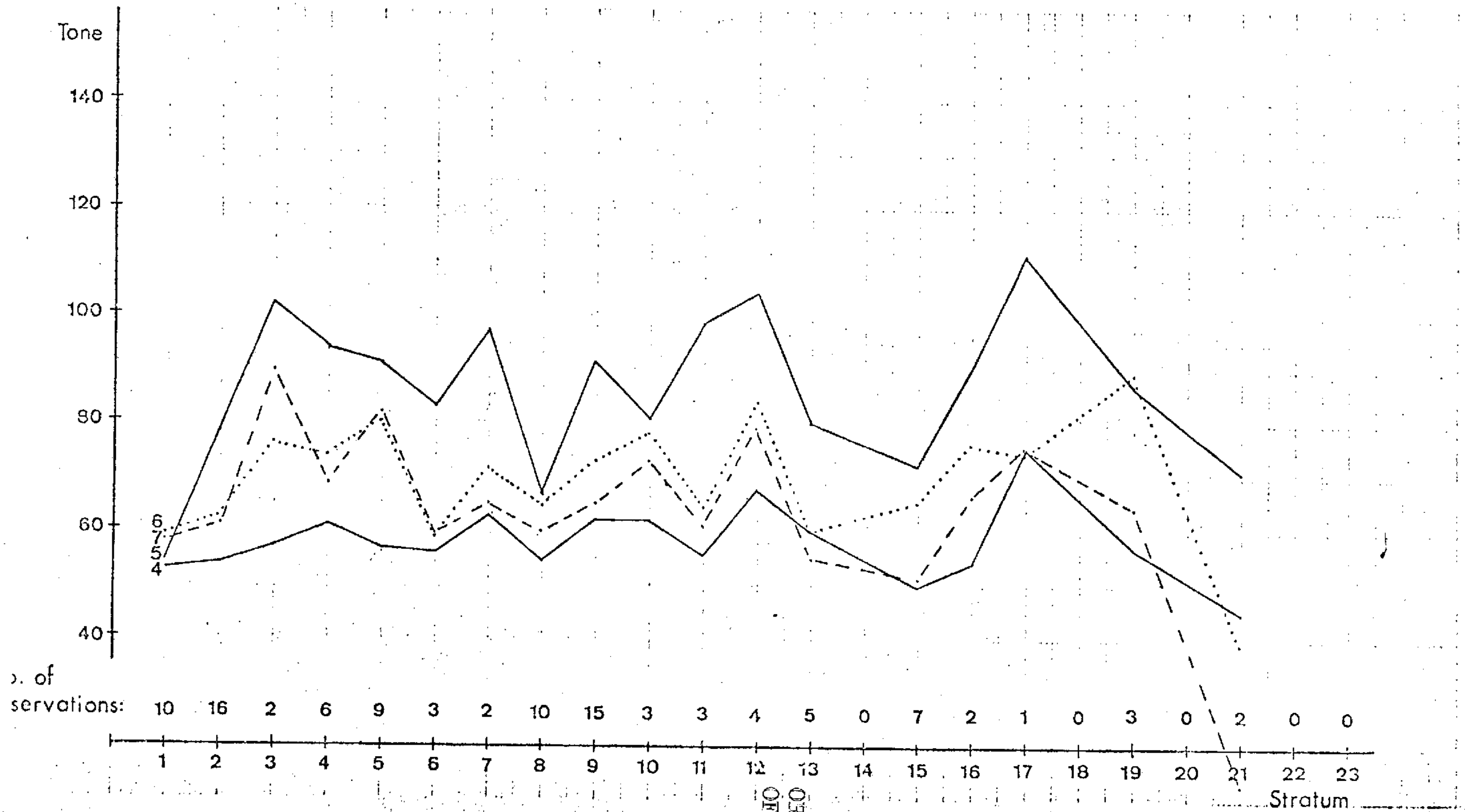


Fig. 7. Tones of strata for tracts 1, 3, 6, and 8.

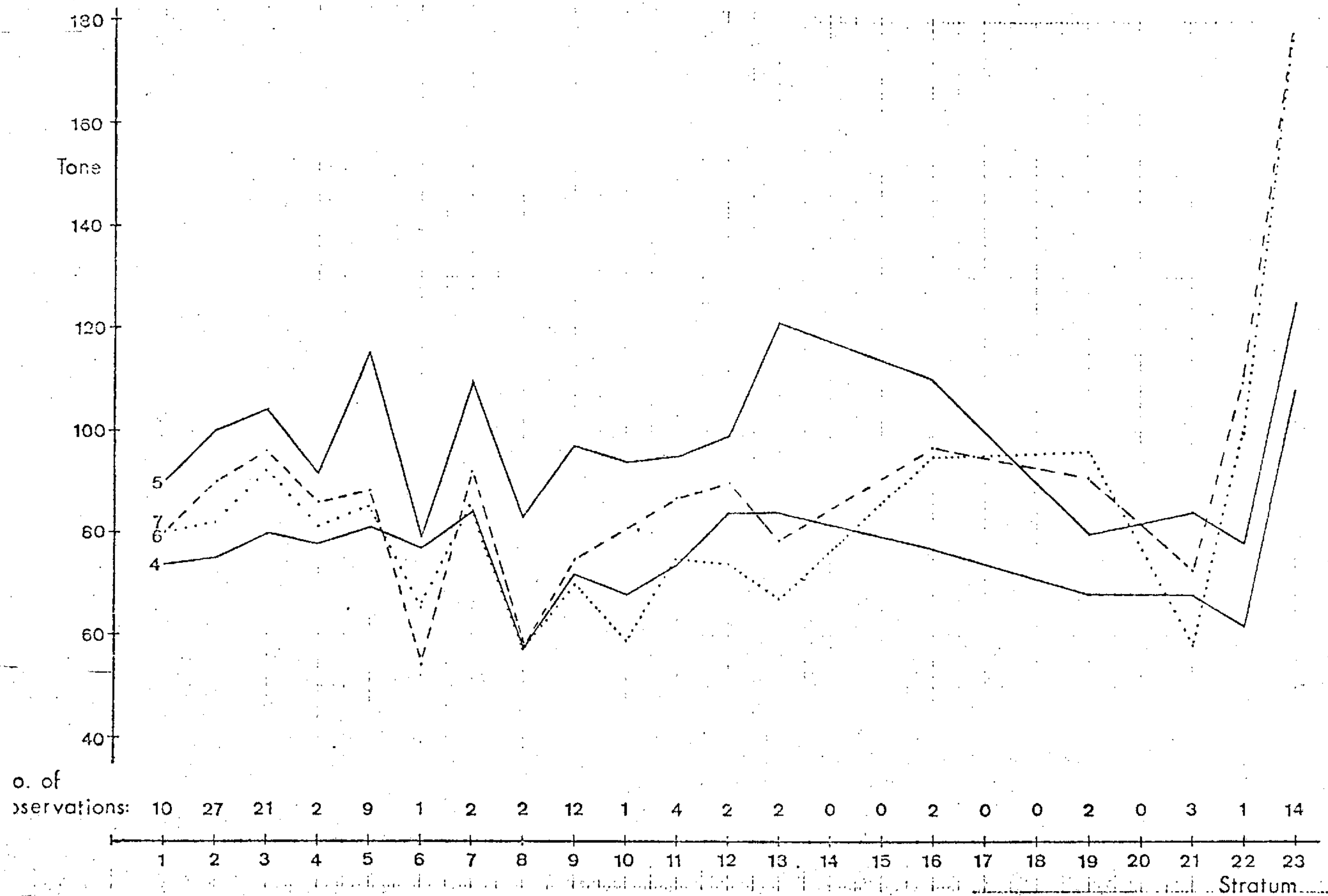
7A. Tract 1.



7B. Tones of strata for tract 3.



7C. Tones of strata for tract 6.



7D. Tones of strata for tract 8.

ORIGINAL PAGE IS OF POOR QUALITY

Reasons for these differences are speculative. They cannot be explained by the data material collected. The possible sources include structure of soil, moisture content of soil, vegetation under tree crown level, angle of solar radiation, and possible errors in reference level of microdensitometric measurements. However, some data collected by geologists indicated that the structure of the soil has no remarkable importance in explanation of the differences.

The mean tonal values of strata 1...23 were calculated also on the basis of all material by eliminating the tractwise systematic differences shown in Table 2. The results are illustrated in Figure 8 and listed in Table 3. The table also shows standard deviations by strata which were calculated by a pooling procedure over separate tracts, as well as deviations without stratification.

Fig. 8 and Table 3 show distinct differences, most of which can be shown to be statistically significant. The stratum 19, waste land (i.e., bogs), showed exceptionally large standard deviations. This was not surprising because some of the bogs are very wet and some dry, and the variety in vegetation on the ground surface is easily seen from the air. Therefore, this stratum was studied in more detail. The results are shown in Table 4.

This table indicates that the set of plots belonging to treeless bogs can be stratified to substrata by the aid of satellite imagery. The means of MSS bands 6 and 7 are well in concordance with the fact that Betula nana (dwarf birch) and Carex species reflect infrared radiation well.

The confidence of results concerning Fig. 8 and Table 3 cannot be presented by any exact expression. One source of error is associated with the placing of plots from aerial photographs to satellite pictures for microdensitometric measurements.

The problem was studied using large compartments. The compartments including at least 3 sample plots (see Fig. 4) were taken by photo interpretation. The tonal MSS values and field characteristics were calculated for the compartments as average values of three sample plots. These values were handled in the same way as single plots for Table 3. The resultant tone values were compared with those calculated on the basis of all plots (Fig. 9).

Stratum	No. of plots	Means by MSS 4	5	6	7	Stand. dev. by MSS 4	5	6	7
1	90	63	67	70	68	9	17	13	17
2	183	62	89	84	85	10	14	14	17
3	87	67	97	90	91	9	11	16	17
4	33	70	96	80	77	9	10	14	13
5	35	69	101	79	80	9	14	12	13
6	35	66	96	82	74	11	12	17	17
7	14	70	105	76	78	12	5	11	14
8	56	55	69	64	59	6	13	11	9
9	61	63	89	70	65	11	15	11	13
10	2	67	97	66	70				
11	13	63	93	69	68	7	16	11	10
12	8	70	97	74	78	6	4	12	14
13	18	66	92	71	66	10	15	14	20
14	2	72	79	53	57				
15	35	55	72	67	57	9	18	12	14
16	25	58	88	79	72	16	19	13	18
17	2	78	107	70	73				
18	3	72	93	80	70				
19	70	58	81	80	72	15	15	22	26
20	1	58	99	78	79				
21	12	45	69	50	47	12	20	14	22
22	2	52	72	71	75				
23	25	94	120	176	176	11	9	10	11
all 1)	812	63	87	80	78	10	14	14	17
all 2)	812					13	19	24	26
all 3)	787		86		75		18		20

1) standard deviations based on pooled variances.

2) " " " " total "

3) as 2 but waters eliminated.

Table 3. Means and standard deviations of tone values (Differences between tracts eliminated).

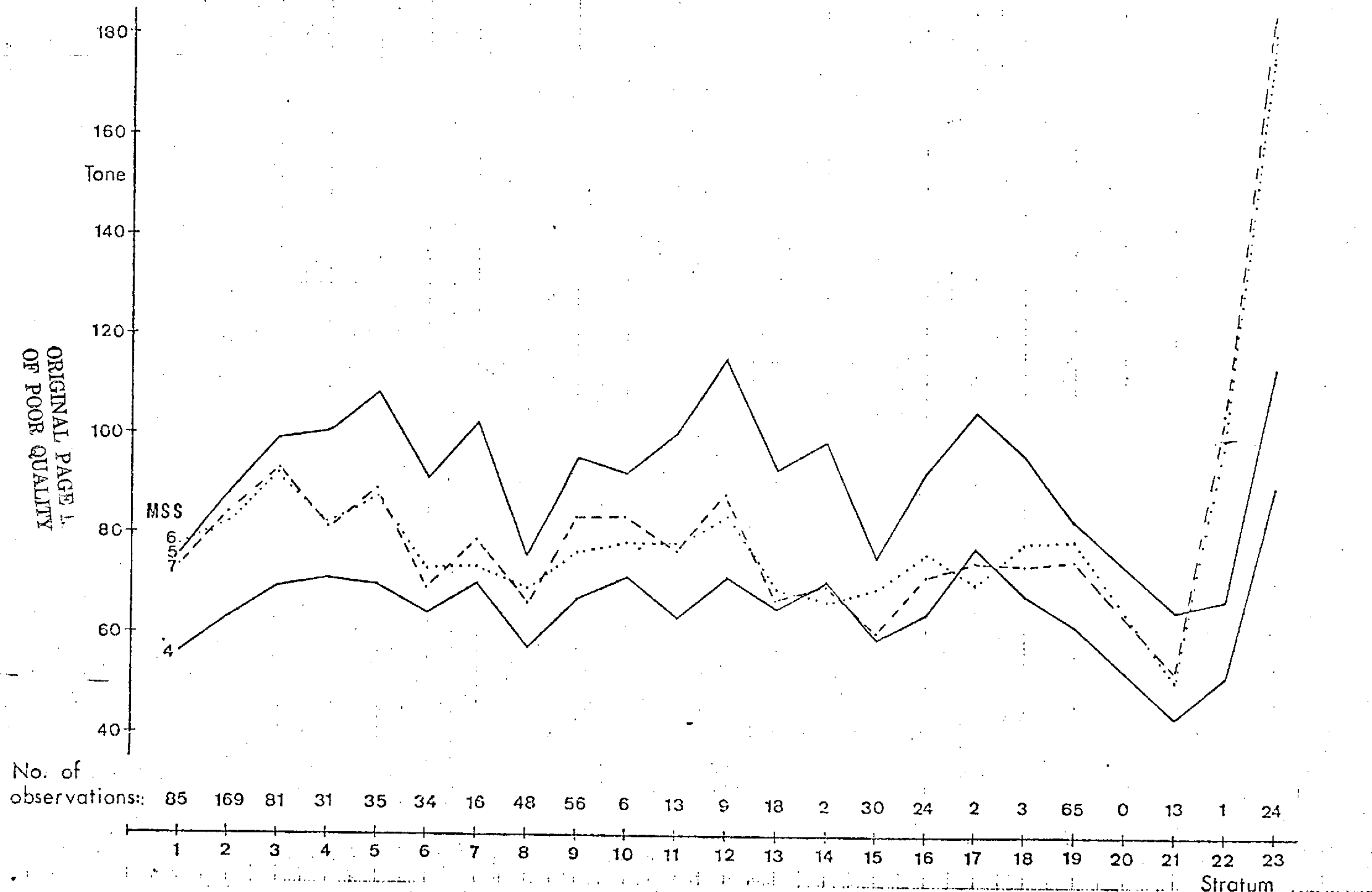


Fig. 8. Tones of strata for all tracts.

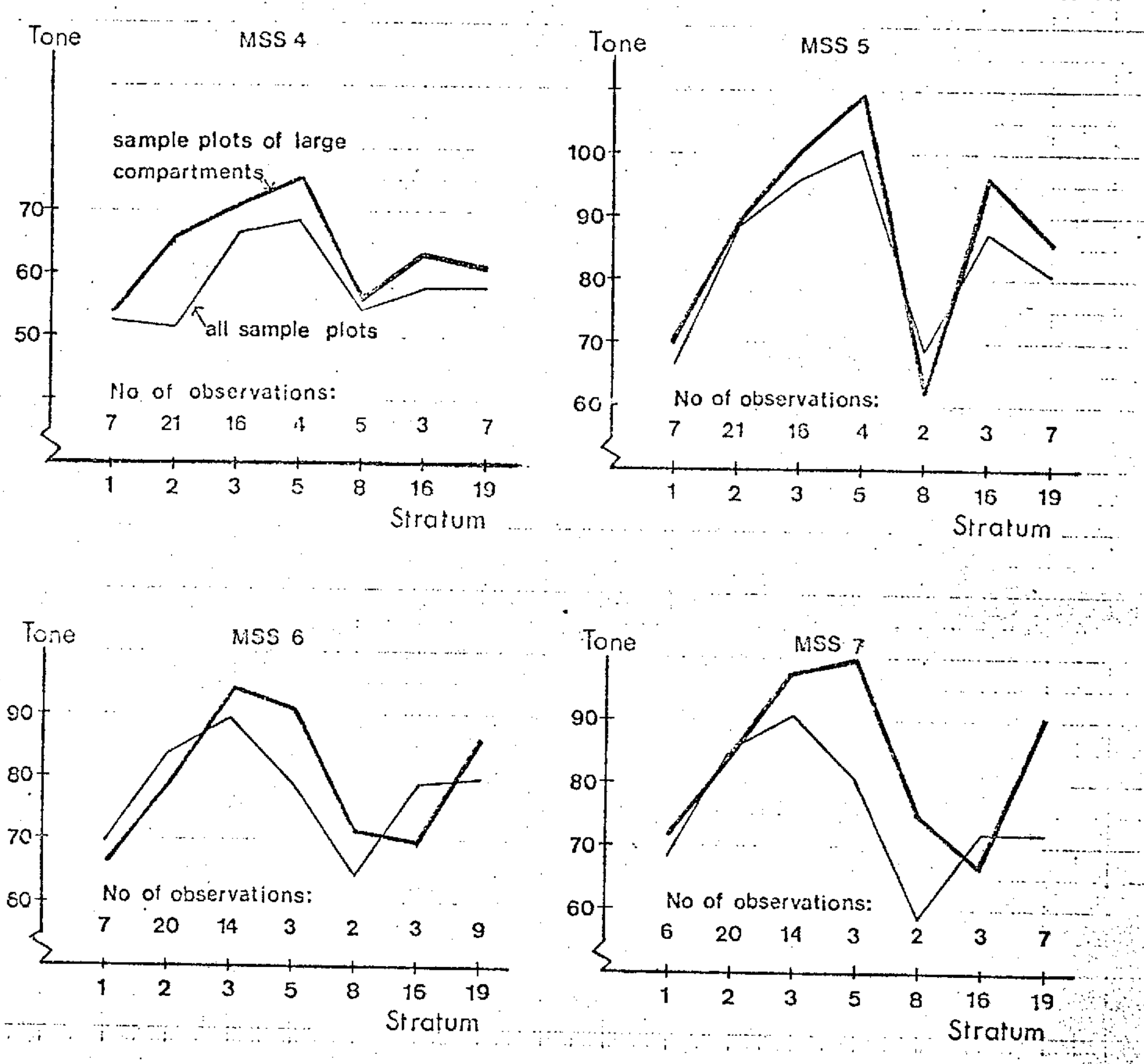


Fig. 9. Tones of large compartments, with those of all sample plots for comparison.

Characteristic species on waste land	No. of obser-vations	MSS			
		4	5	6	7
Betula nana	7	49	67	66	51
Carex	12	59	72	68	56
Sphagnum	9	55	77	77	65
Watary	19	64	87	91	86

Table 4. Tone values of waste land according to some specific vegetation features.

The number of large compartments was about 60 and they were divided into 7 strata. The graphs of Figure 9 indicate that the differences between various strata in Figures 7 and 8 are too small and, consequently, the standard deviations in Table 3 are somewhat too high.

R e g r e s s i o n   f o r   v o l u m e

Another approach in the study of regression was restricted to strata 1...7. The dependent variable to be explained was volume of forest growing stock in total and by tree species: pine, spruce and broad leaves.

Two regression models were tested. The first was of the form $y = a + b_1x_1$ where x_1 = estimate of plot volume from aerial photographs, and the second of the form $y = a + b_1x_1 + b_2x_2 + b_3x_3$ where x_1 = as above, x_2 = tonal value of MSS 5 and x_3 = tonal value of MSS 6. The results are shown in Table 5.

It can be seen in Table 5 that the multiple correlation coefficients are significantly higher for model 2 than for model 1. The relative variances left unexplained by regression estimators have been estimated on the basis of pooled R-values of Table 5. The results are presented in Table 6.

Row	Tract	No. of observations	Model 1					Model 2				
			Degrees of freedom	R				Degrees of freedom	R			
				Pine	Spruce	Bdlf.	All		Pine	Spruce	Bdlf.	All
1	1	37	35	.529	.456	.328	.819	33	.640	.540	.513	.830
2	2	41	39	.000	.778	.666	.896	37	.194	.806	.649	.910
3	3	65	63	.603	.456	.682	.847	61	.689	.669	.727	.833
4	4	61	59	.392	.440	.328	.741	57	.438	.606	.265	.809
5	5	54	52	.254	.232	.446	.640	50	.643	.486	.574	.707
6	6	15	13	.000	.000	.699	.440	11	.000	.000	.709	.226
7	7	57	55	.545	.387	.562	.775	53	.680	.387	.674	.837
8	8	44	42	.547	.503	.284	.814	40	.593	.507	.384	.877
9	Pooled means	374		.405	.433	.489	.771		.542	.546	.551	.809
10	1+2	78	76	.416	.504	.457	.823	74	.510	.476	.491	.838
11	3+4	126	124	.495	.457	.587	.807	122	.608	.618	.600	.858
12	5+6	69	67	.038	.203	.586	.598	65	.584	.348	.683	.634
13	7+8	101	99	.576	.364	.419	.794	97	.650	.423	.480	.853
14	Pooled means			.416	.395	.514	.768		.594	.486	.560	.813
15	All	374	372				.745	370				.784

Table 5. Multiple correlation coefficients for two regression models.

No. of tracts	Row*	Model 1				Model 2			
		Pine	Spruce	Bdlf.	All	Pine	Spruce	Bdlf.	All
1	9	100	100	100	100	85	86	92	85
2	14	99	104	97	101	78	94	90	83
8	15				109				95

* Refers to Table 5.

Table 6. Relative variances left unexplained by the regression estimators for various tract combinations.

The figures of Table 5 and Table 6 are affected by the systematic differences in tonal values and photo interpretations by tracts. The differences shown in Table 2 were not eliminated in this case. The differences in photo interpretation originated largely from the fact that the work was done by three different persons, one of whom was not well experienced.

Table 6 suggests that the usefulness of satellite pictures doesn´t increase when the acreage of inventory area increases. In other words, inconsistencies from one tract to another seem to be larger for MSS tonal values than for photo interpretation. This result was not in accordance with the earliest expectations.

Multiground stratification for volume

The tests leading to the most practical conclusions were performed by stratifying the plots which fell on mineral soil according to four bases. They are marked by letters a, b, c, and d, referring to the procedures of:

a = aerial photo interpretation of plot volume,

b = tone values measured from satellite pictures, where most weight was given to MSS 5 and 6

c = a + b where most weight was given to a, and

d = field estimations of volume in total and by tree species, where most weight was given to total volume.

The plots were stratified tractwise on the bases of a...d to make the strata of three plots as homogeneous as possible. The variances of the volume in total and by tree species were calculated for each stratum. The results obtained are illustrated for total volume in Table 7.

Tract	No. of strata	Basis for stratification				
		a	b	c	d	Total
1	18	249	865	155	7	809
2	15	258	763	244	18	1 294
3	27	293	1066	307	7	1 570
4	21	245	692	234	25	835
5	24	181	248	100	142	362
6	5	151	579	500	34	544
7	27	153	326	141	27	683
8	15	167	62	127	26	603
Pooled		228	585	199	38	874

Table 7. Variances of total tree volumes (m^3/ha) within four kinds of stratification.

Table 7 shows that total variance can be decreased somewhat by the aid of satellite pictures (basis b). Through the use of aerial photographs (basis a) this decrease would be much larger. The use of satellite pictures in addition to aerial photographs (basis c) has had only a minor effect on the variance of total plot volumes within strata. The variances are not affected by systematic differences between tracts because the stratification was made by tracts.

The test procedure of Table 7 was applied also to plot volumes by tree species and to tone values of MSS bands. The results are shown in Table 8 in which the figures refer to pooled variances over tracts (cf. last row of Table 7 and first row of Table 8).

Characteristics	Basis for stratification				
	a	b	c	d	Total
Volume of all tree species	228	585	199	38	874
" " pine	294	326	224	186	427
" " spruce	154	199	139	134	268
" " bdlf.	94	112	74	85	145
Tonal value of MSS 4	163	158	172	161	212
" " " " 5	121	23	60	125	260
" " " " 6	190	95	123	193	254
" " " " 7	389	268	304	413	467

Table 8. Variances of the measures of various measures within strata based on four kinds of stratification.

The variances of tonal values of MSS bands prove that stratification from satellite pictures is based primarily on MSS 5 and MSS 6 (basis b). It also shows the degree with which the variance of tonal values has been decreased when changing from basis a to basis c.

ORIGINAL PAGE IS OF POOR QUALITY

SUMMARY AND CONCLUSIONS

The studies were made on positive transparencies at scale 1 : 400000 processed by ordinary photographic means from bulk product of 1 : 1 million scale. The transparencies were supplied with a grid and dots. The grid was useful when placing the microdensitometric lines and sample plots from aerial photographs. Another important use of the grid was in determining the reference level for the microdensitometric measurements.

The plots were 60 x 60 meters, and the total number of them was about 1000. They were distributed over a large area and they were taken in a reasonably objective way. The plots which fell on the borderline of two greatly different compartments (e.g. the plot included some part heavy stocked forest and other part open area) were eliminated. The proportion of plots of this kind was about 20 %. Thus, the remaining material provided an adequate body of data for statistical analyses.

The procedure of microdensitometric measurements was time consuming because of difficulties in placing the plots from aerial photographs to satellite pictures. It was seen that one of the most important problems to be solved is to find an easy way to mark a relatively small plot from satellite imagery to map or vice versa.

It was found in the tests that there exists a distinct correlation between tonal values of MSS bands and many forestry characteristics (cf. Tables 1 and 3 and Figs. 7 and 8). However, the value of MSS bands in direct estimation of forest characteristics may not be great. The standard deviations within strata (Table 3) are too large. Only estimation of water proved to be reliable.

Nonetheless, the correlation may still be useful for certain forest inventory purposes. When using double sampling the feasibility of first phase sampling depends greatly on how well the characteristics to be inventoried can be stratified by measurements of the first phase.

Fig. 8 and Table 3 show distinct differences between strata, most of which are statistically significant. The standard deviations within strata for MSS bands 4...7 are 10, 14, 14, and 17. The deviations without stratification are 13, 19, 24, and 26 (see Table 3). The comparison of standard deviations indicates that there are good possibilities for using satellite pictures for stratification of large areas in forest inventories. This is due especially to bands 5 and 6. The best result, of course, is obtainable by using a combination of two or more MSS bands.

An endeavor to test the practical value of MSS bands for forest inventory was made under some assumptions which were considered realistic for northern Finland. The forest inventory there is based on double sampling in which the first phase consists of photo interpretations from aerial photography of 1 : 60000. It could be seen that satellite imagery cannot be substituted for aerial imagery at this stage, for example in determining whether a plot belongs to forest land or not. That is why the aerial photography is required, and the question is now whether the use of satellite imagery as an additional source of data is beneficial or not.

The tests to answer this question were restricted to mineral soil, i.e. to strata 1...7 (see Table 1). The characteristics to be estimated were mean volumes of growing stock in total and by tree species. First, multiple coefficients of correlation were studied for two regression models. The first model consisted of plot volumes interpreted from aerial photographs as the one independent variable and the second model had MSS tonal values as an additional independent variable. Another approach was to stratify the plots on the basis of a) aerial photo interpretation only, b) microdensitometric measurements of satellite transparencies alone and, c) aerial photo interpretation and measurements from satellite pictures together. Then, comparison of variances within strata were used to show the possible advantage obtainable from satellite pictures.

Table 5 shows that the multiple coefficient of correlation can be increased when MSS bands are used in addition to photo interpretation. The increase has been approximately from 0.520 to 0.600, in average. If the proportion of variance not explained by the estimator is $1-R^2$, the above increase of R from 0.520 to 0.600 means that the unexplained variance would decrease by about 12 % due to use of satellite pictures.

It was expected that the greatest advantages in using satellite pictures might originate from the fact that the measurements can be made without subjective consideration because the quality of imagery is homogeneous over large areas, and, in this respect, the satellite pictures and measurements differ favorably from aerial photo coverage and photo interpretation. The validity of this expectation was tested by Table 6.

Table 6 showed that the satellite pictures could not meet the expectation of providing a stabilizing factor in estimation of forest growing stock. The improvement in coefficient of multiple correlation due to satellite imagery was not higher for larger material than for separate tracts. This is especially remarkable as the photo interpretations were made by three persons who had different kinds of systematic errors in interpretation. One reason may be that the densitometric measurements may include some missleading differences between the tonal values of separate tracts. The differences in tractwise tonal values were eliminated for Table 3 and Fig. 8 but not for Tables 5 and 6.

The approach of stratifying plots which fell on mineral soil into homogeneous strata resulted in Tables 7 and 8. Stratification and calculations were done by tracts, which eliminated the harmful effect of systematic differences in tonal values between tracts.

Comparison of unexplained variances of plot volumes with total variance produced the following list (cf. Table 8):

Tree species	Total variance	Stratification based on		
		Satellite pictures	Photo interpretation	Both
All	100	67	26	23
Pine	100	76	69	52
Spruce	100	74	57	52
Broadleaf	100	77	65	51

Comparison of these figures leads to the conclusion that the variances can be decreased 15-20 % by using satellite pictures as an additional aid in stratification. This is a somewhat higher percentage than that registered from Table 5 and probably more nearly correct. The satellite pictures alone reduce the relative variance somewhat, but much less than aerial photo interpretation alone.

The potential importance of satellite pictures for forest inventory in northern Finland is probably higher for estimation of volumes by tree species, than for total volume. This conclusion seems justified under the assumption that satellite pictures are used together with panchromatic black and white aerial photographs of 1 : 50000 or 1 : 60000. The interpretation of tree species from these photographs with even modest reliability has often proved to be impossible.

The conclusions to be drawn from the above results might easily be too pessimistic. With better technical facilities the results might have been a bit improved. This is primarily because the locating of sample plots on satellite pictures was not quite correct. It was estimated that displacing of the plots over 60 meters might have happened in 20 % of the plots. The disadvantageous effect of this displacement is indicated in Fig. 9.

Another reason to regard the results as too pessimistic refers to quality of the pictures used. The use of pictures corrected for radiometry or magnetic tapes would probably have produced more favorable results. The experiences obtained emphasize especially that, in addition to the improvement of radiometric accuracy, it is very important to develop techniques for easy and accurate measurement of a sample plot from satellite imagery.

The tests explained here were limited to a few forest characteristics and to pictures taken at one time only. It is to be expected that the usefulness of satellite imagery could be increased markedly by repetition, for at least three reasons: 1) the tonal value of a sample plot is then obtained as a mean from many pictures, 2) the seasonal differences in tonal combinations can be utilized for estimation of a target and, 3) the annual differences in tonal combinations can be utilized for estimation of changes within a target.