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# FOREST INVENTORY BY AERIAL PHOTOGRAPHS

By

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## PREFACE

Whereas the application of aerial photographs to forest inventory is well advanced especially in America, Canada, Sweden, Germany etc., the principles and techniques in regard to aerial photogrammetry are gradually being spread throughout the world. Now, in regard to the estimation of stand volume and its growth to a considerably high degree of accuracy especially in forests extending over a large area, the necessity of reducing inventory cost and cutting down on the inventory period is keenly felt.

Thus, the selection of a practical inventory method with a minimum cost becomes a vital problem. The author is of the opinion that an inventory method based on aerial photographs plus modern statistics is the best qualified to meet the above condition.

According to SEELY, forest inventories can not be adequately carried out without using aerial photographs. In view of the extensive and universal usage of aerial photographs in the United States of America and Dominion of Canada, SEELY's opinion does not seem exaggerated.

The author being in charge of Forest Mensuration at the College of Agriculture of the Hokkaido University since 1947 has repeatedly insisted on the rationalization of inventory methods in forestry and the necessity of aerial photograph's application. Taking forest inventory in Hokkaido as an example, the investigation and re-evaluation of forests ravaged by Typhoon No. 15 in 1954 claim immediate attention. We are convinced that this may only be achieved by using aerial photographs.

Fortunately, the author being given the opportunity to study in America and Canada in the special field of aerial photogrammetry has acquired a considerable amount of knowledge in this direction. It is the intent and desire of the author and various supporters to apply the newly developed principles and techniques in aerial photographs to Japanese forests, primarily in the forest stands of Hokkaido in order to establish or otherwise provide a key to forest inventory. The present paper is a review and discussion of various problems in this direction as presented in literatures plus a report on the author's experiments.

The author wishes to acknowledge the assistance and guidance of various advisors and supporters to whom he is indebted. Dr. Tsutomu MISHIMA, Professor of Forest Management, College of Agriculture, Hokkaido University, Mr. Misao TANIGUCHI, Chief of Tomakomai Experiment Forest, Hokkaido University, Dr. Paul F. GRAVES, Dr. John C. SAMMI, Dr. Bruce F. STANTON, and Dr. Allen F. Horn, Professors of the State University of New York College of Forestry, have made the present studies possible. The author also wishes to acknowledge the valuable assistance of Mr. Yunosuke HISHINUMA and Miss Yōko NAKAO, his corroborators. The author is deeply grateful for their encouragement and their helpful suggestions he has received during his studies. Lastly, the author must add that expense of the present work was mainly defrayed with a grant in Aid for Fundamental Scientific Research from the Rockefeller Foundation.

## CONTENTS

# PART 1. INTRODUCTION

## CHAPTER 1. Historical Development of Aerial Photograph's Application to Forest Inventory

Aerial photographs have been used for developing maps showing a topography and for other purposes such as in forestry. In 1887, the first aerial photographs on record were taken from a baloon by a German forester[2]. Yet, perior to 1919 when WILSON[125] developed a forest stand map from aerial photographs, aerial photographs were in its infancy. Since then, attempts to utilize aerial photographs have been made throughout the world. However, until 1929 when SEELY[110], et al, reported on aerial photographs, no work worthy of note is seen, according to his report, SEELY measured the shadow length of trees directly from aerial photographs and estimated tree height and determined stand volume by using an aerial volume table. Especially in Canada, numerous and valuable work along this line has been reported since. Especially, F.R. WILCOX, G.S. ANDREW, et al, contributed greatly to the development of this study.

In America, GRAFF[120] discussed the necessity of aerial photogrammetry dealing with topography in 1913 and recommended the use of aerial photographs as a means to interpret topography. The study of developing forest stand maps was promoted remarkably during the period of 1919 to 1933. Ecologists–COOPER, CAIN, et al–used aerial photographs to develop plant distribution maps. In 1933, RYKER[99] experimented on identifying tree species directly from aerial photographs in the Sierra Nevada Range in California. In the following year, FOSTER[24] used aerial photographs to measure trees in the bottomland of the Mississippi river, and the techniques of interpreting aerial photographs were adopted by the U. S. Department of Agriculture. During World War II after 1939, the use of aerial photographs increased rapidly, some foresters serving as photo-interpreters in army aerial photogrammetry made special contributions to the establishment of forest inventory method based on aerial photographs and modern statistics. Techniques developed during this period have been applied widely throughout the world since then. R. C.WILSON, E. J. ROGERS, R. N. COLWELL, S. H. SPURR, K. E. MOESSNER, C. E. JENSEN, et al, greatly contributed to the application of aerial photogrammetry to American forestry.

In Germany, an aerial photogrammetry study center under HUGERSHOFF's[33] guidance was established at Tarandt Forest Experiment Station. From 1923 to 1933, German foresters developed forest stand maps by aerial photographs, in addition to this, they measured tree height by parallax difference and measured tree crown diameter directly from aerial photographs. E. ZIEGER, G. MÜLLER, M. R. JACOBS, C. NEUMANN, and other workers contributed greatly to the application of aerial photogrammetry in German forestry. Especially in the Sachsen Forest Experiment Station, aerial photographs were used as an aid to estimate stand volume growth. It may be said that such experiments revolutionized forest inventory in Germany.

In Sweden, aerial photographs were taken widely in 1929 for the purpose of land survey and excellent results were obtained. In the view of this experience, Sweden Forest Experiment Stations applied aerial photogrammetry to forest inventory and obtained far better results than was expected. In 1933, HÄGBERG[120] reported on the techniques of photo-interpretation including method on estimation of stand volume.

After World War II, the use of aerial photographs has greatly increased in America, Canada, and Europe due to the rapid development of aircraft and improvement in aerial cameras and films. Even in several countries of Southeast Asia–Burma, Indnesia, Philipin, Thailand, Vietnam, Cambosia, et al–, a number of forest engineers have recognized that the application of aerial photography in foresty is absolutely necessary to obtain, in a relatively short time, a good overall impression of prevailing forest condition.

Japan aerial photography was utilized for the first time in 1923 in an attempt to map Tokyo after the great earthquake. As for its utilization in forest inventory, all the forests on Saghalin were photographed during 1930 to 1935. These aerial photographs were used in map making and were also used in estimating growing stock in the Saghalin forests. During 1935 to 1939, aerial photographs with a scale of 1 : 15,000 were taken over vast areas in Manchuria for forest inventory purposes. In 1938, the College of Agriculture of the Tokyo University established a course in forest inventory based on aerial photographs. It seems worthy of note that Tokyo University studied aerial photograph inventory methods and the students were lectured on the subject in the Forestry Department. From approximately 1940, several perfectures–Tokyo, Kanagawa, Saitama, and Gunma–adopted aerial photography for the purpose of forest management. After World War II, the Japan isles in its entirety were aerial-photographed by the American Air Force and these aerial photographs with a scale of 1 : 40,000 were loaned to the Japanese Government for the purpose of Japanese industrial development[35]. In 1948, the Japanese Forest Service using the loaned aerial photographs formulated management plans for private and communal forests. In 1952, a topographical map with a scale of 1 : 5,000 and a 10 meter counter line was developed at Tanzawayama district in the Kanagawa prefecture and headwater conservation area in the Tokyo prefecture under the cooperation of the Forest Service, Forest Experiment Station, Japan Forest Technical Association, and Air Survey Company. This was the first fundamental study on aerial photogrammetry in Japan after the World War II. Based on this experience, immediately after the big water damage in the Kinki area, the Ōsaka Branch of Forest Service, the Nara Prefectural Government, and the Wakayama Prefectural Government photographed their respective areas ravaged by floods in an attempt to grasp the actual state and extent of damages and also to make the most of aerial photographs for the purpose of forest management.

In 1954, aerial photographs were used for the investigation of remote forests belonging to private and communal ownerships pending purchasing by the Japanese Government as a protection forest. Moreover at the same time, a fundamental study on photo-interpretation was carried out at the Amagi National Forest in Shizuoka Prefecture under the guidance of Japan Forest Technical Association. Those who played important parts as pioneers in this field were H. NAKAYAMA, C. HARA, M. HORI, U. KIMOTO, K. MATSUKAWA, T. NAKASONE, H. ITAI, N. IMAMI, I. MINE, T. HORIE, N. KAKEBA, J. OHKI, A. HASHITANI, and others.

As mentioned previously, forest inventories based on aerial photographs were carried out in Saghalin and Manchuria approximately 25 years ago. A review of the work reveals that the scope and range together with techniques were well ahead of America and Canada at that time. Work in this field has been renewed since the end of World War II and the Japanese Forest Service, the Forest Experiment Station in Tokyo, Universities, and the Japan Forest Technical Association have been centering their efforts on the following since 1952[95].

**In the case of Forest Service:**

1. Studies on methods of investigating forests by using aerial photographs and training of forest engineers
2. Compiling of data to identify Japanese dominant tree species and forest appearances
3. Analysis of the amount of work done with aerial photographs

**In the case of Forest Experiment Station and Universities–Tokyo and Nagoya-:**

1. Fundamental studies on the development of aerial volume tables
2. Studies on the sampling design using aerial photographs

**In the case of Japan Forest Technical Association:**

1. Identification of Japanese dominant tree species
2. Accuracy of aerial cameras and stereoplanigraph, and analysis of the amount of work done with the above apparatus
3. Analysis of the accuracy on topographical maps
4. Studies on the application of aerial photographs to forestry and the propagation thereof
5. Training of photo-interpreters

# PART II. AERIAL PHOTOGRAPHS USED IN FOREST INVENTORY AND ITS PHOTOGRAPHY

## CHAPTER 2. Fundamental problems in photo-interpretation

### I. Significance of photo-interpretation and its accuracy

In the case of using aerial photographs in forest inventory, it may be said that the techniques and principles belong to the category of applied science. Foresters can obtain much information by making efficient use of aerial photographs. Therefore, it is obvious that foresters are different from photographic engineers who are mainly concerned in the photographs rather than its application. Specialists on aerial photographs are achieving their purpose by making accurate photographs or maps, while foresters must draw information from aerial photographs to contribute to the forestry[3]. The procedure for doing it is called photo-interpretation.

It becomes desirable therefore that foresters must accomplish their work with regard to aerial photographs while aiming at the high accuracy photographic engineers require. However, the balancing between the cost and the accuracy should always be such that foresters will within the cost limit for forest inventory. In other words, at times foresters must be satisfied with a relative accuracy with the cost limit in mind.

### II. Factors governing the quality of photographic images[13,14,16,17)]

Factors governing the quality of photographic images are as follows:

1. Tone and color
2. Image sharpness
3. Stereoscopic parallax
4. Other factors

Tone and color of photographs are influenced by the complicated functions of light conditions such as light reflectivity of the object photographed, light sensitivity of the film employed, light scattering by atmosopheric haze, and light transmission by the filter used.

Image sharpness is also influenced by the complicated functions of aberrations of the lens system, focus of the lens system, image motion at the moment of exposure, and characteristics of photographic materials. Other factors governing the quality of photographic images are time of photography, type of photography, and scale of photographs. Especially, film, filter, scale of photographs, and time of photography should be selected most carefully to fulfil the purpose of the forest inventory planned[117)].

### III. Factors governing the perception and interpretation[17)]

Factors governing the perception and interpretation are as follows:

1. Characteristics of the photo user such as visual and mental acuity
2. Characteristics of the photo user's equipment
3. Techniques employed by the photo user

This thesis does not attach importance to the analysis of factors governing quality of photographic images, perception, and interpretation. The present paper deals mainly with how forest inventory is carried out by using aerial photographs and the techniques of photo-interpretation as modified to be used in Hokkaido for forest inventory.

## CHAPTER 3. Photo Scale

### I. Compution of photo scale

1. For flat terrain[18,101)]

The ratio of a photographic distance between 2 images to the distance on the ground between the corresponding 2 points $\left(\frac{\text{Photo distance } (d)}{\text{Ground distance } (D)}\right)$, when the ground points are situated at sea level, is called the datum scale of the vertical photograph. This datum scale is also expressed by the formula

$$\frac{f \text{ (Focal length of camera lens)}}{H \text{ (Flying height above sea level)}}.$$

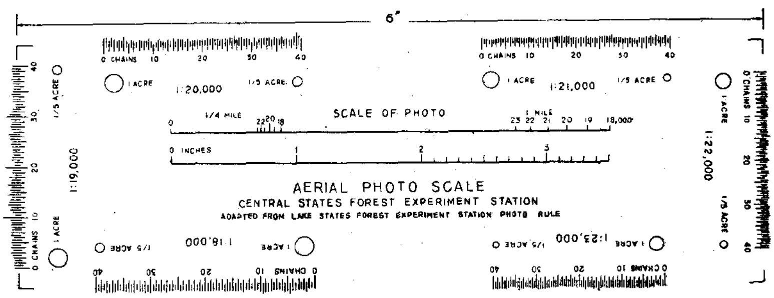
2. For rough terrain

If the terrain is rough, the photo scale changes in accordance with the land elevation above sea level.

(a) How to compute flying height approximately[18,101]

If the flying height is unknown, it is computed by the following formula: $H=\frac{D\cdot f}{d}+\frac{^{h}G_1+{}^{h}G_2}{2}$, where $H$ is the flying height above sea level, $D$ is the ground distance between $G_1$ and $G_2$, $d$ is the photo distance between $G_1$ and $G_2$, $f$ is the focal length of camera, $^{h}G_1$ is the elevation above sea level at $G_1$ point, and $^{h}G_2$ is the elevation above sea level at $G_2$ point.

(b) By using this flying height, the photo scale at $G_3$ point is computed by the following formula: $\text{R. F.}=\frac{f}{H-{}^{h}G_3}$. When the distance between 2 points is measured on aerial photographs, the measurement must be carried out within an effective area near the principal point on aerial photographs[61]. Rogers computed the average photo scale by using 10 lines selected at random on aerial photographs. Every sample plot established on an aerial photograph changes its photo scale in accordance with land elevation above sea level, therefore, the correct area of sample plots must be computed. In this case, the land elevation is obtained by using topographical maps or by computing it in practice. The aerial photo scales shown in Figures 1, 2, 3, are used to determine the size of plot or length on the photograph in each scale.




**Eigure 1.** Aerial photo scale.

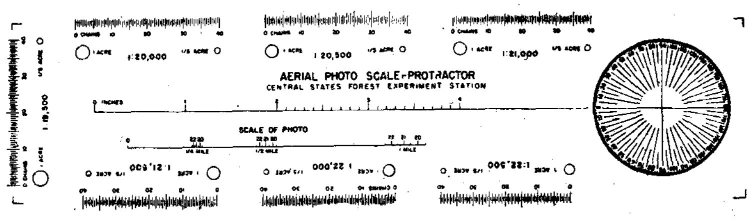



**Figure 2.** Aerial photo scale protractor.

## II. Variations in photo scale

The main cause of variation in photo scale is caused by the difference of the ground elevation. In other words, the flying height varies with the ground elevetion. The focal length of aerial cameras which are generally used in Japan is 210 mm in the case of ordinary angle lens and 115 mm or 150 mm in the case of wide angle lens[52].

If aerial photographs are taken with a 210 mm camera by an aircraft flying

**Table 1.** Diameter of a 1 ha circular plot on a photograph varying with ground elevation.

| Ground Elevation (m) | Flying height (m) | | | | | |
|---|---|---|---|---|---|---|
| | 1,050 | 2,100 | 3,150 | 4,200 | 5,250 | 6,300 |
| 0 | 2.257(cm) | 1.128(cm) | 0.752(cm) | 0.564(cm) | 0.451(cm) | 0.376(cm) |
| 100 | 2.494 | 1.185 | 0.776 | 0.578 | 0.460 | 0.382 |
| 120 | 2.548 | 1.197 | 0.782 | 0.580 | 0.462 | 0.383 |
| 140 | 2.604 | 1.209 | 0.787 | 0.584 | 0.464 | 0.385 |
| 160 | 2.663 | 1.221 | 0,793 | 0,587 | 0.466 | 0.386 |
| 180 | 2.724 | 1.234 | 0.798 | 0.589 | 0.467 | 0.387 |
| 200 | 2.788 | 1.247 | 0.803 | 0.592 | 0.469 | 0.388 |
| 220 | 2.855 | 1.260 | 0.809 | 0.595 | 0.471 | 0.390 |
| 240 | 2.926 | 1.274 | 0.814 | 0.598 | 0.473 | 0.391 |
| 260 | 3.000 | 1.288 | 0.820 | 0.601 | 0.475 | 0.392 |
| 280 | 3.077 | 1.302 | 0.826 | 0.604 | 0.477 | 0.394 |
| 300 | 3.160 | 1.317 | 0.831 | 0.608 | 0.479 | 0.395 |
| 320 | 3.246 | 1.331 | 0.837 | 0.611 | 0.481 | 0.396 |
| 340 | 3.337 | 1.346 | 0.843 | 0.614 | 0.483 | 0.398 |
| 360 | 3.434 | 1.362 | 0.849 | 0.617 | 0.485 | 0.399 |
| 380 | 3.537 | 1.378 | 0.855 | 0.620 | 0.487 | 0.400 |
| 400 | 3.646 | 1.394 | 0.862 | 0.624 | 0.489 | 0.402 |
| 420 | 3.761 | 1.410 | 0.868 | 0.627 | 0.491 | 0.403 |
| 440 | 3.884 | 1.427 | 0.875 | 0.630 | 0.493 | 0.404 |
| 460 | 4.016 | 1.445 | 0.881 | 0.634 | 0.495 | 0.406 |
| 480 | 4.158 | 1.463 | 0.887 | 0.637 | 0.497 | 0.407 |
| 500 | 4.309 | 1.481 | 0.894 | 0.640 | 0.499 | 0.409 |
| 520 | 4.471 | 1.500 | 0.901 | 0.644 | 0.501 | 0.410 |
| 540 | 4.649 | 1.519 | 0.908 | 0.648 | 0.503 | 0.411 |
| 560 | 4.837 | 1.539 | 0.915 | 0.651 | 0.505 | 0.413 |
| 580 | 5.041 | 1.559 | 0.922 | 0.655 | 0.507 | 0.414 |
| 600 | 5.266 | 1.580 | 0.929 | 0.658 | 0.510 | 0.416 |
| 620 | 5.510 | 1.601 | 0.937 | 0.662 | 0.512 | 0.417 |
| 640 | 5.781 | 1.623 | 0.944 | 0.666 | 0.514 | 0.419 |
| 660 | 6.076 | 1.646 | 0.952 | 0.669 | 0.516 | 0.420 |
| 680 | 6.404 | 1.669 | 0.959 | 0.673 | 0.519 | 0.422 |
| 700 | 6.796 | 1.693 | 0.967 | 0.677 | 0.521 | 0.423 |
| 720 | 7.183 | 1.717 | 0.975 | 0.681 | 0.523 | 0.425 |
| 740 | 7.645 | 1.742 | 0.985 | 0.685 | 0.525 | 0.426 |
| 760 | 8.171 | 1.768 | 0.991 | 0.689 | 0.528 | 0.428 |
| 780 | 8.774 | 1.790 | 1.000 | 0.693 | 0.530 | 0.429 |
| 800 | 9.482 | 1.823 | 1.008 | 0.697 | 0.533 | 0.431 |
| 820 | 10.305 | 1.851 | 1.017 | 0.701 | 0.535 | 0.432 |
| 840 | 11.284 | 1.881 | 1.026 | 0.705 | 0.537 | 0.434 |
| 860 | 12.469 | 1.911 | 1.035 | 0.709 | 0.540 | 0.436 |
| 880 | 13.931 | 1.942 | 1.044 | 0.714 | 0.542 | 0.437 |
| 900 | 15.804 | 1.975 | 1.053 | 0.718 | 0.545 | 0.439 |
| 920 | 18.229 | 2.008 | 1.063 | 0.722 | 0.547 | 0.440 |
| 940 | 21.534 | 2.043 | 1.072 | 0.727 | 0.550 | 0.442 |
| 960 | 26.303 | 2.078 | 1.081 | 0.731 | 0.552 | 0.444 |
| 980 | 33.886 | 2.116 | 1.092 | 0.736 | 0.555 | 0.445 |
| 1,000 | 47.412 | 2.154 | 1.102 | 0.741 | 0.558 | 0.447 |

at 1,050 m, 2,100 m, 3,150 m, 4,200 m, 5,250 m, and 6,300 m, the ground above sea level, in each flying height, the photo scale at sea level is respectively 1 : 5,000, 1:10,000, 1 : 15,000, 1 : 20,000, 1 : 25,000, and 1 : 30,000. In such cases, if the average elevation is 500 m, 6 photo scales above sea level will vary as follows: 1 : 2,619, 1 : 7,619, 1 : 12,619, 1 : 17,619, 1 : 22,619, and 1 : 27,619.

The author is convinced that in japanese forest inventory, the most desirable size of sample on aerial photographs is a 1 ha circular plot. The diameter of a 1 ha circular plot is 112.84 m, which is 2.257 cm at 1 : 5,000, 1.128 cm at 1 : 10,000, 0.752 cm at 1 : 15,000, 0.564 cm at 1 : 20,000, 0.451 cm at 1 : 25,000, and 0.376 cm at 1 : 30,000.

In the case of each flying height above sea level, the diameter of a 1 ha circular plot on the photograph varies with the ground elevation as shown in Table 1, and the actual size of circular or square plot on the photograph varies with the photo scale as shown in Figure 3. The second cause of variation in photo scale is caused by the axis of the camera being tilted at the moment of photography. However, the error in photo scale due to tilt is not large[116].

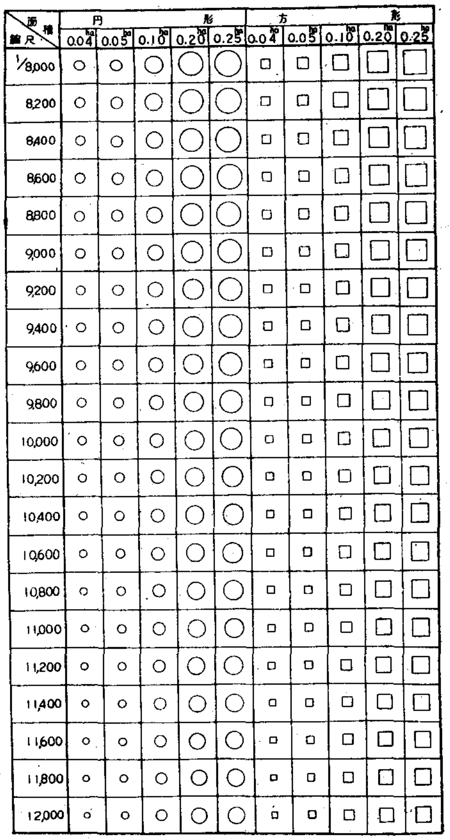



**Figure 3.** Plate showing the size of circular or square plot with regard to photo scale (By Japan Forest Technical Association).

## III. Selection of photo scale for the purpose of forest inventory

The selection of the most suitable photo scale for the purpose of forest inventory is one of the most important problems. The photo scale must be changed in accordance with the contents of information drawn from aerial photographs. Representative information from aerial photographs contains number of trees, tree crown closure, tree crown diameter, tree height, etc.. The stand volume or stand volume growth is estimated as the function of either one or two or more of these factors.

As a rule, the use of a larger photo scale gives a larger amount of information from aerial photographs as compared with a small scale, however as previously mentioned, we must select a suitable photo scale within the cost allowed so as not to exceed the cost limit.

The standard photo scale used in the U. S. Department of Agriculture is 1 : 20,000, which scale is being used broadly in every field, unfortunately, however, it is not quite large enough to give accurate data especially in the case of estimating stand volume or stand volume growth. The most suitable photo scale used in American forest inventory is generally 1 : 15,840 or 1″=1,320′, when more detailed information is required, a scale larger than 1 : 7,200 or 1″=600′ will be used.

If information such as tree form, tree crown shape, tree branches, and cones is required, Sonné's continuous-strip photographs are generally used for the photo-interpretation[76].

According to SPURR's study[116], the effective photo scale is within 1 : 32,000~1 : 5,000, however, the author is of the opinion that 1 : 32,000 is limited to the identification and discrimination of the difference between coniferous wood and hardwood or the difference between forest and non-forest.

Thus, the scale of Japanese aerial photographs taken by the American Air Force after the war (1 : 40,000) is so small that they are of little value for photo-interpretation in forest inventory. The scale of 1 : 15,000 has been recommended by NAKAYAMA who is one of Japanese pioneers in this field[88].

## CHAPTER 4. Season and Films of Photography

Winter photography is highly suitable for the investigation of coniferous wood. The identification of tree species by using Sonné's continuous-strip photographs with a large scale is valuable for the identification of hardwood[111]. Panchromatic film plus minus blue filter or green filter photography is effective to emphasize the contrast among tree species. However, this winter photography is not practical owing to meteorological obstructions.

In fall, especially at the time when tree leaves begin to color, the identification and discrimination of tree species is much easier than in other seasons. However, this type of photography is also not popular owing to approximately the same reason as in winter photography. Panchromatic film plus yellow filter photography is effective in emphasizing the contrast among tree species. Infrared photography is also effective in this season, however, tone and color of hardwood is somewhat darker than in normal cases.

Summer photography has been carried out in every country including Japan because of the absence of meteorological obstructions. Panchromatic film plus green filter or infrared photography is effective in this season[99], however, especially when a larger photo scale than 1 : 10,000 is used, panchromatic photography is more effective owing to its immunity to shadow influence. Summer photographs show a flat appearance and the contrast among tree species is reduced. In addition, tree height measurement often becomes a little complicated owing to the obstruction of hardwood crowns[87].

Spring photographs are suitable for measuring tree height. Unfortunately, the effectiveness of photography in this season is reduced owing to meteorological difficulties[116].

Panchromatic photography generally offers a better resolution and lighter shadows, but exhibits a little tonal contrast among different forest types. Infrared photography presents a maximum of contrast between coniferous and hardwoods, but wet sites and shadows register in black, thus restricting photo–interpretation. In order to separate various forest types without identifying detailed factors in them, infrared photography is the most desirable (Plate 1).

### CHAPTER 5. Influence of Photography-Date upon Photo-Interpretation

In the case of estimating growing stock, standvariables composing the growing stock, and forest stand volume growth, aerial photographs taken most recently must be used. In the area where the forest stand volume growth is high and cutting frequent, photo-interpreters will keenly feel the necessity of the recent photograpes. In southern America, it is noted that aerial photographs older than 5 years depreciate in value owing to the increase in difficulties in interpretation[109]. Foresters in Japan generally used aerial photographs taken by the American Air Force after the war because on other aerial photograph were available for forest inventory. It seems obvious that the utilization of such outdated air maps should be limited to topographical purposes and that reconsiderations be made on the usage of obsolute material.

## PART III. FOREST INVENTORY BY AERIAL PHOTOGRAPHS

### CHAPTER 6. Preparations for Photo-Interpretation

#### SECTION 1. Equipment needed

Equipment considered essential for one interpreter can be had for less than one hundred dollars[29,109]. Generally in America and Canada, photo-interpretation has been carried out effectively and with a resonable accuracy by several foresters and arithmetic mean of their measurement is considered to be correct. It is pointed out that if loaning of equipment is not arranged, the purchasing cost for all equipments may run into several hundred dollars[29,109]. Essential items for photo-interpretation are as follows[109]:

1. Lens stereoscope; folding pocket type (Figure 4)
2. Parallax bar or parallax wedge for measuring object heights
3. Engineer's scale, 6 or 12 inches in length, reading up to 1/50 inch
4. Tree crown density scale

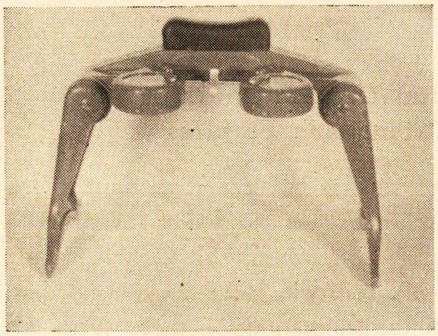


Figure 4–1. Abrams 2–4 Stereoscope Model CB–1.

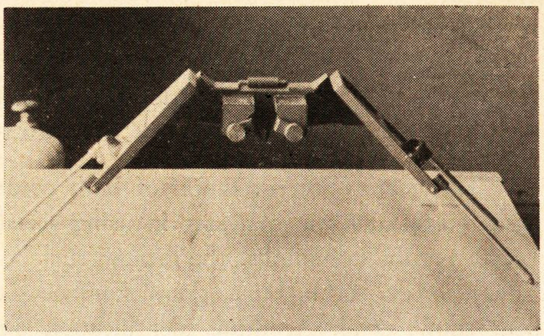


Figure 4–2. Mirror stereoscope commonly used in Japan.

5. Tree crown diameter scale, either wedge or dot type
6. Dot grids for acreage determination
7. China marking pencils for writing on photographbs
8. Drafting instruments, triangles, and drafting tape
9. Needle prick for point picking
10. Clip board for holding stereo-pairs for viewing

Besides the adove, tracing tables, radial plotting devices, vertical sketchmasters, reflecting projectors are required to complete the equipment. Since the equipment is expensive, privately owned equipment is impossible and should be provided by laboratory funds. Moreover, certain items, i.e. parallax bar, parallax wedge, tree crown and diameter scale as used in the U. S. have different scales not used in Japan. Therefore, it is necessary to have a conversion table.

**SECTION 2. Determination of Flight line and Stereoscopic Vision**

**Procedure**[18,23]:

1. Principal points (P. P.) are located at the intersection of lines through opposite fiducial marks.

2. P. P. are then stereoscopically transferred to adjacent photographs, the transferred image centers are called conjugate principal points (C. P. P.).

3. Flight line is accurately determined on each aerial photograph by its own P. P. and C. P. P.

4. The distance between P. P. and C. P. P. is then carefully measured on each aerial photograph which is called photo base. The accuracy of this measurement is within 1/50 inch.[109]

5. The stereoscope is placed with its long axis, parallel to the flight line and with the lenses over corresponding photo images.

6. Pair photos are then slowly moved left and right until the finest stereoscopic vision appears so that flight lines on photographs do not separate from its own position; and then pair aerial photographs are clipped down or fixed with a kind of tape on the board. It is placed in such a way that the photo-

interpretation is done at a constant position.

## CHAPTER 7. Identification and Discrimination of Natural Surface Cover and Man-made Features

The correct interpretation of both natural surface cover and man-made features constitutes the first step in using aerial photographs for forest inventory[108]. Under natural conditions, the ground surface may be covered with various vegetations (timber, scrub, bush, grass, bamboo, et al), bedrock, loose rock, sand, bare soil, snow, et al. Accurate identification and discrimination of these types are frequently of considerable importance for practical purposes. Especially, the most important thing is that the content of vegetations can be identified and discriminated as accurately as possible. The identification and discrimination of tree species conducted generally on a forest stand are based on tree form, characteristics of bark, and the detaild condition of leaf, cone, and seed. On the other hand, in aerial photographs, this identification and discrimination are chiefly based on the condition of visible tree crowns. A physiological appearance of tree crowns is closely related to the following factors:

1. Tone and color
2. Distribution of the size and shape of leaf
3. Distribution of the size and shape of branch
4. Tree height

RYKER[99] conducted investigations in hopes that a correlation between the amount of chlorophyll contained in leaves against tone and color could be established. RYKER attempted to identify 4 tree species—Sugar pine, Ponderosa pine, Douglas fir, and Incense cedar—at Yosemite Valley in California by using photography type reasonably combined with film and filter. In this investigation, Eastman supersensitive panchromatic film plus green filter type was used to make the identification standard in the above 4 tree species. In other words, an identification method of tree species based on both tone and color, and tree crown form. As a result of this investigation, RYKER reported that the amount of chlorophyll was not related to the tone and color but that the age and growing energy of trees were closely related to the amount of chlorophyll. This investigation was limited to open forest stand with matured trees, the photo scale used was 1 : 9,600.

LOSEE[66] attempted to identify tree species–Jack pine, White pine and Red pine, Hemlock, Cedar, White spruce and Balsam, Maple, Yellow birch, and Beech—in Obtibi Power and Paper Company Forest in Ontario, Canada. In this investigation, tone and color of each tree species, tree crown shape and structure of pattern, condition of tree shadows, and characteristics on physiological distribution of tree species were the standard of identifying tree species.

JENSEN and COLWELL[14] attempted to identify tree species by using the following photography type both in the red wood region and the pine region in California. In the photo scale 1 : 20,000, 2 photography types–panchromatic film plus minus blue filter and infrared film plus minus blue filter–were adopted, moreover, in the case of photo scale 1 : 15,000, 3 photography types–panchromatic film plus minus blue filter, infrared plus minus blue filter, and panchromatic film plus green filter–were adopted. Tree species groupes identified in this investigation were commercial conifers, lodgepole pine, non-commercial coniferous, and hardwood. JENSEN and COLWELL reported that the panchromatic film plus minus blue filter was more effective than the others in identifying tree species in aerial photographs with both scales.

On the other hand, SPURR and BROWN[116] reported that infrared film plus minus blue filter was more effective than panchromatic film plus minus blue filter and color film which emphasizes the contrast with regard to tone and color. The photo scale was in the range of 1 : 12,000～1 : 20,000. In these forest inventories of New England, North Carolina, and Alabam, the tree species were generally grouped as coniferous, mixed forest of coniferous, and hardwood.

WIELANDER[130] pointed out in detail that photographic appearance is much more complicated than may be imagined because it is not only influenced by the topographic position but also because it is related to the combination of film and filter, season and time of photography, quality and focal length of lens, and techniques concerning the development and printing of film. Moreover, using aerial photographs covering California and Western Nevada, WIELANDER also reported that basic factors in the identification of timber trees (all coniferous having pulp value) and cordwood trees (coniferous such as Digger pine, Pinon pine, and Juniper) were tone and color of tree crown, structure of its pattern, and tree shadow.

CAROW[12] mentioned that the normal photo scale was 1 : 15,840 and modified infrared film plus filter type was effective in the differentiation of coniferous and hardwood especially in summer and early fall.

YOUNG[136] mentioned that panchromatic film plus minus blue filter was much more superior to the infrared film plus minus blue filter in identifying tree species in northeast of America, moreover, color film photography was disadvantage for the reason why this photography was expensive and also photographic details was indistinct owing to shadows. Thus, YOUNG pointed out the characteristic of each tree species from crown shape, photographic texture, states of ecological distribution of tree species, and characteristic of topography.

From the data at Harvard forest of America on infrared film, the standard of identifying tree species is indicated as follows[107]:

**Darkest**

Black spruce
Red spruce
Balsam fir

Red pine-Scotch pine-Loblolly pine
Jack pine
White pine
White spruce
Hemlock
Larch

**Lightest**

Hardwood

Yellow birch and Maple have been found to photograph darker than most other hardwoods, however, this has not been definitely established as yet. Besides these, flat needle trees such as Hemlock reflect light and do not photograph as dark as Pine and Spruce.

From almost the same view-point as in the case of Harvard forest, LOSEE[63] made public the ranking of light strength of tree images from various combinations of film and filter. This ranking is in the following order:

1. White birch, Aspen, Tamarack
2. Sugar maple, Beech, Yellow birch
3. Red oak
4. Cedar
5. Spruce, Balsam fir

Especially, the ranking of tone and color was expressed in figures based on the difference of density (0.12). Thus, LOSEE studied on the standard of identifying tree species from its own tone and color under a given circumstance.

DAEHN[21] advocated a scale by which to measure tone and color which is called "tone scale". In Japan, the tone scale as shown in Figure 5 has been devised as an aid in photo-interpretation.

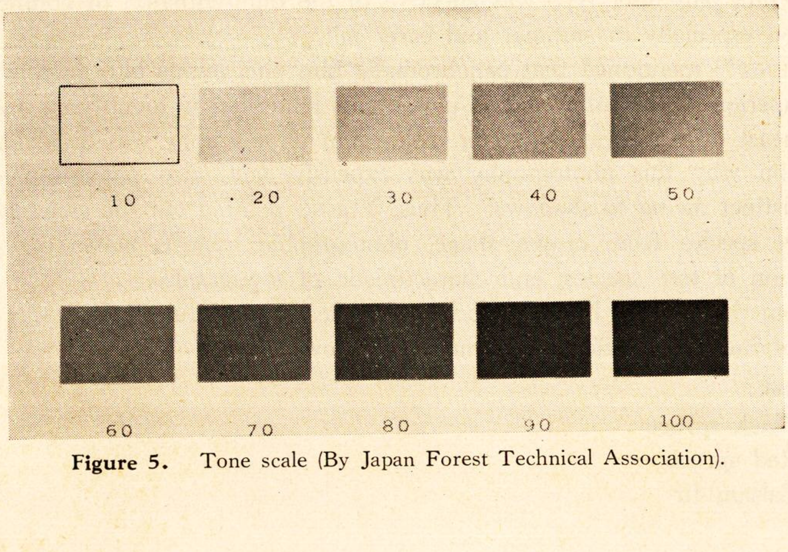



**Figure 5.** Tone scale (By Japan Forest Technical Association).

The Japan Forest Technical Association[51] has conducted studies on the standard of tree species identification in the headwater conservation area of the Tamagawa. The results obtained in this study are as indicated in Table 2. The standard of identifying tree species made by NAKAYAMA[90] is as indicated in Table 3.

These standards are based on crown shape, tone and color, tree shadow, ecological distribution of trees, and vertical and horizontal appearance of trees. The author is of the opinion that since these standards, as HORIE[38] and ITAI[42] mentioned, are correctly used only under special conditions, modifications are necessary in their application to other areas. Even in Canada and America, there is no universal identification standard which can be used in a vast area in so far as the identification of tree species is concerned. Thus, it is imperative

**Table 2.** Standard of identifying tree species in the headwater conservation area of the Tamagawa, Japan.

| Tree species | Tree form | Tone and color | Shadow | Remarks |
|---|---|---|---|---|
| Urajiromomi Baramomi (Fir) | Comparatively large, kegel Top—round | Dark black Slightly light grey | Dark Tree form—distinct | Natural regenerated, pure stand or mixed with Kometsuga (Northern Japanese hemlock) on mountain-top and mountain roof, elevation—more than 1,200 m. Baramomi distributed in hardwood |
| Tsuga (Southern Japanese hemlock) | Irregular crown, small umbrella type Top—indistinct | Dark grey Stunted growth-grey | Slightly light Top—indistinct | Natural regenerated, pure stand or line-like distribution, position—mountain roof, elevation—less than 1,200 m. |
| Kometsuga (Northern Japanese hemlock) | Small crown, normal kegel Top—sharp | Light grey Top—dark grey | | Natural regenerated, the same as the above |
| Sugi (Japanese cedar) | Normal kegel shaped crown Top—distinct | Shady side—dark black grey | Very dark This appears as upright needles to top | Planted |
| Hinoki (Japanese cypress) | Top—indistinct, round | Black grey Sunny side—light, indistinct | Top—indistinct, slightly dark colored | Planted |
| Chousengoyou (Korean pine) | Distinct crown Top appears as spots | Sunny side—whitish grey Shady side—dark grey | Top—indistinct, slightly dark | Planted, limited one area |
| Karamatsu (Larch) | Distinct circular crown, Top—slightly distinct | White spot or whitish grey | Light shadow, however, shows tree form distinctly. | Planted as overwood of Hinoki |
| Nara (Oak) | Irregular shaped crown due to suspended branch groups | Light whitish grey | Indistinct crown, stem looks like wire. | Natural regenerated, most commonly distributed tree species |

**Table 3.** Standard of identifying tree species on aerial photographs (by Nakayama).

| Tree species | Tone and color | Degree of tone and color | Shape of crown | Outward aspect, position, and others |
|---|---|---|---|---|
| Sugi (Japanese cedar) | Grey black | 30—40 | Kegel or round | Each crown in forest stand can be distinguished distinctly and unevenness of crown canopy is remarkable. |
| Hinoki (Japanese cypress) | Grey black, lighter than Sugi | 35—45 | Kegel or round, outline of crown is not so distinct as Sugi. | Each crown in forest stand can not be distinguished so distinctly as Sugi. |
| Matsu (Pine) | Grey black or grey | 40—50 | Shape is similar to Sugi. Outline is indistinct. | Each crown in forest stand can not be distinguished as distinctly as Sugi and Hinoki. |
| Hardwood | Grey | 50—60 | Round or irregular | Each crown in forest stand can •not be distinguished more distinctly than Matsu. Shape of each crown in young forest is generally round. |
| Madake (Bamboo) | Grey | 50—60 | Small shape, round | This species is widely found on hill-sides and river-sides. |
| Mousouchiku (Bamboo) | Light grey, once in a while, similar to white | 60—70 | Small shape, round | This species is distributed near farm houses. |
| Hachiku (Bamboo) | Light grey, once in a while, similar to white | 60—70 | Small shape, round | This species is distributed on hill-sides, Hachiku near farm houses can not be separeted from Mousouchiku. |

that an improvement in photography by a proper combination of film, filter, and photo scale should be made as rapidly as possible together with a local standard of identifying tree species. Natural grass land generally shows a comparatively even texture. The color tone is light to medium grey ordinarily, but may be darker on valley bottoms where water lies near the surface[108].

Man-made features generally contrast with natural surface cover. Man-made features concerned with forest inventory are road, bridge, power line, building, mine, farm, nursery, et al. Our attention must be focussed on the content, size, type, and distribution of natural surface cover and man-made features. Plates (2~6) will give us some perception of identifying natural surface cover and man-made features on the aerial photographs covering the Tomakomai Experiment Forest of Hokkaido University.

# CHAPTER 8. Stand-classification of Aerial Photographs

## SECTION 1. Significance of Stand-classification

The foremost of requirements in photo-interpretation in order to estimate the growing stock of forest stand is to delineate forest stand having different type and appearance for mapping forest stands[130]. Most of the conditions in forest stands may be recognized directly from aerial photographs, however, the information concerning distribution of diameter class, increment, mortality, and quality of trees (sound, blemish, wound rot, etc.) is usually determined from ground survey. It is evident that when the accuracy of photo-interpretation is at its maximum and the cost of ground survey is at its minimum, the cost of delineating forest stands comes to a minimum. Generally speaking, the use of aerial photographs must be conducted with the above in mind.

Fundamental factors of delineating forest stands are tree species, group of tree species, tree crown diameter, tree height, tree crown closure, etc.. These factors are the most appropriate standard for delineating forest stands because measurement of the same can be readily made on the ground and compared with variables on aerial photographs. The standard of delineating forest stands in accordance with the peculiarity of the investigation area takes on combination-forms of factors above-mentioned. Each forest stand which has been delineated corresponds to each stratum in a population of the investigation area. Since the strata generally tend to be more uniform in its contents through such a stratification, the sampling error margin is reducěd to a certain extent[25]. The author is convinced that a great deal of emphasis should be placed on accurately locating type lines. Northern Forest Experiment Station in America[77] calculated the efficiency of delineating forest stands by using SNEDICOR's formula.

## SECTION 2. Standard of Stand-classification

For a maximum accuracy, stand-classification must be done under a stereoscope. Before interpreting aerial photographs, foresters should already have the necessary information on the survey area to be used as guides when examining photographs. Reconnaissance is a chif basis for an accurate photo-interpretation and provides preliminary information on the location of recognized forest type and forest site-estimation which is mentioned in CHAPTER 10.

Natural vegetation is classified by the percentage of ground space covered by component factors or by the combination of patterns[130]. Characteristics with the exception of forest stands–barren, open water, cultivated ground, urban–are also generally described in a forest stand map.

WIELANDER[130] established identification standards for these factors by using tone and color. At this point, the author proposes to review and study some examples of classification standards used at present in Canada and America for the purpose of improving Japanese forest inventory.

## I. Canada[28]

(a) Forest inventory in Nova Scotia

**Height**

| | | |
|---|---|---|
| Up to | 20 feet | 1 |
| | 21–40 feet | 2 |
| | 41–60 feet | 3 |
| | 61 feet and more | 4 |

**Type** (Percentage of total volume per acre)

| | | | |
|---|---|---|---|
| Up to | 25 percent | Hardwood | S (Softwood) |
| | 26– 50 percent | Harnwood | SH (Softwood-Hardwood) |
| | 51– 75 percent | Hardwood | HS (Hardwood-Softwood) |
| | 76–100 percent | Hardwood | H (Hardwood) |

**Canopy density**

| | | |
|---|---|---|
| Up to | 25 percent | 1 |
| | 26– 50 percent | 2 |
| | 51– 75 percent | 3 |
| | 76–100 percent | 4 |

For instance, **3 S 2** as expressed in this code system indicates the following: Tree height, 41–60 feet; type,softwood; canopy density, 26–50 precent.

(b) Forest inventory in New Brunswick

**Non-productive forest**

This forest can not produce merchantable sized timbers.

**Unstocked**

This contains cut-over area, burned area, and field going back to forest.

**Cover type**

| | |
|---|---|
| S | Coniferous occupies more than 75 percent of total volume. |
| SH | Coniferous occupies 50–75 percent of total volume. |
| HS | Hardwood occupies 50–75 percent of total volume. |
| H | Hardwood occupies more than 75 percent of total volume. |

Moreover, height is divided into 3 classes having 20 feet class interval and density also into 3 classes.

(c) Forest inventory in Ontario

**Cover type**

| | |
|---|---|
| Coniferous | 75–100 percent of main stand coniferous |
| Mixwood | 25– 75 percent of main stand coniferous |
| Hardwood | 0– 25 percent of main stand coniferous |

**Forest condition**

Insect damage, fungi damage
Cutting-partial or clear
Blowdown
Burned, but, with vigorous regeneration

**Age class**

Mature
Immature
Reproduction

**Height**

| | |
|---|---|
| 91 feet and more | A |
| 61-90 feet | B |
| 30-60 feet | C |
| Up to 30 feet | D |

**Canopy density**

| | |
|---|---|
| 91-100 percent (fully stocked) | 1 |
| 61- 90 percent (stocking normal) | 2 |
| 31- 60 percent (medium density) | 3 |
| 30 percent and less (open density) | 4 |

Ontario State is so vast that special standards are made for inaccessible areas.

(d) Forest inventory in Manitoba

**Cover type**

| | | |
|---|---|---|
| S | 76-100 percent | Coniferous by basal area |
| M | 51- 75 percent | Coniferous by basal area |
| N | 26- 50 percent | Coniferous by basal area |
| H | 0- 25 percent | Coniferous by basal area |

**Height**

| | | |
|---|---|---|
| 1 | Average height of main stand | 0-10 feet |
| 2 | Average height of main stand | 11-20 feet |
| 3 | Average height of main stand | 21-30 feet |

**Canopy density**

| | |
|---|---|
| A | 0-20 square feet per acre basal area |
| B | 21-40 square feet per acre basal area |
| C | 41-60 square feet per acre basal area |

(e) Forest inventory in Alberta

**Species composition**

Coniferous which reaches to 10 percent or more of total volume and hardwood which reaches to 25 percent or more of total volume are identified as a significant value on aerial photographs respectively.

**Height**

This is expressed by the average height of dominant or co-dominant trees.

| | |
|---|---|
| 1 | 5–30 feet |
| 2 | 31–60 feet |
| 3 | 61–80 feet |
| 4 | 81 feet or more |

**Canopy density**

| | |
|---|---|
| A | Spare stocking |
| B | Medium stocking |
| C | Full stocking |
| D | Over stocking |

Site-classificatiaon in Alberta is very simple. It is expressed as either good or poor, and sign Z stands for poor sites. Thus, the expression **C3 SwPA** in this code system indicates the following contents:

Fully stocked, height 61–80 feet, White spruce most prevalent species, Pine at least 10 percent of stand volume, Aspen at least 25 percent of stand volume, good site.

(f) Forest inventory in British Columbia[11]

**Cover type**

Immature forest
Mature forest
Immature non-commercial cover
Mature non-commercial cover
Not satisfactory restocked
Selection logged forest

Beside these, each stand is characterized by age class, height class, and volume class in accordance with almost the same point mentioned above.

**II. America**

(a) JENSEN's method[45]

JENSEN classified vegetation cover and land. Status elements in California are as follows:

| | | | |
|---|---|---|---|
| *C* | Commercial coniferous | *G* | Grass |
| *K* | Non-commercial coniferous | *M* | Marsh |
| *H* | Hardwood | *B* | Bare ground |
| *S* | Chaparral | *R* | Rock |
| *T* | Sagebrush | *A* | Cultivated land |
| *F* | Bushy herbs | *U* | Urban-Industrial |

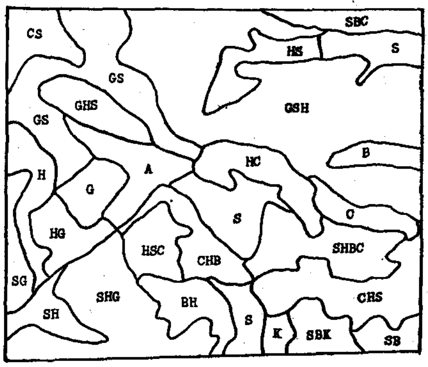



**Figure 6.** A sample map showing the classification of vegeta tion cover and other status elements.

Figure 6 shows a sample map classifying vegetation cover and other land status elements.

Such a classification is attempted on either an aerial photograph or a base map, and sometimes dominant or co-dominant tree species in each forest stand is indicated by sign or color formulated in advance. Classification standard of tree crown closure is as follows:

Dense: Tree crown occupies 80 percent or more of ground space
Semidense: Tree crown occupies 50–80 percent of ground space
Open: Tree crown occupies 20–50 percent of ground space
Very open: Tree crown occupies 5–20 percent of ground space
Unstocked: Tree crown occupies less than 5 percent of ground space

JENSEN's forest stand classification method and its modified version have been broadly used in America and Canada.

(b) WIELANDER's method[130)]

This method was formulated for forests in western Nevada and California.

**Age class**

A Small immature timber trees (under sawlog size)
B Large immature timber trees
C Mature timber trees
D Immature cordwood trees
E Mature cordwood trees

**Tree crown closure**

Dense: Tree crown cover occupies 80 percent or more of ground space
Semidense: Tree crown cover occupies 50–80 percent of ground space
Open: Tree crown cover occupies 20–50 percent of ground space
Very open: Tree crown cover occupies 5–20 percent of ground space

**Age structure**

1 Old growth Mature forest stand occupies 80 percent or more of tree crown space.
2 Old growth–Young growth Mature forest stand occupies 50–80 percent of tree crown space.
3 Young growth–Old growth Mature forest stand occupies 20–50 percent of tree crown space.

| | |
|---|---|
| 4 Young growth | Mature forest stand occupies less than 20 percent of tree crown space. |

Besides these, both CAROW's classification method carried out in Lake States and WOOD's method for Western yellow pine are well known in America.

### III. Japan

According to the preliminary plan for Japanese forest inventory reported by the Forest Service, the stand-classification standard of aerial photographs is as follows:

**Type of forest**

a Natural forest b Artificial forest

**Cover type**

| | |
|---|---|
| N | Coniferous |
| NL | Mixed forest of coniferous and hardwood |
| L | Hardwood |

**Tree species**

| | | | |
|---|---|---|---|
| S | Sugi | Q | Kashi |
| A | Akamatsu | P | Matsu |
| E | Ezomatsu | K | Karamatsu |
| M | Momi | Hi | Hiba |
| Na | Nara | Be | Kaba |
| H | Hinoki | B | Buna |
| Ku | Kuromatsu | EL | Evergreen hardwood |
| T | Todomatsu | DL | Deciduous hardwood |
| Tu | Tsuga | | |

**Age**

| | | | |
|---|---|---|---|
| Up to 20 years | I | 60–100 years | III |
| 20–60 years | II | More than 100 year | IV |

**Height**

| | | | |
|---|---|---|---|
| Up to 8 m | $h_1$ | 16–25 m | $h_3$ |
| 8–16 m | $h_2$ | More than 25 m | $h_4$ |

**Diameter**

| | | | |
|---|---|---|---|
| Up to 10 cm | $d_1$ | 25–40 cm | $d_3$ |
| 10–25 cm | $d_2$ | More than 40 cm | $d_4$ |

**Tree crown diameter**

This is measured by meter unit, however, the standard of diameter class has not been indicated.

Each forest stand stratum can be expressed as Plate 7. However, all things taken together at the present stage of Japanese aerial photogrammetry indicate that such a standard of stand-classification is a little too complicated especially in the case of photo-interpretation of natural forest. Both age and diameter classes in the case of interpreting natural forest are not required.

NAKAYAMA[91] suggested that since it has become necessary to deal with forest statistics from an international viewpoint, it would be desirable to adopt an international classification standard in future.

The author is of the belief that an overly complicated stand-classification standard is not effective in view of the intensity of the present Japanese forestry and it is further suggested that stand-classification standards should rather be subdivided step by step instead of a blind adoption of standards used in America and Canada.

## CHAPTFR 9. Area Determination of Stands delineated and classified

### SECTION 1. Direct Determination of Stand Area in Aerial Photographs

At first, each forest stand is classified and then the area of each forest stand is respectively estimated, if we use vertical photographs of flat terrain and the flying height is constant, the photo scale is not appreciably altered and areas can be measured directly from contact prints, strictly speaking, this is generally impossible, and the area determination usually goes with some errors.

WINKWORTH[132] employed some area determination methods such as 10 dot grids, 20 dot grids, 40 dot grids, transects 0.5 inch apart, transects 1.0 inch apart, and polar planimeter. Their accuracy was compared against each other. In the case of areas with irregular shape, 40 dot grids and one inch transect method gave better results than the others. Especially in America and Canada, the preferred method of determining area on aerial photographs is with dot grids and acreage measuring grid[6] as shown in Figures 7, 8. The author wishes to recommend the use of dot grid method in Japanese forest inventory because the procedure in this method is very simple and the accuracy is high.

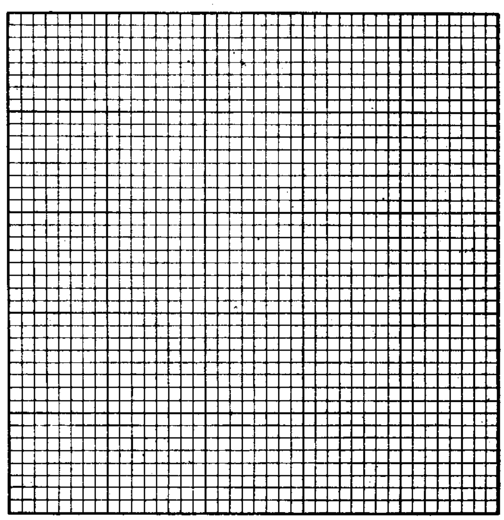


Figure 7. Acreage measuring grid.

Where the area measurement is not critical, the area is measured on aerial photographs, however, the area should be measured within the effective areas of alternate prints in each flight strip. If 9 inch by 9 inch photographs with 60 percent endlap and

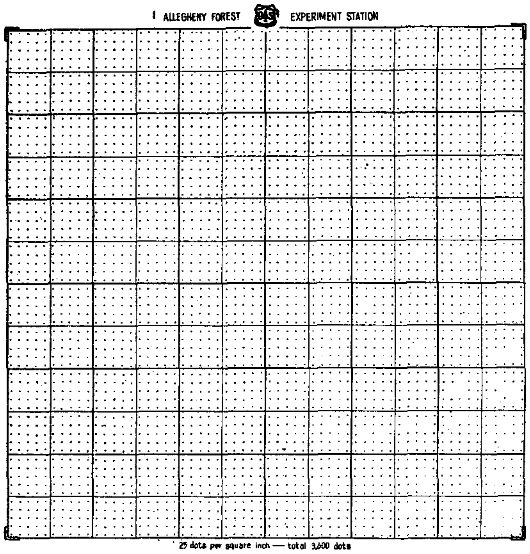



**Figure 8.** Dot grid.

30 percent sidelap are assumed, alternate photographs will have effective areas of about 3.6 by 3.6 inches around the principal points.

**SECTION 2. Area Determination on Base Maps especially developed**

As a rule, a base map is developed by radial line methods[18,23].

1. Aerial photographs with principal points and conjugate principal points are used for developing a base map and the construction of base map requires only the length of one line designated as control line. This line should have well-defined terminal points, the elevations of which are not needed.

2. So-called radial or pass points are chosen near the 4 corners and along margins of each photograph at approximately opposite principal points $X_2$ and $Y_2$ in Figure 9–1 are the pass points for the second photograph, $X_3$ and $Y_3$ for the third photograph etc..

Templets constructed for developing base map.

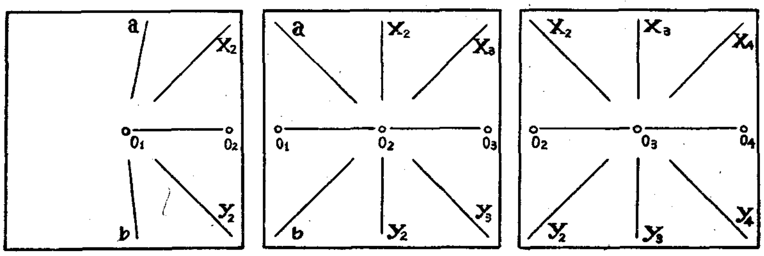
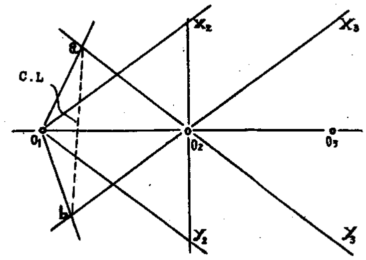



**Figure 9–1.** Radial line method

3. Radial line templets are constructed as Figure 9-2.
4. Upon completion of the above, a suitable scale is chosen, depending upon this scale, the correct map length of the control line AB is calculated (ab on the photograph).
5. Templet No. 1 is taped down on a separate suitable drafting board and then Templet No. 2 is placed on Templet No. 1 with the lines joining at P.P. and C.P.P.. Slide Templet No. 2 along the line until the intersection of the rays through control points. A and B are separated by the correct map distance, which are measured by the scale of the map base selected. Templet No. 2 is then taped down. It will be noted that the map position of the radial points $X_2$ and $Y_2$ can be locatd by the intersection of respective rays.

Principle of radial line method.




C. L.: Correct map distance of AB.

**Figure 9-2.** Radial line method

6. Templet No. 3 is placed on the joining at P.P. and C.P.P. of Templet No. 2 and slide along the line until the rays through $X_2$ and $Y_2$ on Templet No. 3 intersect with the positions of $X_2$ and $Y_2$ already determined.
7. The positons of the control points, pass points, and ray centers are then transferred to a map sheet.
8. Lastly, a vertical sketchmaster, Saltzman projector, and others must be used to project the photographic images-stand boundaries, roads, streams, and other special points.

Since in Japanese forest inventory estimations are made in such a way that stand volume is estimated on each sub-compartment or compartment and also since the volume control is done on every sub-compartment or compartment, the use of stand-classification method indicated in the previous chapters may cause some confusion in Japanese forest management. Therefore, Japanese Forest Service made the preliminary plan for forest inventory based on aerial photographs and tried to relieve this confusion. However, a strict adherence to sub-compartments or compartments which came from Germany will cause insurmountable problems in carrying out forest inventory based on both aerial photographs and sampling methods. The author is of the opinion that as a rule a stand-classification must be done without being restricted by the limitations of sub-compartments or compartments. The author's modified method is that after delineating and classifying forest stands on aerial photographs without being restricted by the limitations of sub-compartments or compartments, compartments in the first periodic block are delineated on the aerial photographs and then the content-stand volume, stand volume volume growth, et al-of each compartment is estimated in detail, other periodic blocks do not need the investigation in each compartment. If the content of sub-compartments is required with regard to the first periodic block, the necessity of maintaining present sub-compartments must be tested by using aerial photographs taken most recently and then the area of each sub-compartment must be newly determined on the aerial photograph or the base map.

## CHAPTER 10. Site Estimation in Aerial Photographs

The principal criteria for site quality in aerial photographs is topography, geologic formations and soils, vegetation, and tree height–tree crown diameter ratio. Topography on aerial photographs is generally exaggerated under a stereoscope and the photo-interpretation is comparatively easy.

It is well known in America and Canada that geologic formation, soils, and vegetation are correlated with topography.

### SECTION 1. Method using Characteristics of Topography

MOESSNER[68] classified the following 3 site qualities in conformity with topography, especially with azimuth.

**Upper slope**

Ridge top, upper 3/4 part of warm south-facing-slope, and upper 1/4 part of cool north-facing-slope

**Lower slope**

Coves, ravines, lower 1/4 part of warm south-facing-slope and lower 3/4 part of cool north-facing-slope

**Bottomland**

Area near stream, and low bench

The degree of the slope is measured in percentage on the photogaaph by using a transparent plate on which printing as seen in Figure 10 was made[69].

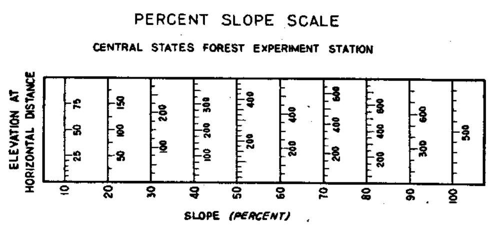



**Figure 10.** Percent slope scale.

SEEIY[114] classified the following 5 site qualities in conformity with topography.

| | |
|---|---|
| Well drained bottom lands | Site I |
| Moderate slopes and bench lands | Site II |
| Steep slopes | Site III |
| Poorly drained flats | Site IV |
| Hilltops and ridges | Site V |

In the forest inventory of Kentucky and southern Illinois, tree height, tree crown diameter, tree crown closure, and stand volume respectively showed significant difference in 3 different topographic sites.

Abitibi Power and Paper Company[66] in Canada classified 5 sites — wet flat, dry flat, lower slope, upper slope, and ridge top.

Losee[62] mentioned that the site difference comes from topographic and agronomical difference, moreover, he reported that the agronomical difference was closely related to the topography as a result of numerous investigations in this field and while it is understood that topography provided an important key in the understanding of site quality, since topography has not as yet been studied to perfection, the site is determined with consideration to both topography and vegetations.

Especially in Canada, a close relationship has been found between site and topography in the presence of outstanding glacier influences. This is due to a progressive change in drainage, soil acidity, and quality of carbon acid gas. Water washed soils, lacking fertility have been formed in the lowest lands by a glacial function, however, such a tendency is not found in the upper lands. A method of expressing site quality from both topography and vegetations is expressed as follows[28]:

| | | | |
|---|---|---|---|
| $V_1$ | Jack pine ridge top | $Y_1$ | Jack pine flat |
| $V_2$ | Black spruce ridge top | $Y_2$ | Poplar flat |
| $W$ | Hardwood upper slope | $Z_1$ | Wet flat |
| $X_1$ | Black spruce lower slope | $Z_2$ | Cedar flat |
| $X_2$ | Mixed lower slope | | |

## SECTION 2. Method using Agronomical and Geological Characteristics

The nature of soils and underlying geologic formations is usually indicated by topographic features[68,116]. A low level area or a bottomland near a stream consists of a fluvial or a lacustrine deposit, in non-forested area, many soil types and geologic formations can be identified directly from aerial photographs, on the other hand, in a forested area, much information concerning soils and geology are obtained in detail by analyzing topography, vegetations, land use, erosion, surface drainage, and other factors. The standard of classifying soils determined by Moessner is as follows[68]:

**Residual soils**

I Western Pennyroyal

This area consists of sand stone, lime stone, and shale. Especially sand stone is dominant.

II Western Pennyroyal consisting of lime stone only

III Western Coal Field

This area contains coal and some other underlying materials.

IV Cumberland

This area consists of sand and gravel in an old coastal plain classified as the Tennessee river section.

**Aeolian soils**

V JACKSON Purchase Loessal

This area consists of heavy loessal mantel covering sand, gravel, and clay in the old coastal plain.

VI This area consists of fine sand mixed with gravel and clay, goes with a partial mantel of loess shown in *V*.

**Alluvial soils**

VII Bottomland (Alluvium)

As a rule, such soil groups are found in bottomland, and this group is easily identified directly from aerial photographs.

### SECTION 3. Method using Characteristics of Vegetations

Vegetation itself is one of the most important factors used for classifying site quality, site indicator plants are already known among us.

Many tree species and groups of tree species can be recognized in aerial photographs, the occurrence of a given tree or a group of trees is sometimes sufficient to permit the identification of underlying soils and classification of site quality. Especially, several tree species–Willow, Hannoki, Yachidamo, etc.—have a high value in classifying site quality. Moreover, characteristics of forest stand such as tree crown canopy, diameter distribution, and tree height distribution are highly related to the site quality.

### SECTION 4. Method using Tree Height-Tree Crown Diameter Ratio[116]

Tree height as well as crown diameter can be measured with a fairly high degree of accuracy in aerial photographs. It is obvious that tree height–tree crown diameter ratio is greater in better sites. Therefore, the ratio of tree height to tree crown diameter provides a measure of site quality.

### SECTION 5. Other Methods

#### I. FERREE's modified method[63]

This method was made public by FERREE and the criteria of this metnod is topography, soil, and growth conditions as defined below:

**Site I**

This site is characterized by moist, well-drained, fairly deep soils, and it is found in protected coves or along streams or bottomlands. In mature forest stands, dominant or co-dominant hardwood trees produce 3 or more 16 foot logs per tree, on the other hand, coniferous being dominant or co-dominant produce

5 or more 16 foot logs.

**Site II**

This site is characterized by soils being intermediate in moisture, depth, drainage, and fertility and is generally found in slope areas or poorly drained plateau lands. Besides these, forest stands that have been cut or burned fall under this site quality classification. In mature forest stands, dominant and co-dominant hardwood trees produce from 2 to $2\frac{1}{2}$ 16 foot logs per tree, on the other hand, coniferous being dominant and co-dominant produce from $2\frac{1}{2}$ to 5 16 foot logs per tree.

**Site III**

This site is characterized by shallow, dry stony, or compact soils and is generally found on ridges and mountain tops.

**II. Site-classification of Petawawa Forest Experiment Station**

From the viewpoint of ecological conditions considering topography, soils, vegetation, Petawawa Forest Experiment Station classified site qualities as follows:

**Ridge series**

*Vaccinium* site type
*Aster–Gaultheria* site type

**Dry series**

*Vaccinium–Gaultheria* site type
*Maianthemum–Corylus* site type
*Trillium* site type

**Moist series**

*Cornus–Maianthemum* site type
*Cornus–Linnaea* site type
*Aralia* site type

**Swamp series**

*Shagnum–Ledum* sity type
*Shagnum–Carex trisperma* site type
*Hylocomium–Mitella* site type
Hardwood swamp

Standards for classifying site quality have not been presented as yet in Japanese forest inventory with aerial photographs. The author believes that the reason for this is that a complicated site classification system is not welcomed. At the present stage in Japanese aerial photogrammetry, this must be considered as an inevitable consequence of circumstances. However, the necessity of site-classification from aerial photographs will increase shortly in Japanese forest inventory.

## CHAPTER 11. Sampling Design

Forest inventory in the old days was carried out using large area investigation principles. However, in recent years the above is being replaced by sampling method. Even in Japan, KINASHI[58] introduced this system and contributed to Japanese forest inventory.

It is known to-day that, in forest inventory, in order to cover vast areas with a high degree of accuracy, aerial photography combined with modern statistic principles must be used[103].

First, aerial photographs most suitable for the purpose of inventory must be adopted and next stand-classification must be conducted as accurately as circumstances permit, in order to reduce the variance of estimating standvariables, the total number of sample plots, and the cost for investigation. It has been mentioned that the confidence interval should be more than 95 percent and the sampling error should not exceed $\pm 10$ percent in order to fulfil the essential purpose of forest management. The sampling design procedure is as given below :

### SECTION 1. Choice of Cruising Method (Strip or Plot)

In strip samples, the majority of trees are generally measured in the direction of the strips established in the investigation area. Therefore, in the investigation area where the distribution of forest type or topography shows a distinct feature, parallel strips running at right angle to this feature become good samples, in which variations are comparatively small. According to the author's experi-[83] ence, in a special crusing covering a small area–200～300 ha, cruising based on sample strips is effective to fulfil the purpose. The number of these strips required should be at least 20–30, furthermore, it is necessary that these strips are so spaced as to cover the entire area. In a vast area, however, the sample strip system seldom represents the entire area. Thus, most of the forest inventories based on aerial photographs especially in America and Canada are based on the plot system — circular, rectangle, and square.

In short, after grasping the general tendency of forest type and topography, the method of crusing (Strip or plot) must be chosen.

### SECTION 2. Plot Size and Shape, Width of Strip

The shape of sample plot is either circular or square or rectangle.

OSBORNE[96] pointed out that if the long axis of sample plot was at right angles to the tendency of forest conditions, the rectangle was the most effective and theoretical. Further, HASEL[118] from his experience in the Ponderosa pine forest reported that sampling errors decreased in such cases.

Quite recently, sampling methods using circular plotting has been generally adopted in American and Canadian forest inventory. A sample plot must at least contain 20–30 trees above the lower limitation of measuring diameter. A large sized sample plot is uaually used for open forest stands containing large sized trees. On the other hand, a small sized sample plot is generally used for small sized trees in dense forest stands. Some examples of plot size are shown in Table 4.

According to HASEL's study[118] on the comparison of cruise accuracy due to the size of sample plot, the sampling effect, using 5 acre plots, was 63 percent of the effect of $2\frac{1}{2}$ acre plots and 10 acre plots were 40 percent of the effect of $2\frac{1}{2}$ acre plots.

BICKERSTAFF[118] pointed out from data collected in Ontario that $\frac{1}{15}$ acre plots required 20 percent additional cruising time when compared with $\frac{1}{10}$ acre plots. As a rule, in America and Canada, 1 acre plots have been adopted in photocruise and are interpreted accordingly. When ground survey is carried out together with photo-interpretation, sample plot areas indicated in Table 4 are established on aerial photographs. The centers are the same as those in 1 acre plots. These sample plots were then allocated on the ground as shown in CHAPTER 11-SECTION 5. Thus, the accuracy of the photocruise may be tested.

**Table 4.** Size of sample plot

| Proposer | Size of sample plot (Acre) | Remarks |
|---|---|---|
| American standard | $\frac{1}{4}$ | Immature forest stand |
| American standard | $\frac{1}{5}$ – $\frac{1}{15}$ | Immature forest stand |
| Gevorkiantz | 1 | Forest stand containing 24″ and more trees in Lake States. |
| Gevorkiantz | $\frac{1}{5}$ | Forest stand containing 10″–22″ trees in Lake States. |
| Gevorkiantz | $\frac{1}{10}$ | Forest stand containing 6″–8″ trees in Lake States. |
| Gevorkiantz | $\frac{1}{15}$ | Forest stand containing 2″–4″ trees in Lake States. |
| Savage | $\frac{1}{2}$ | Mature forest stand in Northwest America |

In Japanese forest inventory[31], the following plot sizes are used: Stand volume estimation—0.1 ha rectangle (25 m × 40 m or 20 m × 50 m). Stand volume growth estimation—0.01 ha rectangle (10 m × 10 m or 5 m × 20 m)., in this case, an increment borer is used.

Volume estimation in young or medium aged forest stand—0.05 ha rectangle (20 m × 25 m). Growth estimation in young or medium aged forest stand—0.005 ha rectangle (5 m × 10 m). In the case of using circular plot, 0.04 ha circular plot is for stand volume estimation, and 0.004 ha circular plot for stand volume growth estimation. When 0.1 ha plot size is not sufficient to obtain detailed data, 0.15 ha (30 m × 50 m) or 0.2 ha (40 m × 50 m) is used. This unit area of sample plot cruised is constant in every stratum classified.

Judging from the present stage of Japanese aerial photogrammetry and technical advancement, the author is of the belief that the most desirable size of a sample plot is 1 ha on aerial photographs and approximately $\frac{1}{3} \sim \frac{1}{10}$ ha on the ground, moreover, the use of a circular plot is highly desirable. According to the author's study at the Tomakomai Experiment Forest of Hokkaido University whose terrain may be considered as a plain, even a 1 ha circular Plot could be transferred to the ground without so much difficulty. To be precise, 6 cruisers took 5.3 houres to transfer a 1 ha circular pot on the ground and to measure standvariables–tree heights and diameters–in it. When applied to an irregular terrain, the shape of a sample plot on the ground is not always tied to the circular one. The reasons for this are as follows:

1. An aerial stand volume table in Japan is generally developed so that it can show us a stand volume per hectar.

2. A considerable amount of difficulties still remain in coming to hand large-scale good-quality aerial photographs covering a vast area.

The width of sample strip cruised is generally 10 m (32.8 feet) in Europe and 1∼1.5 chain (33–66 feet) in north America.

In 1948, H. A. MEYER[118] proposed the usage of a narrow strip 1 rod ($16\frac{1}{2}$ feet width). The main reason for this is that both border lines of sample strip can be easily checked by using $8\frac{1}{4}$ feet pole which is easy to carry.

Accrding to CANDY's study[118], in a sample strip having a 66 feet width, a 20 percent error in basal area was seen and in a 33 feet width sample strip, a 10 percent error was present.

According to SPURR's studies during 1923–1929, the width of sample strip was 3 percent narrower than the exact width in spite of exhaustive work. In short, it is noted that the width of sample strip must be determined so as to contain at least several tree crowns.

If areas sampled are comparatively small and not-continuous, exhaustive attention must be paid in the sampling process. Assuming that they are circular plots, their centers should not be outside the investigation area. Therefore, the center of sample plot must be moved inward so that the entire sample plot enters into the area cruised. In England[118], LAURIE proposed the following techniques to establish sample plots under such circumstances:

1. All sample plots in which centers fell outside of the forest stand were omitted.

2. If a plot-center was allocated on aerial photographs so that more than $\frac{2}{3}$ length of the radius fell inside of the forest stand cruised, the whole of the plot must be moved into the forest stand.

FINNEY and PALCA mentioned that this proposal is most reasonable from a statistical viewpoint.

**SECTION 3. Intensity of Sampling**

Savage determined the number of sample plots required per stratum from GEVORKIANTZ and GIRARD's formula $n=\frac{N\times T^2C^2}{Na^2+T^2C^2}$, where $n$ is the number of plots sampled, $N$ is the entire number of plots that can be possibly established, $C$ is the coefficient of variation expressed by percentage in which 10 is full, and a is the allowable sampling error expressed by percentage in which 10 is full.

Further, Savage studied how the number of plots to be sampled was influenced by factors such as area, coefficient of variation, and sampling error and arranged the result obtained in a table.

BRUNSON and JENSEN[7] calculated the number of plot to be sampled from the so-called "Error Formula" $E^2=\frac{A-Na}{AN}\times f$ by DUERR and GEVORKIANTZ, where $E$ is the accuracy shown by percentage in which 10 is full, $A$ is the area, $N$ is the number of plots required, a is the sample plot size, and $f$ is the constant determined by forest conditions, $f$ was determined at each volume class as follows:

| | |
|---|---|
| 1.31 | 0–1,400 b. f. |
| 0.14 | 1,500–4,900 b. f. |
| 0.09 | More than 5,000 b. f. |

Thus,

To ± 5 percent accuracy, $N=\frac{400\cdot Af}{A+400f}$

To ±10 percent accuracy, $N=\frac{100\cdot Af}{A+100f}$

To ±20 percent accuracy, $N=\frac{25\cdot Af}{A+25f}$

To ±30 percent accuracy, $N=\frac{Af}{0.09A+f}$

These formulas generally increase the accuracy of cruising carried out in areas where large volumes of growing stock exist.

FERREE[25] selected a reasonable number of sample plots previously and then calculated the mixed percentage of the volume belonging to each tree species, its standard deviation, and its probable error. Thus, he determined the number of plots required from the following formula:

$$\frac{\text{Probable error}}{\text{Probability expected}}=\frac{\text{Standard deviation}}{\sqrt{\text{Number of sample plots}}}$$

JOHNSON[118] adopted the formula $n=\frac{\sigma^2}{(SE)^2}$ to determine the number of sample plots, where $n$ is the number of sample plots required, $\sigma$ is the standard deviation of plot-volume in a forest condition class to be sampled, and $SE$ is the allowable probable error.

In the investigation of natural resources in forests based on so-called "Area Sampling"[91] carried out in Japan during 1953–1954, the number of sample plots was given by the formula $0.05 \geqq \frac{2}{\sqrt{n}}\cdot\frac{\sigma}{X}$, where 0.05 is the probable error aimed at, 2 is t value in 95 percent confidence interval, $n$ is the number of plots sampled, $X$ is the average volume per sample plot, and $\frac{\sigma}{X}$ is the coefficient of variation, moreover, in this investigation, 1.3 was used as the average coefficient of variation in all Japan.

In the northeast of America, the following formula has been sometimes used[10]. The number of sample plots on the ground $(m)$ is $\frac{aC}{aA+b\sqrt{AB}}$, where $C$ is the total cruising cost determined previously, $A$ is the cruising cost per sample plot on the ground, $B$ is the interpretation cost per sample plot, a is $\sum pi\cdot Si$ ($pi$ is the area percentage of each stratum and $Si$ is the standard deviation of the volume in each stratum), and $b$ is $\sqrt{\sum pi(\overline{X}-xi)^2}$ ($xi$ is the average volume in each stratum and $\overline{X}$ is $\sum pi\cdot xi$). The number of sample plots on the photo $(N)$ is $\frac{C-mA}{B}$. The division of sample plots to each stratum on the ground is determined by the formnla $r_1=\frac{pi\cdot si}{\sum pi\cdot si}$. Therefore $r_1$ shows the number of sample plots per stratum.

According to the inventory plan for Japanese national forests based on sampling method[31], the number of sample plots is determined by following the process given below. At first, the sampling ratio $(\varphi)$ in each stratum is determined by the formula $\varphi=\left(\frac{2}{E}\right)^2\frac{\sum N_i(\bar{x}_i\cdot C_i)^2}{(\sum N_i\cdot\bar{x}_i)^2}=\left(\frac{2}{E}\right)^2\frac{\sum N_i\cdot S_i^2}{X^2}$, $X=\sum N_i\cdot\bar{x}_i$, $n_i=\varphi\cdot N_i$, where $\varphi$ is the sampling ratio, $E$ is the presumptive error, $\bar{x}_i$ is the presumptive average volume in each stratum, $C$ is the presumptive coefficient of variation in each stratum, $S_i$ is the presumptive variance in each stratum, $n_i$ is the number of plots sampled in each stratun, and $N_t$ is the total number of plots in each stratum. In the national forest administrated by 9 Branches of Japanese Forest Service (except Hokkaido), at the rate of 1 sample plot to 500 and also in 5 Branches of Hokkaido, at the rate of 1 sample plot to 1,000, so-called "Fixed Plot or Permanent Plot" is assumed to be established to determine mortality and growth in a given period. Each formula above-mentioned must be respectively used in accordance with the condition of each stratum. The formula $n=\frac{4AC^2}{e^2A+4aC^2}$ is the most popular in the present day Japan, where $n$ is the necessary number of plots, $A$ is the total number of plots or the total area, $C$ is the coefficihnt of variation of stands, a is the area of 1 plot, and $e$ is the sampling error percent.

### SECTION 4. Allocation of Sample Plots on Aerial Photographs

When the plots to be sampled from each stratum are determined, they must be allocated on aerial photographs and then equally distributed all over the stratum. In order to allocate sample plots on aerial photographs, a transparent plate on which 1 acre circular plots were equally curved has been used in America and Canada. Through a hole in the center of each circular plot, a needle point is pierced to mark the position of plot-center on an aerial photograph.

In order to allocate sample plots on a stratum, the random number is generally used. Such an allocation of sample plots must be done within the so-called "Effective Area" in aerial photographs. The effective area of each photograph is determined on each photograph. We are assured of better results because the interpretation is confined to the minimum central position where the distortion and error due to topography, tip, and tilt are minimum.

If the area to be cruised extends a vast scope, aerial photographs are numbered and placed a pile. Next, a photograph is taken from the pile by using the random number[35]. The transparent plate is then covered on the photograph and the random number is used again. If the number selected falls in the stratum, it is pin-pricked as a sampling unit location, if it does'nt, the photographisis returned to the pile. Thus, this procedure is repeated until the required number of sample plots is pin-pricked on aerial photographs.

In Japan, grid lines 5 mm or 1 cm square are drawn on a working map with a scale of 1 : 20,000, a topographical map with a scale of 1 : 50,000 is also sometimes used for this purpose. Instead of drawing grid lines directly on a working or a topographcal map, a transparent plate as shown in Figure 7 has been used in Japan. Grid points are then numbered in every stratum and the number of sample plots determined previously is allocated in each stratum by using the random number.

## SECTION 5. Method by which Sample Plots are transferred on the Ground

In general, the accuracy of forest inventory based on aerial photographs is checked by ground measurement. The centers of sample plots determined on aerial photographs are transferred by measuring the distances and its directions from the ground points having a outstanding characteristic. In this case, it is necessary that the distances are properly corrected by considering the angle of inclination. The most desirable thing, of course, is to have.the same sized sample transferred to the ground. However, since this is difficult, in America, 1 acre sample plot has been adopted on aerial photographs and $\frac{1}{2}\sim\frac{1}{3}$ acre sample plot on the ground.

## SECTION 6. Mathematical Basis for estimating the Magnitude of Population

In the estimation of the magnitude of population from aerial photographs, a sampling desigh based on the stratification has been adopted by pioneers in the field of aerial photogrammetry. The real value of stratification comes when the strata are delineated so that the variation of stand volume or other values to be estimated within a given stratum is much less than that for the entire forest. The stratification in this case means the stand-classification from aerial photographs mentioned previously. At first, sample plots are chosen at random from each stratum in the forest and then the stand volume–as an example–is estimated in each stratum. The growing stock of entire forest can be estimated through the following procedure:

The magnitude of population $X=\sum_{i=1}^{L}X_i=\sum_{i=1}^{L}\sum_{j=1}^{N_i}x_{ij}$ can be assumed from $X'=\sum_{i=1}^{L}X'_i=\sum_{i=1}^{L}\left(\frac{N_i}{n_i}\sum_{j=1}^{n_i}x_{ij'}\right)=\sum_{i=1}^{L}\left(\frac{N_i}{n_i}\cdot x'_i\right)$, in other words, $X'$ is an unbiased estimate of $X$, the variation in this case is $V(X')=\sum_{i=1}^{L}N_i^2=\frac{N_i-n_i}{N_i-1}\frac{\sigma_i^2}{n_i}$

$$=\sum_{i=1}^{L}\left(\frac{N_i}{n_i}\right)^2\frac{n_i}{n_i-1}\sum_{j=1}^{n_i}(x'_j-\bar{x}')^2\frac{N_i-n_i}{N_i}.$$

where $i$ ··· Symbol of each stratum

$j$ ··· Symbol of unit in each stratum

$N_i$ ··· Total number of units in each stratum or Area of each stratum

$n_i$ ··· Number of samples in each stratum or Sampling area in each stratum

$\sigma_i^2$ ··· Population variance in each stratum

$\hat{\sigma}_i^2=S_i^2\frac{N_i-1}{N_i}$ $\qquad S_i^2=\frac{\text{Sum of square}}{n_i-1}$

$X'_i$ ··· Total estimate of samples in each stratum

$$\text{Sampling error of mean} \cdots \left( \frac{t\sqrt{\frac{S_i^2}{n_i} \frac{N_i-n_i}{N_i}}}{\bar{x}'_i} \right) \times 100$$

In the stratified sampling method, the number of plots to be sampled is determined independently in each stratum, however, in the proportional sampling method, the sample weight in each stratum is respectively equal ratio. Accordingly, in the case of using the latter method, $\frac{n_i}{N_i}=f_i$, $\frac{n_1}{N_1}=\frac{n_2}{N_2}=\cdots=\frac{n_L}{N_L}=\frac{n}{N}=f$.

$X'=\frac{1}{f}\sum_{i=1}^{L}\sum_{j=1}^{n_i}x_{ij'}=\frac{1}{f}\sum_{i=1}^{L}x'_i$, the variance in this case is $V(X') \doteqdot \frac{1-f}{f}\sum_{i=1}^{L}N_i\sigma_i^2$

where $f\cdots$ Percentage to be sampled

Since the area sampled changes in accordance with the variation in ground elevation, the elevation at necessary points must be calculated by using a height finder or a topographical map and then the photo scale must be determined to calculate the correct area. The total of these corrected areas is an essential sampling area ($n_i$).

### SECTION 7. Importance of Double Sampling in Forest Inventory based on Aerial Photographs

Double sampling is widely used in timber cruising and research of timber increment. This method is also highly important in forest inventory based on aerial photographs. In a broad sense, double sampling may be applied to any sampling scheme, when applied to stratified random scheme, the standard error and other pertinent statistics are found by covariance analysis. When applied to a simple random classification, the standard error of the estimate of the dependent variable are found by regression analysis. The stand volume per ha or other standvariables may be estimated on aerial photographs and then only a selection of the stands may be transferred to the ground to remeasure the stand volume per ha or standvariables in detail. The correlation between photo and ground estimates for the selection in question may form the basis for correcting the photo estimates of those stands not measured on the ground, the results from aerial photographs always may be recalculated and they may be greatly improved.

## CHAPTER 12. Measurement of Standvariables in each Sample Plot

### SECTION 1. Tree Count

NEUMANN[84] counted the number of trees in 15 Spruce forest stands on aerial photographs with a scale of 1 : 7,500. The error was −8.9 percent, when small sized trees under 10 cm in diamter at breast height were omitted, plus errors from

2.3 to 12.4 percent were found in 7 forest stands, and minus errors from 2.0 to 14.5 percent were found in other 7 forest stands while there was no error in 1 forest stand.

NASH[87] counted the number of trees above 4″ and more in diameter at breast height on aerial phtographs with a scale of 1 : 7,200 and checked the accuracy of photo-interpretation. There was −4.8 percent error in coniferous wood and −4.3 percent in hardwood.

FERREE[25] mentioned that the number of invisible trees contained in the lower layer was necessary in order to obtain the accurate number of trees and a table concerned with invisible trees had to be locally made from ground survey.

YOUNG[135] expressed the percentage of trees which could be contained in a forest stand as a function of both reciprocal of trees and photo scale. Thus, he pointed out that by changing the photo scale from 1 : 3,500 to 1 : 15,840, the accuracy of counting number of trees in 2 groups of tree species–Spruce fir and Pine Hemlock–approximately decreased by 20 percent.

According to NAKAYAMA's study[92], the systematic errors of the tree counts compared with the dominant trees always gave minus errors and ranged from −5±34 trees to −60±46 trees per ha both at a 95 percent probability, however, −15±8 trees per ha at the same probability was obtained for all the sample plots. The standard errors of estimate of each locality ranged from ±56 trees to ±90 trees per ha, while it was ±75 trees per ha for all the plots and these percentage of the average number of trees per ha ranged from ±8 percent to ±12 percent, while it was ±11 percent for all the plots.

In order to determine the possibility of forest inventory by aerial photographs, some tests were carried out on 3 cruisers (undergraduates) under the supervision of the author at the Tomakomai Experiment Forest of Hokkaido University. In these tests, large scale photographs—1 : 5,200 panchromatic summer photography as shown on Plates 2∼6–were utilized, and the estimates were made by the cruisers who had not been previously trained in photo-interpretation.

The first step in our photo-interpretation was to count the number of trees in each of the 44 hardwood sample plots —the size of a sample plot is 0.2 ha— representing the condition of the Tomakomai Experiment Forest ravaged by the Typhoon No. 15 in 1954, and the estimates obtained from aerial photographs were checked against a careful ground measurement. The number of trees counted on the ground were divided into 2 groups—dominant trees and suppressed trees, and then the number of trees interpreted from aerial photogrphs were com-

**Tabl 5.** Distribution of the number of dominant trees per plot.

| No. of trees | No. of plots | % |
|---|---|---|
| 0– 50 | — | — |
| 51–100 | 14 | 31.8 |
| 101–150 | 15 | 34.1 |
| 151–200 | 10 | 22.7 |
| 201–250 | 3 | 6.8 |
| 251–300 | 1 | 2.3 |
| 301–350 | 1 | 2.3 |
| Total | 44 | 100.0 |

pared only with the former.

The number of dominant trees in the 44 sample plots ranged from 65 to 310 trees per ha. The distribution of the number of plots by the number of dominant trees per ha is shown in Table 5, and the distribution of the number of plots by symbol of error in tree count from aerial photographs in Table 6. If the estimates were compared with the total number of trees on the ground, all sample plots would show minus errors. The absolute errors of tree count on aerial photographs ranged from 0 to 125 trees per ha, and most of these errors were made in plots under 50 trees. The percentage errors ranged from 0 to 45.4 percent and most of them were under 30 percent (Table 7).

**Table 6.** Error of tree count showed by plus and minus symbols.

| Symbol | No. of plots | % |
|---|---|---|
| 0 | 1 | 2.3 |
| − | 39 | 88.6 |
| + | 4 | 9.1 |
| Total | 44 | 100.0 |

**Table 7.** Distribution of the number of plots by absolute and percentage error in tree count from aerial photographs.

| Absolute error class | No. of plots | % | Percentage error lcass | No. of plots | % |
|---|---|---|---|---|---|
| 0– 25 | 25 | 56.8 | 0–10 | 15 | 34.1 |
| 26– 50 | 10 | 22.7 | 11–20 | 9 | 20.5 |
| 51– 75 | 5 | 11.4 | 21–30 | 10 | 22.7 |
| 76–100 | 1 | 2.3 | 31–40 | 6 | 13.6 |
| 101–125 | 3 | 6.8 | 41–50 | 4 | 9.1 |
| Total | 44 | 100.0 | Total | 44 | 100.0 |

Lastly, the error of tree count was summarized as shown in Table 8. Through *t*-test, a significant difference could be recognized between ground measurement and photocruise at a 5 percent level. The average error of all sample plots is $-31\pm10$ trees per ha at a 95 percent probability and the averge error percentage may be regarded as approximately−23 percent, however, these errors tended to be eliminated when correction factors of each photo-interpreter were used.

**Table 8.** Error of tree count from aerial photographs (at a 95 percent probability)

| | Ground | Photo | Difference |
|---|---|---|---|
| $M$ | $137\pm16$ | $106\pm10$ | $-31\pm10$ |
| $\sigma$ | $56\pm12$ | $34\pm\ 8$ | $32\pm\ 6$ |
| $t$-test | | | * |

$M$: Arithmetic mean.
$\sigma$: Standard deviation of arithmetic mean.

### SECTION 2. Tree Crown Closure

Tree crown closure is defined as the proportion of the area of a stand or other homogeneous unit covered by the crown of trees. Tree crown closure can be measured on both aerial photographs and the ground.

According to NASH and MOESSNER's studies[67], tree crown closure is closely related to the growing stock. There are several methods of determining tree crown closure on aerial photographs which are listed as follows:

1. Method by using dot grid[109,124]
2. Method by using tree crown density scale[67]
3. Method by using "Reverse Moosehorn" photo aid[87]

1. The dot grid as shown in Figure 8 is placed on the photograph and dots falling on tree crowns are counted. The tree crown closure is shown as the proportion of the total number of dots within the area investigated.

2. The tree crown density scale which was made previously as shown in Figure 11 is used for the determination of tree crown closure.

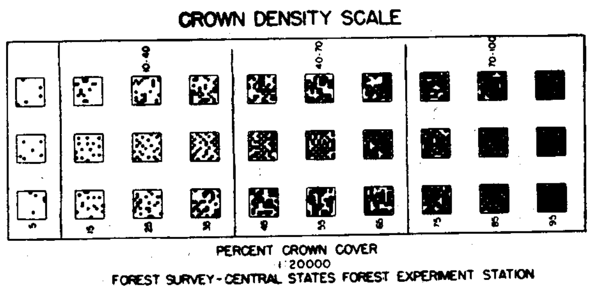



**Figure 11.** Tree crown density scale.

3. This method is quite similar to the transect method. An instrument with dots carved on a thin transparent film as shown in Figure 12 is placed on the photograph to measure the tree crown closure and the number of dots falling on the tree crowns is counted accurately. This procedure is repeated at the constant interval–one quarter of an inch–until it covers the entire area to be investigated.


**Figure 12.** "Reverse Moosehorn" photo aid.

$$\text{The tree crown closure is } \frac{\text{Number of dots counted}}{\text{Number of rows} \times \text{Number of dots within a row}} \times 100$$

NASH highly praised this method, however, it is obvious that the photo scale should be large enough to recognize dots. The author ventures to point out that since black dots are sometimes apt to be indistinct on white and black photographs, they should be improved.

WORLEY and MEYER H. A.[128] compared the dot grid method with the tree crown density scale method as to 93 sample plots especially by changing photo-interpreters respectively and determined significant systematic error and personal error. Through this study, no significant difference due to different tools could be recognized, however, significant difference in regard to the measurement accuracy of tree crown closure between photo-interpreters could be recognized in some degree.

Tree crown closure estimated directly from aerial photograph must be checked by measurement values from the ground. In older times, a projection of tree crowns was developed to calculate a tree crown closure. Recently so-called "Moosehorn Crown Closure Estimator" as shown in Figure 13[98] has been used for this purpose. Tree crowns are peeped at through a peep sight ring and the area of tree crowns covered is measured in the same manner as in the dot grid method.

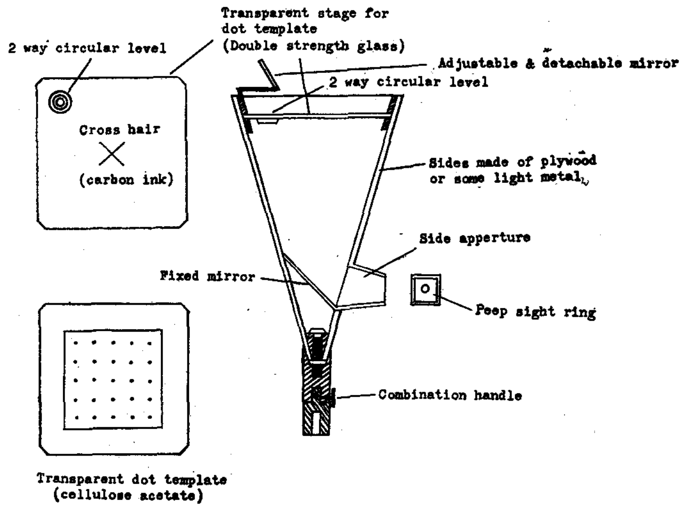



**Figure 13.** Sectional view and parts of the "Moosehorn Tree Crown Closure Estimator".

NASH[87] compared the measurement values obtained by "Moosehorn Crown Closure Estimator" on the ground with the values obtained from aerial photographs. In this case, aerial photographs taken of the Sonné camera with a scale of 1 : 600 were used and the average tree crown closure of 11 forest stands was 4.9 percent smaller than that of the ground survey.

The author tested the accuracy of photocruise concerning tree crown closure in Compartment 29 of the Horonai Working Unit of Tomakomai Experiment Forest by the following method:

At first, an instrument with grid carved on the transparent film as shown in Figure 7 is placed on the area to be investigated, and then the tree crown density scale as shown in Figure 11 is placed beside the photograph and is slided up and down until the densities in each grid on the photographs and the scale correspond.

The average tree crown closure of Compartment 29 obtained through this procedure was 61.1 percent. Next, the author selected 8 sample strips on the ground and developed the projection maps of individual tree crown to estimate the actual tree crown closure. Thus, the author obtained 56.6 percent. Namely, no remarkable difference could be recognized between both estimates.

## SECTION 3. Tree Crown Diameter

There are 3 methods to measure the tree crown diameter, namely,

1. Method of using tree crown diameter scale (Dot size) printed on a piece of film as shown in Figure 15[46]
2. Method of using a micrometer wedge shown in Figure 14
3. Method of using a stereoscopic micrometer

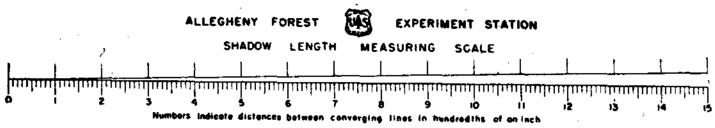



**Figure 14.** Shadow length measuring scale.

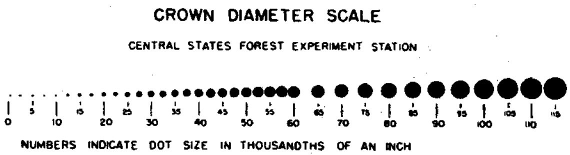



**Figure 15.** Tree crown diameter scale (Dot size).

In the case of measuring tree crown diameter, it is very effective to use a supplementary table showing the relation between the tree crown diameter expressed by $\frac{1}{1,000}$ unit and the actual tree crown diameter in each photo scale as shown in Table 13.

LOSEE[65] measured tree crown diameters of 22 uniform forests in Canada on aerial photographs with a large scale by using a stereoscope. Tree crown diameters were measured with the average error of $-0.09 \pm 0.33'$ at a 95 percent probability on aerial photographs with a scale of 1 : 1,200. However, tree crown diameters could not be satisfactorily measured on aerial photographs with a scale of only 1 : 7,200.

WORLEY and MEYER H. A.[128] reported that 3 photo-interpreters measured 36 trees 2 times by using the dot sized tree crown diameter scale and the micrometer wedge. The results obtained by these tools were compared with each other. Through this study, no significant difference due to different tools could be recognized, moreover, no significant difference in regard to the accuracy of measuring tree crown diameter between coniferous wood and hardwood could be recognized.

NAKAYAMA[92] reported that the systematic error of the average tree crown diameter estimation showed plus or minus values and ranged from $-0.2 \pm 0.2$ m to $0.5 \pm 0.3$ m at a 95 percent probability, while the average value for all sample plots was $-0.01 \pm 0.06$ m at the same probability.

The second step in our photo-interpretation was to estimate the average tree crown diameter per plot. Tree crown diameters in each plot were measured with a crown diameter scale as shown in Figure 15. The same 44 hardwood sample plots which were used for the tree count test, previously mentioned, were also used for this estimation, and the crown diameters of all dominant trees in each of the sample plots were measured on the ground. These average tree crown diameters ranged from 4.0–8.4 m. The distribution of the number of plots by average tree crown diameter are shown in Table 9.

**Table 9.** Distribution of the average tree crown diameters per plot.

| Average crown dia. (m) | No. of plots | % |
|---|---|---|
| 3.0–4.0 | 1 | 2.3 |
| 4.1–5.0 | 20 | 45.4 |
| 5.1–6.0 | 11 | 25.0 |
| 6.1–7.0 | 8 | 18.1 |
| 7.1–8.0 | 2 | 4.6 |
| 8.1–9.0 | 2 | 4.6 |
| Total | 44 | 100.0 |

Next, approximately $\frac{1}{4}$ of the dominant trees in each plot were chosen at random on aerial photographs as sample trees for estimating the average tree crown diameter, and the estimates obtained through this procedure were compared with those measured from the ground. As shown in Table 10, most of the sample plots showed plus errors.

**Table 10.** Error of the estimation of average tree crown diameter showed by plus and minus symbols.

| Symbol | No. of plots | % |
|---|---|---|
| 0 | 2 | 4.6 |
| − | 3 | 6.8 |
| + | 39 | 88.6 |
| Total | 44 | 100.0 |

The absolute errors in this case ranged from 0 to 3.5 m, which were distributed irregularly in each class as shown in Table 11.

**Table 11.** Distribution of the number of plots by absolute and percentage error in average tree crown diameter estimation from aerial photographs.

| Absolute error class (m) | No. of plots | % | Percentage error class | No. of plots | % |
|---|---|---|---|---|---|
| 0–0.5 | 11 | 25.0 | 0–10 | 15 | 34.0 |
| 0.6–1.0 | 2 | 4.6 | 11–20 | 2 | 4.6 |
| 1.1–1.5 | 10 | 22.7 | 21–30 | 8 | 18.2 |
| 1.6–2.0 | 2 | 4.6 | 31–40 | 4 | 9.1 |
| 2.1–2.5 | 6 | 13.6 | 41–50 | 6 | 13.6 |
| 2.6–3.0 | 10 | 22.7 | 51–60 | 9 | 20.5 |
| 3.1–3.5 | 3 | 6.8 | | | |
| Total | 44 | 100.0 | Total | 44 | 100.0 |

The percentage errors ranged from 0 to 60 percent and approximately $\frac{1}{5}$ of all sample plots showed errors exceeding 50 percent. The reasons for this are as follows :

1) The 3 interpreters who participated in this photocruise had a tendency to select the larger trees as samples.

2) 2 or more tree crowns were liable to be interpreted as a single tree crown, especially in the hardwood forest.

**Table 12.** Error of average tree crown diameter estimation (at a 95 percent probability).

| | Ground (m) | Photo (m) | Difference (m) |
|---|---|---|---|
| *M* | 5.5±0.32 | 7.1±0.26 | 1.6±0.36 |
| σ | 1.1±0.24 | 0.8±0.18 | 1.2±0.26 |
| *t*-test | | | * |

*M*: Arithmetic mean.
σ: Standard deviation of arithmetic mean

Through this experience, the author keenly feels that techniques for distinguishing individual tree crowns in hardwood forest must be further improved.

The error of average tree crown diameter estimation was summarized in Table 12. Through t-test, a significant difference could be recognized between ground measurement and photocruise at a 5 percent level. The average error of all sample plots is 1.6±0.36 m at a 95 percent probability and the average error percentage may be regarded as approximateley 29 percent.

**Table 13.** Actual tree crown diameter for photo tree crown diameter and photo scale.

| Photo crown diameter (Thousandth of 1 cm) | Photo scale (m) | | | | |
|---|---|---|---|---|---|
| | 1 : 10,000 | 1 : 15,000 | 1 : 20,000 | 1 : 25,000 | 1 : 40,000 |
| 5 | 0.50 | 0.75 | 1.00 | 1.25 | 2.00 |
| 10 | 1.00 | 1.50 | 2.00 | 2.50 | 4.00 |
| 15 | 1.50 | 2.25 | 3.00 | 3.75 | 6.00 |
| 20 | 2.00 | 3.00 | 4.00 | 5.00 | 8.00 |
| 25 | 2.50 | 3.75 | 5.00 | 6.25 | 10.00 |
| 30 | 3.00 | 4.50 | 6.00 | 7.50 | 12.00 |
| 35 | 3.50 | 5.25 | 7.00 | 8.75 | 14.00 |
| 40 | 4.00 | 6.00 | 8.00 | 10.00 | 16.00 |
| 45 | 4.50 | 6.75 | 9.00 | 11.25 | 18.00 |
| 50 | 5.00 | 7.50 | 10.00 | 12.50 | 20.00 |
| 55 | 5.50 | 8.25 | 11.00 | 13 75 | 22.00 |
| 60 | 6.00 | 9.00 | 12.00 | 15.00 | 24.00 |
| 65 | 6.50 | 9.75 | 13.00 | 16.25 | 26.00 |
| 70 | 7.00 | 10.50 | 14.00 | 17.50 | 28.00 |
| 75 | 7.50 | 11.25 | 15.00 | 18.75 | 30.00 |

## SECTION 4. Tree Height

When a tree height measurement is attempted directly from aerial photographs, either displacement or parallax difference or length of tree shadow is required. Displacement is obtained from a single photograph and others are obtained from pair photographs.

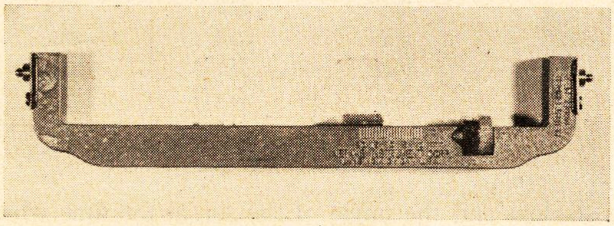
### 1. Displacement method[116]

The formula from which tree height is calculated is $h=\frac{d \cdot H}{r}$, where $h$ is the height in feet, $d$ is the length of tree image in inches on the photograph, $r$ is the distance of the top of the tree from nadir point in inches, and $H$ is the flying height in feet. However, this method is not actually used so often.

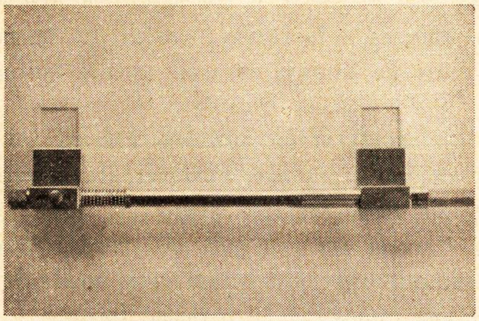
**2. Parllax difference method**[1,65,72,100,115,122]

The standard parallax formula is $h=\frac{H \cdot dp}{b+dp}$, where, $h$ is the height in feet, $dp$ is the parallax difference in inches, $b$ is the distance between P.P. and C.P.P., and $H$ is the flying height. With the exception of America and Canada, such measurement methods of tree height has been broadly adopted in every country lately. It is the author's hope that this method will be adopted in Japanese forest inventory based on aerial photographs. The most important instruments in measuring the parallax difference are a parallax wedge and a parallax bar–height finder–as shown in Figure 16. In the case of using these American or

1. Abrams Height finder Model HF–2.



2. Parallax bar commonly used in Japan.



3. Parallax wedge.

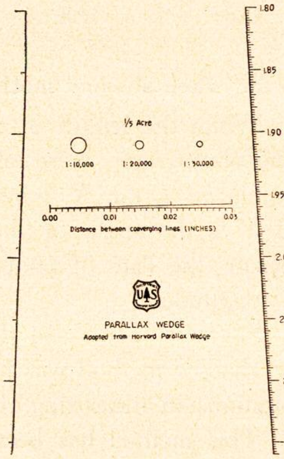



**Figure 16.** Parallax bar (Height finder).

Canadian instruments for the purpose of investigating Japanese forests, it is emphasized that the measurement unit should be converted into Japanese unit prior to usage. We also need supplementary tables as shown in Table 14 to calculate the tree height simply. Since a parallax bar has a measurement unit expressed in mm, we can calculate tree height in m by measuring photo base in cm. Accordingly, a parallax bar is far more convenient for Japanese forest inventory than a parallax wedge.

**Table 14.** Parallax bar conversion factors for use with deviced reading to 0.01 mm parallax ($dp$).

| Photo base $b$ (cm) | Height (m) per millimeter of $dp$, for scales ($RF$) of | | | | |
|---|---|---|---|---|---|
| | 1 : 10,000 | 1 : 15,000 | 1 : 20,000 | 1 : 25,000 | 1 : 40,000 |
| 6.50 | 31.8 | 47.7 | 63.6 | 79.5 | 127.3 |
| 6.75 | 30.6 | 46.0 | 61.3 | 76.6 | 122.6 |
| 7.00 | 29.6 | 44.4 | 59.1 | 73.9 | 118.3 |
| 7.25 | 28.6 | 42.8 | 57.1 | 71.4 | 114.2 |
| 7.50 | 27.6 | 41.4 | 55.2 | 69.0 | 110.5 |
| 7.75 | 26.7 | 40.1 | 53.5 | 66.8 | 106.9 |
| 8.00 | 25.9 | 38.9 | 51.8 | 64.8 | 103.7 |
| 8.25 | 25.1 | 37.7 | 50.3 | 62.8 | 100.6 |
| 8.50 | 24.4 | 36.6 | 48.8 | 61.0 | 97.6 |
| 8.75 | 23.7 | 35.6 | 47.4 | 59.3 | 94.8 |
| 9.00 | 23.1 | 34.6 | 46.1 | 57.6 | 92.2 |
| 9.25 | 22.4 | 33.7 | 44.9 | 56.1 | 89.8 |
| 9.50 | 21.9 | 32.8 | 43.7 | 54.7 | 87.4 |
| 9.75 | 21.3 | 32.0 | 42.6 | 53.3 | 85.3 |
| 10.00 | 20.8 | 31.2 | 41.6 | 52.0 | 83.1 |
| 10.25 | 20.3 | 30.4 | 40.6 | 50.7 | 81.1 |
| 10.50 | 19.8 | 29.7 | 39.6 | 49.5 | 79.2 |

### 3. Tree shadow method

When the length of tree shadow and the angle of the sun at the time when aerial photographs were taken are known, the tree height can be calculated by the formula $h = L \tan X$, where $h$ is the tree height, $L$ is the length of tree shadow, and $X$ is the angle of the sun in degrees. In order to calculate the angle of the sun, the date of photography must be known as well as the latitude and the longitude.

SEELY[112] mentioned that when the angle of the sun was known, while this tree shadow method was highly convenient in practice, however, there were many limitations in measuring the tree height from the tree shadow.

This method has been used in Canada for the past 20 years. When the tree shadow falls on the ground without any obstruction, this method can be used accurately. However, it is almost impossible in a dense forest.

NASH[87] reported that in the case of measuring tree heights ranging from 20 to 60 feet, the standard error was 2.2～2.5 feet. Especially with regard to the characteristics of tree shadow, the splendid studies by COLWELL, JENSEN[14] and LOSEE[63] can not be overlooked.

SPURR[116] mentioned that if the photo-interpretation was done by skilled engineers, the parallax difference method would give us far more accurate values than the shadow method and the error of height measurement would not be over 10 feet and in general the difference of measurement value between aerial photographs and the ground would be within 5 feet.

MOESSNER, BRUNSON, and JENSEN[71] indicated that the average error of 38 forest stand heights was not larger than 6 feet on aerial photographs with a scale of 1 : 20,000 and the standard error was 10 precent.

LOSEE[65] measured tree heights on 2 large scale photographs of 1 : 7,200 and 1 : 1,200, and obtained the average error $0.6 \pm 2.1'$ for the former scale and $2.1 \pm 0.5'$ for the latter scale.

SAMMI[106] studied the cofficient of variation for repeated tree height measurements and found that this increased with parallax difference.

MOESSNER[72] calculated the average of forest stand heights directly fom 3 different scale photographs and compared with measurement values on the ground, however, no remarkable difference could be recognized due to the photo scale.

NAKAYAMA[92] reported that the systematic error of average tree height estimation always showed minus values and these errors ranged from $-1.1 \pm 1.0$ m to $-3.0 \pm 0.8$ m at a 95 percent probability. The standard error of estimation for the average of all sample plots was $\pm 2.8$ m which was $\pm 14$ percent of average tree height, however, this percentage decreased to $\pm 11$ percent when the systematic error was excluded.

The third step in our photo-interpretation was to estimate the average tree height per plot. Tree heights in each plot were measured with a parallax bar as shown in Figure 16–2. The same 44 hardwood sample plots which were used for the tree count and the average tree crown diameter estimation tests, mentioned previously, were also used for this estimation, and the heights of all dominant trees in each of the sample plots were measured on the ground.

These average tree heights ranged from 11.7 to 20.3 m. The distribution of the number of plots by average tree height as shown in Table 15, most of the sample plots were under 18 m.

Next, approximately $\frac{1}{4}$ of the dominant trees in each plot were chosen at random on aerial photographs as sample trees for estimating the average tree height, and the estimates obtained by this procedure were compared with those

**Table 15.** Distribution of the average tree height per plot.

| Average tree height (m) | No. of plots | % |
|---|---|---|
| 11.0–12.0 | 3 | 6.8 |
| 12.1–13.0 | 3 | 6.8 |
| 13.1–14.0 | 12 | 27.2 |
| 14.1–15.0 | 10 | 22.7 |
| 15.1–16.0 | 6 | 13.6 |
| 16.1–17.0 | 2 | 4.6 |
| 17.1–18.0 | 5 | 11.4 |
| 18.1–19.0 | — | — |
| 19.1–20.0 | 2 | 4.6 |
| 20.1–21.0 | 1 | 2.3 |
| Total | 44 | 100.0 |

**Table 16.** Error of the estimation of average tree height showed by plus and minus symbols.

| Symbol | No. of plots | % |
|---|---|---|
| 0 | 2 | 4.5 |
| − | 37 | 84.1 |
| + | 5 | 11.4 |
| Total | 44 | 100.0 |

measured from the ground. As shown in Table 16, most of the sample plots showed minus errors.

The absolute errors in this case ranged from 0 to 5.5 m, and most of them were under 4.0 m. The percentage errors ranged from 0 to 38.4 percent, and most of them were under 30 percent as shown in Table 17.

**Table 17.** Distribution of the number of plots by absolute and percentage error in average tree height estimation from aerial photographs.

| Absolute error class (m) | No. of plots | % | Percentage error class | No. of plota | % |
|---|---|---|---|---|---|
| 0–1.0 | 11 | 25.0 | 0–10 | 15 | 34.1 |
| 1.1–2.0 | 7 | 15.9 | 11–20 | 11 | 25.0 |
| 2.1–3.0 | 13 | 29.6 | 21–30 | 12 | 27.3 |
| 3.1–4.0 | 7 | 15.9 | 31–40 | 6 | 13.6 |
| 4.5–5.0 | 3 | 6.8 | | | |
| 5.0–6.0 | 3 | 6.8 | | | |
| Total | 44 | 100.0 | Total | 44 | 100.0 |

The error of average tree height estimation was summarized in Table 18. Through t-test, a significant difference could be recognized between ground measurement and photocruise at a 5 percent level. The average error of all sample plots is $-2.3\pm0.61$ m and the average error percentage may be regarded as approximately $-15$ percent.

**Table 18.** Error of average tree height estimation from aerial photographs (at a 95 percent probability).

| | Ground (m) | Photo (m) | Difference (m) |
|---|---|---|---|
| $M$ | $14.9\pm0.61$ | $12.6\pm0.73$ | $-2.3\pm0.61$ |
| $\sigma$ | $2.0\pm0.42$ | $2.4\pm0.51$ | $2.0\pm0.44$ |
| $t$-test | | | * |

$M$: Arithmetic mean.
$\sigma$: Standard deviation of arithmetic mean.

### SECTION 5. Stand Volume

With aerial photographs suitable for the purpose of forest inventory and an aerial stand volume table or an aerial tree volume table, the total stand volume ($X'$) of sample plots chosen from each stratum can be readily determined. Since the area of each stratum ($N$) has already been determined by the method mentioned previously, the total stand volume of each stratum is calculated from the formula $X'=\frac{N}{n}x'$, where $n$ is the area of plots sampled. Lastly, the stand volume of each stratum is totalized.

According to Spurr, the initial studies concerning the determination of stand volume from aerial photographs was carried out in Germany during 1925–1933. Later, foresters in Canada–Wilson, Seely, and Andrews—opened up a new field from a view-point of practical application and developed aerial stand volume tables based on tree crown closure or tree height, together with volume tables from tree crown closure and tree height. Likewise, foresters in various countries have respectively developed aerial stand volume tables.

**1. Estimation of Stand Volume by Aerial Stand Volume Table**[19,32,78,86,97]

The accurate number of trees in forest stand can not be obtained directly from aerial photographs with ordinary quality and photo scale. Accordingly, it has been said in America and Canada that aerial tree volume tables fail to play an important part in photo-interpretaiton, if aerial photographs taken most recently and reliable aerial stand volume tables can be obtained, average stand volume per unit area can be estimated with a minimum of field work. Estimates are made in terms of gross volume, as amount of cull or defect can not be adequately estimated.

The aerial stand volume table by MOESSNER[73] which has a historical significance in American and Canadian forest inventory was developed from the relationship between the volume per acre and standvariables—tree crown diameter, tree crown closure, and tree height. The aerial stand volume table in American Central States developed by BRUNSON and JENSEN and the aerial stand volume table of Loblolly pine and Slash pine in California developed by MINOR are quite similar to MOESSNER's table above-mentioned. In addition to this, SPURR developed aerial stand volume table of White pine and Loblolly pine from the relationship between stand volume per acre and tree height. Pole also developed aerial stand volume table of Douglas fir from the relationship between stand volume per acre and standvariables—tree height and tree crown closure. There are many others besides these in America and Canada.

According to the preliminary plan for Japanese forest inventory based on sampling method[31], the aerial stand volume table will be developed by following the procedure given below:

1. Using base map, working map, forest inventory book, and working book, forest divisions such as working unit, compartment, and sub-compartment are filled in on aerial photographs under a stereoscope. If a forest stock in a sub-compartment or a compartment is not homogeneous, the forest stock is generally subdivided under the stereoscope so as to render it homogeneous. However, this division is usually done within the effective area of aerial photographs.

2. The field book for sampling inventory is divided into dominant tree species and 5 age groups of forest stand age; 1–10 years, 10–20 years, 20–40 years, 40–60 years, and 60 years or more, moreover, hardwood natural forest is divided into young (1–20 years), medium (21–60 years), and old (61 years more). The stand-classification is in proportion to the idea of stratification.

3. Forest stock division is done on tree species contained in the upper layer of the forest.

4. With regard to the points surveyed on the ground, in the case of an

artificial forest, at first, sample plots of 50 m square (One side line has a corresponding length of 5 mm on aerial photographs with a scale of 1 : 10,000) are established on the photographs and then the number of tree crowns in each square on the photographs is counted. However, in the case of natural forest, the average tree crown diameter is calculated after measuring each tree crown diameter by using wedge or stereoscopic micrometer. If the average tree crown diameter can not be determined on aerial photographs, the number of tree crowns is used instead of the average tree crown diameter.

5. The volume determination formula per ha should be made depending on the number of trees recognized directly from aerial photographs especially in the case of photo-interpretation in artificial forest. On the other hand, in the case of natural forest, the average tree crown diameter obtained directly from aerial photographs is used to make the volume determination formula and then the aerial stand volume table is developed by this formula. The form of the simplest aerial stand volume table is shown in Table 19. The procedure of developing aerial stand volume table in Japan may be considerably simplified since it is not necessary to express the content by "board feet" unit.

**Table 19.** Aerial stand volume table.

Name of working unit__________ Dominat tree species__________

| Number of trees on the photo / Stand age | (   ) $m^3$ | (   ) $m^3$ | (   ) $m^3$ | (   ) $m^3$ | (   ) $m^3$ | (   ) $m^3$ |
|---|---|---|---|---|---|---|
| 1—10 | | | | | | |
| 11—20 | | | | | | |
| 21—30 | | | | | | |
| 31—40 | | | | | | |
| 41—50 | | | | | | |
| 51—60 | | | | | | |
| 60 more | | | | | | |

Remarks: i. This table is developed for each dominant tree species.
ii. Number of trees in ( ) is per ha.
iii. In the case of natural forest, tree crown diameter is sometimes used instead of number of trees.

As mentioned previously, the estimation of stand volume in Japanese forest inventory has been done hitherto with measurement standards of sub-compartment or compartment. The calculation of stand volume in a sub-compartment or a compartment is done by following the procedure given below:

1. Identification of age classes in sub-compartment or compartment.
2. Selection of photographic points in each sub-compartment or compartment by systematic or random sampling. 10 points are usually selected in each sub-compartment or compartment, especially in a small area, 5 points are correct.
3. Using an aerial stand volume table, the volume per ha is determined

at every point established on the photograph whereupon the average of these measurement values is calculated. The stand volume of sub-compartment or compartment is given by the formula: $V=$ Average stand volume $\times$ Area of sub-compartment or compartment. Since it is very difficult to accurately determine the age class in a natural forest, this preliminary plan for Japanese forest inventory leaves considerable room for improvement, at least with regard to age-classification. With the general approach of the Japanese Forest Service as described above, the development of aerial stand volume table was initiated in 1958.

SUZUKI[123] developed an aerial volume table based on the relationship between stand volume per ha ($V$) and standvariables–number of trees ($n$) and modified tree crown closure ($r$), the volume estimation formula he used is $\log V = a + b_1 \log r + b_2 \log r$, where $b_1$ and $b_2$ are constants which change with each growing region.

NAKAYAMA[92] used the following volume estimation formula to develop an aerial stand volume table, namely, $V=(a+H^2)/(b+H)$, where $V$ is the stand volume, $H$ is the stand height, and $a$ and $b$ are constants.

NAKASONE developed an aerial stand volume table from average tree height and average tree crown diameter, the volume estimation formula he used is $V=a+b\bar{H}+c\,\overline{CD}$, where $V$ is the stand volume, $\bar{H}$ is the average tree height, $\overline{CD}$ is the average tree crown diameter, and $a$, $b$ and $c$ are constants.

The author developed 3 aerial stand volume tables of hardwood in the Tomakomai Experiment of Hokkaido University as shown in Table 20. The author's volume estimation formula is $V=a+bN+c\bar{H}$, $V=a+bN+c\overline{CD}$, and $V=a+bN+c\overline{CD}+d\bar{H}$, where $N$ is number of dominant trees, $\overline{CD}$ is the average tree crown diameter, $\bar{H}$ is the average tree height, and $a$, $b$, $c$, and $d$ are constants.

The Forestry Affairs Division of Nara Prefecture[30] developed an aerial volume table for artificial forest–Sugi and Hinoki–from average tree crown diameter and average tree height. The volume estimation formula used in this case was $V=0.775\ x^{1.371}\ y^{0.995}$, where $x$ is the average tree crown diameter and $y$ is the average tree height, in addition to this, the number of trees per ha must be known in all such occasions.

The volume for artificial forests can readily be developed from a yield table. As shown in Table 21, the author has developed an aerial volume table for Todomatsu (Todo fir) and Ezomatsu (Ezo spruce) in Teshikage district, Hokkaido. The yield table by SHIMAMOTO[37] was used in this study. The volume estimation of artificial forest is conducted as follows:

a. Several test trees are selected in 1 ha circular plot on aerial photographs.
b. Height of test trees is measured.
c. Using Table 21, volume of test trees is respectively estimated and then the arithmetic mean of these volumes is calculated.

**Table 20.** Aerial stand volume table of hardwood in the Tomakomai Experiment Forest of Hokkaido University ($m^3$).

1. From the relationship between stand volume per ha and standvariables-number of dominant trees and average tree height ($N:\bar{H}:V$).

| Average tree height (m) | Number of trees (25–74) | (75–124) | (125–174) | (175–224) | (225–274) | (275–325) |
|---|---|---|---|---|---|---|
| 8 | | | | | 15 | 33 |
| 9 | | | | 12 | 32 | 49 |
| 10 | | | 10 | 28 | 47 | 65 |
| 11 | | 8 | 26 | 44 | 63 | 81 |
| 12 | 5 | 24 | 42 | 60 | 79 | 97 |
| 13 | 21 | 40 | 58 | 76 | 95 | 113 |
| 14 | 37 | 56 | 74 | 92 | 111 | 129 |
| 15 | 53 | 72 | 90 | 108 | 127 | 145 |
| 16 | 69 | 88 | 106 | 129 | 143 | 161 |
| 17 | 85 | 104 | 122 | 140 | 159 | 177 |
| 18 | 101 | 120 | 138 | 156 | 175 | 193 |
| 19 | 117 | 136 | 154 | 172 | 191 | 209 |
| 20 | 133 | 152 | 170 | 188 | 207 | 225 |
| 21 | 149 | 168 | 186 | 204 | 223 | 241 |
| 22 | 165 | 184 | 202 | 220 | 239 | 257 |
| 23 | 181 | 200 | 218 | 236 | 255 | 273 |
| 24 | 197 | 216 | 234 | 253 | 271 | 289 |
| 25 | 213 | 232 | 250 | 269 | 287 | 305 |

2. From the relationship between stand volume per ha and standvariables-number of dominant trees and average crown diameter ($N:\overline{CD}:V$).

| Average tree crown diameter (m) | Number of trees (25–74) | (75–124) | (125–174) | (175–224) | (225–274) | (275–325) |
|---|---|---|---|---|---|---|
| 2.0 | | | | | | 18 |
| 2.5 | | | | | 20 | 34 |
| 3.0 | | | 8 | 22 | 37 | 51 |
| 3.5 | | 11 | 25 | 39 | 53 | 68 |
| 4.0 | 13 | 27 | 42 | 56 | 70 | 85 |
| 4.5 | 30 | 44 | 58 | 73 | 87 | 101 |
| 5.0 | 46 | 61 | 75 | 89 | 104 | 118 |
| 5.5 | 63 | 77 | 92 | 106 | 120 | 135 |
| 6.0 | 80 | 94 | 108 | 123 | 137 | 151 |
| 6.5 | 97 | 111 | 125 | 140 | 154 | 168 |
| 7.0 | 113 | 128 | 142 | 156 | 171 | 185 |
| 7.5 | 130 | 144 | 158 | 172 | 187 | 201 |
| 8.0 | 147 | 161 | 180 | 190 | 204 | 218 |
| 8.5 | 164 | 178 | 192 | 206 | 221 | 235 |
| 9.0 | 180 | 195 | 209 | 223 | 237 | 252 |
| 9.5 | 197 | 211 | 226 | 240 | 254 | 268 |
| 10.0 | 214 | 228 | 242 | 257 | 271 | 285 |

3. From the relationship between stand volume per ha and standvariables-number of dominant trees, average tree crown diameter, and average tree height ($N$: $\overline{CD}$: $\overline{H}$: $V$).

| Average tree crown diameter (m) | Number of trees | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average tree height (7.5–12.4 m) | | | | | | Average tree height (12.5–17.4 m) | | | | | |
| | (25–74) | (75–124) | (125–174) | (175–224) | (225–274) | (275–325) | (25–74) | (75–124) | (125–174) | (175–224) | (225–274) | (275–325) |
| 2.0 | | | | | | 28 | | 8 | 23 | 38 | 54 | 70 |
| 2.5 | | | | | | 38 | 2 | 17 | 33 | 48 | 64 | 79 |
| 3.0 | | | | 16 | 32 | 48 | 12 | 27 | 43 | 58 | 74 | 89 |
| 3.5 | | | | 26 | 42 | 57 | 21 | 36 | 52 | 67 | 83 | 98 |
| 4.0 | | | 20 | 36 | 51 | 67 | 31 | 46 | 62 | 77 | 93 | 108 |
| 4.5 | | 14 | 30 | 45 | 61 | 76 | 40 | 56 | 72 | 87 | 103 | 118 |
| 5.0 | 9 | 24 | 40 | 55 | 71 | 86 | 50 | 66 | 81 | 97 | 112 | 128 |
| 5.5 | 18 | 34 | 49 | 65 | 80 | 96 | 60 | 75 | 91 | 106 | 122 | 137 |
| 6.0 | 28 | 43 | 59 | 74 | 90 | 105 | 69 | 85 | 100 | 116 | 132 | 147 |
| 6.5 | 37 | 53 | 69 | 84 | 100 | 115 | 79 | 94 | 110 | 126 | 141 | 157 |
| 7.0 | 47 | 63 | 78 | 94 | 109 | 125 | 89 | 104 | 120 | 135 | 151 | 166 |
| 7.5 | 57 | 72 | 88 | 103 | 119 | 134 | 98 | 114 | 129 | 145 | 161 | 176 |
| 8.0 | 66 | 82 | 96 | 113 | 129 | 144 | 108 | 124 | 139 | 155 | 171 | 186 |
| 8.5 | 76 | 92 | 107 | 123 | 138 | 154 | 118 | 134 | 149 | 164 | 180 | 195 |
| 9.0 | 86 | 101 | 117 | 132 | 148 | 163 | 127 | 143 | 158 | 174 | 190 | 205 |
| 9.5 | 95 | 111 | 127 | 142 | 158 | 173 | 137 | 153 | 168 | 184 | 199 | 215 |
| 10.0 | 105 | 121 | 136 | 152 | 167 | 183 | 147 | 162 | 178 | 193 | 209 | 224 |

| Average tree crown diameter (m) | Number of trees | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average tree height (17.5–22.4 m) | | | | | | Average tree height (22.5–27.5 m) | | | | | |
| | (25–74) | (75–124) | (125–174) | (175–224) | (225–274) | (275–325) | (25–74) | (75–124) | (125–174) | (175–224) | (225 274) | (275–325) |
| 2.0 | 34 | 49 | 65 | 80 | 96 | 111 | 75 | 91 | 106 | 122 | 137 | 153 |
| 2.5 | 43 | 59 | 74 | 90 | 106 | 121 | 85 | 101 | 115 | 131 | 146 | 162 |
| 3.0 | 53 | 69 | 84 | 100 | 115 | 131 | 95 | 110 | 126 | 141 | 157 | 172 |
| 3.5 | 63 | 78 | 94 | 109 | 125 | 140 | 104 | 120 | 135 | 151 | 166 | 182 |
| 4.0 | 72 | 88 | 103 | 119 | 135 | 150 | 114 | 130 | 145 | 161 | 176 | 192 |
| 4.5 | 82 | 98 | 113 | 129 | 144 | 160 | 124 | 139 | 155 | 170 | 186 | 201 |
| 5.0 | 92 | 107 | 123 | 138 | 154 | 169 | 133 | 149 | 164 | 180 | 195 | 211 |
| 5.5 | 101 | 117 | 132 | 148 | 163 | 179 | 143 | 159 | 174 | 190 | 205 | 221 |
| 6.0 | 111 | 127 | 142 | 158 | 173 | 189 | 153 | 168 | 184 | 199 | 215 | 230 |
| 6.5 | 120 | 137 | 152 | 167 | 183 | 198 | 162 | 178 | 193 | 209 | 224 | 240 |
| 7.0 | 130 | 146 | 161 | 177 | 192 | 208 | 172 | 188 | 203 | 219 | 234 | 250 |
| 7.5 | 140 | 156 | 171 | 187 | 202 | 218 | 182 | 197 | 213 | 228 | 244 | 259 |
| 8.0 | 150 | 165 | 181 | 196 | 212 | 227 | 191 | 207 | 222 | 238 | 253 | 269 |
| 8.5 | 159 | 175 | 190 | 206 | 221 | 237 | 201 | 216 | 232 | 248 | 263 | 279 |
| 9.0 | 169 | 185 | 200 | 216 | 231 | 247 | 211 | 226 | 242 | 257 | 273 | 288 |
| 9.5 | 179 | 194 | 210 | 225 | 241 | 256 | 220 | 236 | 251 | 267 | 282 | 298 |
| 10.0 | 188 | 204 | 219 | 235 | 250 | 266 | 230 | 245 | 261 | 277 | 292 | 308 |

**Table 21.** Aerial volume table for Ezomatsu (Ezo spruce) and Todomatsu (Todo fir) Teshikaga district, Hokkaido.

| Tree height (m) | Ezomatsu ($m^3$) | Todomatsu ($m^3$) | Tree height (m) | Ezomatsu ($m^3$) | Todomatsu ($m^3$) |
|---|---|---|---|---|---|
| 5 | 0.01 | — | 16 | 0.32 | 0.34 |
| 6 | 0.02 | 0.02 | 17 | 0.41 | 0.41 |
| 7 | 0.03 | 0.03 | 18 | 0.51 | 0.51 |
| 8 | 0.04 | 0.05 | 19 | 0.62 | 0.61 |
| 9 | 0.06 | 0.06 | 20 | 0.77 | 0.75 |
| 10 | 0.08 | 0.09 | 21 | 0.94 | 0.93 |
| 11 | 0.10 | 0.12 | 22 | 1.13 | 1.15 |
| 12 | 0.13 | 0.15 | 23 | 1.35 | 1.41 |
| 13 | 0.17 | 0.19 | 24 | 1.59 | 1.67 |
| 14 | 0.21 | 0.23 | | | |
| 15 | 0.26 | 0.29 | | | |

d. Number of trees in 1 ha circular plot is counted.

e. The average volume of test trees and the number of trees in 1 ha make the stand volume per ha.

With regard to tree count, tree crown diameter measurement, tree crown closure measurement, and tree height measurement, literature surveys supplemented by the author's experience have been mentioned in the previous sections. While these are of little value in themselves, they may be useful in determining other factors that can not be seen or measured directly from aerial photographs. If the relationships that exist between the factors that can be measured and the ones that can not be seen on aerial photographs can be determined, then it may be possible to estimate these latter factors in an indirect manner. The stand volume is one of them and is of prime importance.

The 44 hardwood sample plots mentioned in the previous sections were also used for the stand volume estimation test. Stand volumes of all sample plots were estimated by 100 percent ground cruise using NAKAJIMA's volume table and then converted to the estimates per ha. These stand volumes ranged from 29 to 185 $m^3$. The distribution of the number of plots by stand volume class is shown in Table 22.

**Table 22.** Distribution of the number of plots by stand volume class.

| Stand volume class ($m^3$) | No. of plots | % |
|---|---|---|
| 0– 50 | 14 | 31.8 |
| 51–100 | 16 | 36.4 |
| 101–200 | 14 | 31.8 |
| Total | 44 | 100.0 |

Per ha stand volumes using aerial photographs were estimated by using author's aerial stand volume tables and compared with those measured on the ground.

The distribution of the number of plots by plus and minus symbols of error is shown in Table 23.

**Table 23.** Distribution of the number of plots by plus and minus symbols of error*.

| Symbol | Aerial stand volume table | | |
|---|---|---|---|
| | $N:\bar{H}:V$ No. of plots | $N:\overline{CD}:V$ No. of plots | $N:\overline{CD}:\bar{H}:V$ No. of plots |
| 0 | — (—) | — (1) | 2 (1) |
| — | 40 (15) | 6 (16) | 17 (16) |
| + | 4 (29) | 38 (27) | 25 (27) |
| Total | 44 (44) | 44 (44) | 44 (44) |

* Bracketed figures show the distribution of the number of plots in the case that measurement errors were excluded.

The use of aerial stand volume table based on the number of dominant trees and average tree height has a tendency to produce minus errors frequently due to understimates of 2 standvariables-number of dominant trees and average tree height, and the use of aerial stand volume table based on the numer of dominant trees and average tree crown diameter has a tendency to produce plus errors frequently which is mainly due to overestimates of average tree crown diameter, particularly in the uneven-aged hardwood forest, while the use of aerial stand volume table based on the number of dominant trees, average tree crown diameter, and average tree height has a tendency to keep minus and plus errors in check against each other and shows fairly good results. The distribution of the number of plots by absolute and percentage error classes is shown in Table 24 and the error of stand volume estimation was summarized in Table 25.

Judging from Table 24 and Table 25, the estimation of the average stand volume of all sample plots showed far better results than in the case of individual stand volume. Although the average errors in the first 2 tests-($N:\bar{H}:V$)

**Table 24.** Distribution of the number of plots by absolute and percent error in stand volume estimation from aerial photographs*.

| Absolute error class (m³) | Aerial stand volume table | | | Percent class error | Aerial stand volume table | | |
|---|---|---|---|---|---|---|---|
| | $N:\bar{H}:V$ No. of plots | $N:\overline{CD}:V$ No. of plots | $N:\overline{CD}:\bar{H}:V$ No. of plots | | $N:\bar{H}:V$ No. of plots | $N:\overline{CD}:V$ No. of plots | $N:\overline{CD}:\bar{H}:V$ No. of plots |
| 0– 30 | 16 (38) | 7 (36) | 31 (36) | 0– 20 | 9 (23) | 7 (19) | 21 (19) |
| 31– 60 | 18 (6) | 19 (8) | 8 (8) | 21– 40 | 9 (14) | 8 (16) | 10 (15) |
| 61– 90 | 7 (—) | 11 (—) | 5 (—) | 41– 60 | 7 (5) | 2 (5) | 5 (3) |
| 91–120 | 3 (—) | 7 (—) | — (—) | 61– 80 | 6 (2) | 2 (2) | — (3) |
| | | | | 81–100 | 13 (—) | 4 (1) | 4 (2) |
| | | | | Ober 100 | | 21 (1) | 4 (2) |
| Total | 44 (44) | 44 (44) | 44 (44) | Total | 44 (44) | 44 (44) | 44 (44) |

* Bracketed figures show the distribution of the number of plots in the case that measurement errors were excluded.

**Table 25.** Error of stand volume estimation from aerial photographs at a 95 percent probability ($m^3$)

| | Average stand volume per ha | Error of photocruise Aerial stand volume table | | | Error of photocruise excluded measurement errors Aerial stand volume table | | |
|---|---|---|---|---|---|---|---|
| | | $N:\bar{H}:V$ | $N:\overline{CD}:V$ | $N:\overline{CD}:\bar{H}:V$ | $N:\bar{H}:V$ | $N:\overline{CD}:V$ | $N:\overline{CD}:\bar{H}:V$ |
| $M$ | 86±14 | −41±10 | 46±12 | 7±10 | 0±20 | 1±8 | 3±8 |
| $\sigma$ | 48±10 | 31± 6 | 43±10 | 31± 6 | 20±14 | 26±6 | 24±6 |
| $t$-test | | * | * | | | | |

$M$: Arithmetic mean.
$\sigma$: Standard deviation of arithmetic mean.

and ($N:\overline{CD}:V$)–ranged as high as 50 percent or thereabouts, the last test ($N:\overline{CD}:\bar{H}:V$) was within 10 percent. Moreover, the average errors of aerial stand volume tables used in this study were within 4 percent.

It is strongly suggested that in the photo-interpretation of uneven-aged hardwood forest, the interpreters must exercise special care in the selection of the aerial stand volume table to be used, particularly in the case of beginners. In this study, the aerial stand volume table ($N:\overline{CD}:\bar{H}:V$) showed fairly good results, which reason has been mentioned previously.

The estimation of stand volume from aerial photographs can not be said to be accurate, mainly because of measurement errors. Since the correlation between photo and ground estimates would form the basis for correcting the photo estimates, the results from photocruise may be corrected by using so-called correction factors. These correction factors are very useful for correcting the photo estimates of those stands not measured on the ground. After such double sampling procedures, an aerial stand volume table must be used carefully. Moreover, photo-interpreters must exclude the error of the aerial stand volume table itself.

In order to supplement the data related to the basis for correcting photo estimates, 13 out of 133 one ha circular plots, sampled on the arial photographs covering the Tomakomai Experiment Forest of Hokkaido University were transferred on the ground, and the volume of all trees in each one ha circular plot was measured by NAKAJIMA's volume table.

The photo estimates of 13 one ha circular plots were checked against these ground estimates as shown in Table 26.

In comparison with the same plots measured on the ground, the total volume estimate by aerial stand volume table ($N:\bar{H}:V$) was 38.7 percent low, the total volume estimate by aerial stand volume table ($N:\overline{CD}:V$) was 17.2 percent high, and the last one by aerial stand volume table ($N:\overline{CD}:\bar{H}:V$) was 8.4 percent low. Again, in the case of using aerial stand volume table ($N:\overline{CD}:\bar{H}:V$), a resonably good result was obtained. As seen in Table 26, although the stand

Table 26. Photocruise results in 1 ha circular plots*.

| Plot No. | Estimates from photocruise | | | 100 percent ground cruise | Deviation from 100 percent ground cruise in percent Aerial stand volume table | | |
|---|---|---|---|---|---|---|---|
| | $N$ | $\overline{CD}$ (m) | $\overline{H}$ (m) | $V$ (m³) | $N:\overline{H}:V$ | $N:\overline{CD}:V$ | $N:\overline{CD}:\overline{H}:V$ |
| 1 | 87 | 7.02 | 12.10 | 61 | −60.6 (− 9.0) | 109.8 ( 54.1) | 3.3 ( 39.3) |
| 2 | 113 | 6.73 | 15.62 | 84 | 4.8 ( 64.3) | 32.2 ( 9.5) | 11.9 ( 57.2) |
| 3 | 156 | 6.83 | 15.10 | 131 | −31.2 ( 6.9) | 8.4 (− 6.1) | −10.0 (− 1.1) |
| 4 | 131 | 7.02 | 11.84 | 91 | −53.8 (−18.7) | 56.0 ( 18.7) | −14.3 ( 10.0) |
| 5 | 97 | 6.86 | 15.24 | 45 | 60.0 ( 166.6) | 184.4 ( 109.0) | 131.1 ( 182.2) |
| 6 | 122 | 7.36 | 13.50 | 121 | −53.7 (−12.4) | 19.0 ( 3.3) | − 5.8 (− 9.2) |
| 7 | 116 | 6.29 | 12.42 | 120 | −80.0 (−38.3) | − 7.5 (−23.3) | −55.8 (−24.2) |
| 8 | 174 | 7.02 | 15.78 | 155 | −31.6 ( 1.0) | − 8.4 (−20.6) | −22.5 ( 1.9) |
| 9 | 146 | 7.10 | 16.12 | 129 | −17.8 ( 33.3) | 10.1 (− 4.7) | − 7.0 ( 22.5) |
| 10 | 125 | 7.01 | 14.61 | 171 | −47.2 (−28.7) | −16.9 (−36.8) | −29.8 (−41.5) |
| 11 | 128 | 6.86 | 17.46 | 178 | −23.5 (− 4.5) | −20.2 (−39.8) | −10.0 (−20.2) |
| 12 | 102 | 6.84 | 13.36 | 91 | −56.0 (−20.9) | 40.6 ( 3.2) | 14.3 (− 6.6) |
| 13 | 111 | 7.25 | 12.80 | 112 | −64.2 (−19.6) | 28.5 (− 3.6) | 1.8 (−10.7) |
| Total | | | | 1,490 | −38.7 ( 0.0) | 17.2 (− 6.6) | − 8.4 ( 0.9) |

* Bracketed figures show the errors of the photo estimates which were re-calculated by correction factors.

volume estimates are not accurate for individual stand, these errors tended to average out so that total volume estimates were accurate enough to satisfy the purpose of reconnaissance cruise.

In order to correct the volume estimates for errors of standvariables-number of dominant trees, average tree crown diameter, and average tree height, the correction factors were used. These values mainly vary with the characteristics of the photo user such as mental and visual acuity, however, as far as the data at the Tomakomai Experiment Forest are concerned, these correction factors may be regarded as 1.20 for tree count, 0.85 for average tree crown diameter, and 1.15 for average tree height. The stand volume estimates from aerial photographs were re-calculated by the correction factors obtained through double sampling procedures, thus, the results agreed closely with the 100 percent ground cruise. The above test makes it clear that combined photo and ground cruises were considerably more accurate than the estimates from aerial photographs alone.

The forest in question is located at the foot of Mt. Tarumae and while the terrain is partially irregular, as a whole it may be considered as a plain. Therefore, the variation in ground elevation and its effecet upon the area were not taken into consideration.

## 2. Estimation of Stand volume by Aerial Tree Volume Table

An aerial tree volume table is generally developed from the relationship between volume per tree and variables such as tree height, tree crown diameter, or both of the above. The procedure of develping this table is almost the same as in the case of aerial stand volume table. The only point that differs from aerial stand volume table is that the data in this case are collected tree by tree. The following aerial tree volume tables are standard in America and Canada: Total visible height-Crown diameter volume table by MINOR, Total height-Crown width volume table by SPURR and U. S. Forest Service, and Height-Crown width volume table for Red spruce, Balsam fir, and Eastern Hemlock in White Mountain forest by BROMER and JURAM.

In order to estimate the volume of coniferous wood mixing sporadically in the hardwoods of the Tomakomai Experiment Forest of Hokkaido University, the author developed an aerial tree volume table from the relationship between volume per tree and tree height as shown in Table 27. Generally speaking, an aerial tree volume table is not suitable for estimating the volume of natural forest stand.

**Table 27.** Aerial tree volume table for the coniferous wood in the Tomakomai Experiment Forest of Hokkaido University ($m^3$).

| Tree height (m) | Ezomatsu (Ezo spruce) | Todomatsu (Todo fir) | Tree height (m) | Ezomatsu (Ezo spruce) | Todomatsu (Todo fir) |
|---|---|---|---|---|---|
| 5 | 0.01 | 0.01 | 18 | 0.57 | 0.52 |
| 6 | 0.02 | 0.02 | 19 | 0.69 | 0.64 |
| 7 | 0.03 | 0.03 | 20 | 0.84 | 0.78 |
| 8 | 0.04 | 0.04 | 21 | 1.00 | 0.95 |
| 9 | 0.06 | 0.06 | 22 | 1.19 | 1.16 |
| 10 | 0.08 | 0.08 | 23 | 1.42 | 1.43 |
| 11 | 0.11 | 0.10 | 24 | 1.70 | 1.74 |
| 12 | 0.14 | 0.13 | 25 | 2.03 | 2.18 |
| 13 | 0.19 | 0.17 | 26 | 2.38 | 2.76 |
| 14 | 0.24 | 0.22 | 27 | 2.84 | 3.77 |
| 15 | 0.30 | 0.28 | 28 | 3.41 | |
| 16 | 0.38 | 0.35 | 29 | 4.08 | |
| 17 | 0.47 | 0.42 | 30 | 4.91 | |

### 3. Estimation of Stand Volume by Stereogram

Stereoscopic photographs of a stand in which the volume is know are pasted on the field book and necessary items of standvariables related to stand volume are filled in around the stereoscopic photographs in the field book. In this case, pair photographs must be pasted on the field book so that a stereoscopic vision can be obtained. This is called a **stereogram**[91]. A stereogram for each tree species or forest type is necessary. The stand volume to be estimated is determined by comparison with this stereogram.

### 4. Estimation of Stand Volume by Coefficient as compared against Normal Forest

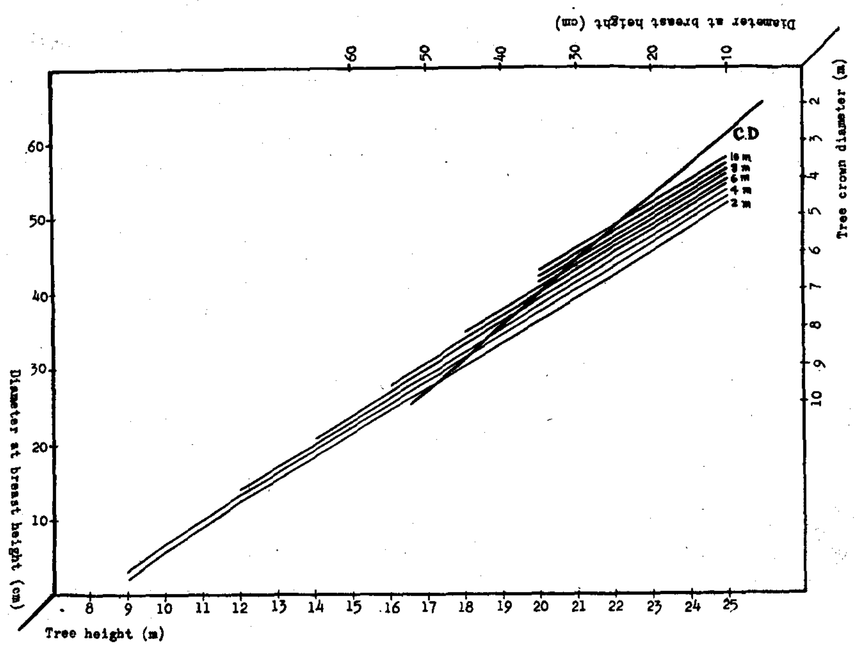
The relationship between the ratio of each number of trees in normal forest and actual forest to be measured and the ratio of their volumes must be determined previously[55,56]. At the present stage, this method can be used only in artificial forests.

### 5. Estimation of Stand Volume by Stand Profile

A profile of the tree crowns in the tree crowns in the forest stand can be described with precise instruments–Aerocartograph, Multiplex, et al. From the relationship between the known profile area and the stand volume measured on the ground, so-called profile area stand volume tables can be constructed for a given forest type. It is obvious that the usefulness of such a stand volume table lies in the volume estimation of uneven-aged forest. However, the instruments needed for such a photo-interpretation have not been broadly propagated in Japan as yet.

## SECTION 6. Stem Diameter

Standvariables which are visible on aerial photographs are number of trees, tree crown closure, tree crown diameter, tree height, and some others. Especially at both edges of low-altitude continuous-strip aerial photographs, occasionaly, trees with the entire stem is visible are seen. The diameter of such trees can be measured directly from the photograph. First, the breast height point is




C. D.: Tree crown diameter.

**Figure 17.** Relationship of tree height and visible tree crown diameter to stem diameter for hardwood in the Tomakomai Experiment Forest of Hokkaido University.

mesured on the photograph and then the diameter at the same position is measured by a micrometer wedge. This is a special case, in most cases, a stem diameter is estimated in an indirect manner.

A number of independent studies have demonstrated that a stem diameter is correlated directly with tree crown diameter and tree height. Figure 17 illustrates the relationship of both tree height and visible tree crown diameter to stem diameter at breast height for hardwood in the Tomakomai Experiment Forest of Hokkaido University. As seen in this Figure, the relationship approaches a straight line in form.

**SECTION 7. Stand Volume Growth**

Stand volume growth in an investigation area is generally obtained by repeating stand volume estimation in the same area using the same method every 5 years which is accepted as a working period. In other words, the stand volume growth is calculated from the formula $Z=\frac{V_2-V_1+N}{n}$, where $V$ is the stand volume at the beginning of the working period, $V_2$ is the stand volume at the end of the working period, $N$ is the amount of cutting during this period, and $n$ is the repeating period. The amount of cutting ($N$) is usually calculated from the working book, however, this is also calculated on aerial photographs by using a similar method as mentioned in CHAPTERS (8～12)

In Japanese forest inventory, the estimation of stand volume growth is carried out together with the inventory concerned with the stand volume. The size of sample plots is approximately equivalent to $\frac{1}{10}$ of that of the stand volume estimation. The sampling design and the analysis of the data collected are approximately the same as in the case of stand volume. At first, the diameter increment during the past 5 years is calculated from a slender piece of annual ring taken from the tree by using an increment borer and then the volume growth percentage during this period is calculated from diameter increment obtained.

The method above-mentioned is not as effective as estimations based on aerial photographs taken during a definite of time. However, when comparatively old aerial photographs—2 or 3 years from the time of photography–are used, corrections of stand volume are made by using the volume growth obtained by increment borer method. The idea concerned with the determination of stand growth from repeated photography in the same investigation site comes from the Sachsen Forest Experiment Station. This Station adopted growth determination methods based on aerial photographs as a supplementary method to **"Control Method by Biolley"** in 1931.

**SECTION 8. Forest Drain**

OSBORNE[96] mentioned that a possible method in the estimation of a forest drain during a definite period was the repetition of measurements of stand-variables in the same sample plots. A forest drain usually occurs by fire, cutting, mortality, growth, and so on.

BICHFORD[9,10] reported a so-called "Modified method of OSBORN's method" to estimate the drain. BICHFORD called this **"the photo method".** In order to apply this method, it is necessary to have aerial photographs covering the exact area investigated previously. Repetition of photography at the same site is essential for effective photo-interpretation. Stumps and their deterioration are used as criteria for repetition of photography together with obvious changes in forest appearance. The procedure of estimating forest drain is as follows:

I. The distribution of areas belonging to each drain class is investigated. The condition of the forest drain is divided into 4 classes, namely:

1. Cutting or cut over area; absolutely no indications are recognized on aerial photographs.
2. Cutting or cut over area is barely recognizable on aerial photographs.
3. Light cutting; trees not exceeding half of crown canopy were removed.
4. Heavy cutting; more than half of crown canopy was removed.

II. In order to secure the data concerning felled trees, sample plots are selected from each drain class as mentioned in CHAPTER 11–SECTION 3. BICHFORD used NEUMANN's formula to determine the number of plots to be sampled. According to the preliminary plan for Japanese forest inventory based on samling method[31], aerial photographs are taken every 5 years. Therefore, it will become possible to estimate the forest drain from these aerial photographs every 5 years. The author ventures to recommend this method to the Japanese Forest Service.

## CHAPTER 13. An Example of Forest Inventory by Aerial Photographs for Large Area

### The general description

1. Location of flight: Tomakomai Experiment Forest of Hokkaido University
2. Total area: 2,771 ha
3. Topography: The forest in question is located at the foot of Mt. Tarumae and while the terrain is partially irregular, as a whole it may be considered as a plain.
4. Forest condition: Nearly pure hardwood forest (Old growth)
5. Season of photography: August, 1959
6. Type of camera: K–24
7. Film used for this photography: Panchromatic film
8. Focal length of camera: 5 inch
9. Film sixe: 5 × 5 inch

10. Photo scale: 1 : 5,200 (Negative)

**The estimation of total stand volume**

1. The stand-classification and the area determination of the stands delineated and classified*

| Working Unit | No. of Comp. | Hardwood forest (ha) | Secondary forest (ha) | Artificial forest (ha) | Cut over area (ha) | Total (ha) |
|---|---|---|---|---|---|---|
| Kumanosawa | 40 | 798 | | | 12 | 810 |
| Kamihoronai | 33 | 533 | 45 | 134 | | 712 |
| Horonai | 41 | 76 | 97 | 379 | 4 | 556 |
| Yamanokami | 39 | 277 | 73 | 319 | 24 | 693 |
| Total | 153 | 1,684 | 215 | 832 | 40 | 2,771 |
| % | | 60.8 | 7.8 | 30.0 | 1.4 | 100.0 |

* Dot grid was used for the area determination.

2. Sampling design: Proportional sampling method
3. Shape and size of a sample plot: 1 ha circular plot
4. Necessary plot numbers: The formula $n=\frac{4aC^{2}*}{e^{2}A+4aC^{2}}$ was used for the determination of necessary plot numbers.

   * Presumptive sampling error percent: 10%
   Presumptive coefficient of variation of standvolumes: 60%

| Working Unit | Necessary plot numbers |
|---|---|
| Kumanosawa | 63 |
| Kamihoronai | 42 |
| Horonai | 6 |
| Yamanokami | 22 |
| Total | 133 |

5. Correction factors obtained through doudle sampling:

   1.20 ...... The correction factor for correcting number of dominant trees estimated on the aerial photographs

   0.85 ...... The correction factor for correcting average tree crown diameter estimated on the aerial photographs

   1.15 ...... The correction factor for correcting average tree height estimated on the aerial photographs

6. Aerial stand volume table used: The author's aerial stand volume table developed from the relationship between stand volume per ha and 3 standvariables–number of dominant trees, average tree crown diameter, and average tree height.
7. Estimate of total stand volume;

   a) Total stand volume of hardwood forest (Old growth)

| Working Unit | $\sum_{i=1}^{L}\left(\frac{N_i}{n_i}x_i'\right)$ (m³) | $\sum_{i=1}^{L}\left(\frac{N_i}{n_i}\right)^2\frac{n_i}{n_i-1}\sum_{j=1}^{n_i}(x_j'-\bar{x}')^2\frac{N_i-n_i}{N_i}$ (m³) | Standard error | Error percentage |
|---|---|---|---|---|
| Kumanosawa | 82,257.3 | 10,979,282.3 | | |
| Kamihoronai | 48,122.2 | 12,791,352.3 | | |
| Horonai | 8,329.6 | 295,718.4 | | |
| Yamanokami | 25,201.2 | 4,887,636.6 | | |
| Total | 163,910.3 | 28,953,989.5 | 5,380.8 | 3.28 |

The total stand volume of hardwood forest may be regarded as $163{,}910 \pm 5{,}380\ m^3$.

b) Total volume of coniferous wood

In order to estimate the volume of coniferous wood mixing sporadically in hardwoods of the forest in question, the author's aerial tree volume table as shown in Table 27 was used.

| Working Unit | Sample estimates | | Assumed total volume (m³) |
|---|---|---|---|
| | Number of sample plots* | Volume of coniferous wood (m³) | |
| Kumanosawa | 63 (26) | 104.95 | 1,329 |
| Kamihoronai | 42 (12) | 68.70 | 872 |
| Horonai | 6 (2) | 4.80 | 61 |
| Yamanokami | 22 (—) | — | — |
| Total | 133 (40) | 178.45 | 2,262 |

* Bracketed figures show the number of plots contained coniferous wood.

The sampling error percent in this case did not fall within the necessary accuracy—10 percent.

c) It is regretable that the stand volume estimation of secondary forest and artificial forest was not included in this paper because of the absence of aerial stand volume tables. The author intends to develop these aerial stand volume tables.

8. Coefficient of variation and sampling error percent of the average stand volume.

| Working Unit | Coefficient of variation (%) | Sampling error percent (95% probability) (%) |
|---|---|---|
| Kumanosawa | 32.37 | 8.06 |
| Kamihoronai | 50.23 | 15.01 |
| Horonai | 15.24 | 16.76 |
| Yamanokami | 41.80 | 18.25 |
| Total | | 6.49 |

Also from the coefficient of variation estimated on the photographs, necessary number of plots in each Working Unit can be independently computed by using the formula: $n = \frac{4AC^2}{e^2A + 4aC^2}$.

## PART IV. CONCLUSION

In the previous chapters, theories and techniques on the application of aerial photogrammetry to forest inventory were indicated and discussed. The methods of American and Canadian forest inventory based on aerial photographs were introduced in Japan since the termination of World War II. Several preliminary forest inventories have been carried out in such prefectures as Okayama, Nara, Nagasaki, Ōsaka, etc..

In February 1958, the Japanese Forest Service revised regulations related to the management of national forests and in May 1958, the Director General of the Forest Service issued directions on preliminary plans for forest inventory based on both sampling methods and aerial photographs to each Branch of the Forest Serviec. As mentioned in CHAPTER 1, our history concerning the utilization of aerial photographs is fairly long. Forest inventories based on aerial photographs were carried out in Saghalin and Manchuria approximately 25 years ago. The results compare admirably with techniques in other countries in those days. Unfortunately, the development of Japanese aerial photogrammetry was brought to a complete standstill by the war. In order to compensate for the time lost, strenuous efforts must be made in this field. From this viewpoint, the revision of regulations related to the management of national forest has a great significance.

The main purpose of the author's work is to offer fundamental data which can be effectively used in Japanese forest inventory, especially in Hokkaido forest inventory. However, our forests have many characteristics which differ somewhat from American and Canadian forests. Accordingly, it is pointed out that an outright adoption of foreign techniques and principles in aerial photogrammetry without adaptation is highly inadvisable. Thus, modifications are suggested for Hokkaido forest inventory.

### CHAPTER 14. Fundamental Problems on the Application of Aerial Photogrammetry to Forest Inventory in Hokkaido

The author wishes to point out several fundamental problems which must be considered in order to establish practical investigation key points in Hokkaido. It goes without saying that the key to forest inventory based on aerial photographs can be established only through a great deal of experience. Since this thesis is confined to litrature surveys supplemented by the author's studies in

Hokkaido, further advanced studies must be progressed in order to cope with various difficulties in the application of aerial photogrammetry to Hokkaido forest inventory.

### 1. Quality of aerial photographs

In future inventory, much information may be expected directly from aerial photographs. Hence, the quality of aerial photographs to be used in interpretation is a matter of first importance. Especially, photo scale should be at its maximum with due respect to financial limitations. It is suggested that at least 1 : 15,000 or more is necessary. Likewise, summer photography with panchromatic film plus a proper filter is recommended to insure satisfactory results.

### 2. Identification of tree species and stand-classification

In spite of the technical level of the present advanced aerial photogrammetry in the world, identification of tree species is not without difficulties. Even in America and Canada, researchers admit the existence of difficulties and unsolved problems in so far as identification of tree species is concerned. Fortunately, the introduction of low-altitude continuous-strip aerial photography is highly promising in the identification of tree species. However, the photography in question has not as yet been broadly applied in practice.

It is strongly suggested that aerial photographs with the highest standard of quality as possible be utilized. As the next step in line, the setting-up of standards of identifying dominant or co–dominant tree species from the shape of tree crown, the tone and color, the outward aspect of trees, and the ecological distribution of each tree species is necessary. In Hokkaido forest inventory, the standards of identifying tree species must be prepared for Ezomatsu (Ezo spruce), Todomatsu (Todo fir), Karamatsu (Larch), Nara (Oak), Sennoki (Castor), Yachidamo (Swamp ash), Shinanoki (Japanese linden), and Kaede (Maple) which are considered as the useful tree species of Hokkaido. In addition to these, in Hokkaido, there are various secondary forests characterized by the abundant growth of hardwood, which plays an important part as pioneer stands at sites where wind damages, mountain fire, and land slips occured. The distribution of these secondary forest can be accurately investigated from the characteristics of the tone and color, the shape of crown, et al on the aerial photographs. Such investigation must be done as soon as possible in view of the fact that hardwood problem has become serious in present Hokkaido forestry.

For instance, in aerial survey with the management plan in forestry in mind, the identification of each individual tree species is not necessary. Stand-classification is sufficient for this purpose. Such a stratification in forests has an important significance in jointly utilizing sampling methods. It is desirable to express the content of forest stands classified by a code system.

With regard to the intensity of the present Japanese forestry, the standards of stand-classification should not be complicated. It seems advisable to approach gradually to the detailed classification system which is broadly used in present day America and Canada.

Simple stratification is suggested for Hokkaido forests. In Hokkaido forests, 3 classifying groups are suggested, i. e., coniferous wood, mixed coniferous and hardwood, and hardwood. The content of forest stand is expressed by a code system. Each of the standvariables such as tree crown diameter, number of trees, tree crown closure, and the tree height may be divided into 3～4 classes to indicate the content in detail. The interval of each class will be determined through a reconnaissance. The area determination of forest stands classified must be done on the base map developed by using radial plotting devices because most of Hokkaido forests are marked by entangled masses of mountain.

According to the preliminary plan for Japanese forest inventory, stand-classification based on sub-compartments or compartments is to be carried out in national forests. This is because sub-compartments or compartments have been accepted as the absolute working unit in our management plan. However, a strict adherence to sub-compartments or compartments which came from Germany will cause insurmountable problems in carrying out forest inventory based on both aerial photographs and sampling methods.

The author's modified method is that after delineating and classifying forest stands on aerial photographs without being restricted by the limitations of sub-compartments or compartments, the content–stand volume, stand volume growth, et al—of each sub-compartment or compartment is estimated in detail, other periodic blocks do not need it. If the content of sub-compartments is required with regard to the first periodic block, the necessity of maintaining present sub-compartments must be tested by using aerial photographs taken most recently and then the area of each sub-compartment must be newly determined on the base map. It is of the author's belief that sand-classification must be done without being restricted by the limitations of sub-compartments or compartments.

Besides these, our attention must be focussed on the man-made features. Plates 2～6 will give us some perception of identifying natural surface cover and man-made features on the aerial photographs covering the Tomakomai Experiment Forest of Hokkaido University. It goes without saying that such a work is only a qualitative interpretation. Accordingly, photo-interpreters must establish the quantitative key to forest inventory through a great deal of experience.

### 3. Site-classification

Site-classification of forest stands classified by aerial photograph is likeweise necessary mainly from a viewpoint of planting trees. The site-classification system based on topography by Moessner or Seely is suggested as the most suitable for Hokkaido forest inventory. Most of the Hokkaido forests have a considerably steep grade and the distribution of tree species in natural forests is often influenced by topography to some extent.

**4. Area determination of forest stands classified**

For a flat or a near flat terrain, the area is determined directly from aerial photographs. In other cases, control lines, principal points, conjugate principal points, and other pass points are transferred to the base map by using instruments such as radial plotting devices, at the same time, the boundaries of each forest stand are also transferred to the base map by using various projectors or sketchmasters. Next, the area of each forest stand is determined on the base map. The using of dot grid method is very simple and the accuracy is high as compared with others. Accordingly, it is desirable that a dot grid is used in our phto-interpretation. As mentioned previously, most of the Japanese forest are marked by entangled masses of mountain and it is desirable to develop base maps on all types of forest inventory.

**5. Sampling desigh**

Double sampling is highly important in order to ensure the accuracy of forest inventory based on aerial photographs. The most desirable size of a sample plot is 1 ha on aerial photographs and approximately $\frac{1}{3} \sim \frac{1}{10}$ ha on the ground, moreover, the use of circular plot is highly desirable. According to the author's study at the Tomakomai Experiment Forest whose terrain may be considered as a plain, even a 1 ha circular plot could be transferred to the ground without so much difficulty. To be precise, 6 cruisers took 5.3 hours to transfer a 1 ha circular plot on the ground and to measure the diameter and height of all trees in it. However, when applied to the irregular terrain, the shape of a sample plot is not always tied to the circular one.

The idea of using stratification in forest inventory as advocated by the Japanese Forest Service seems to be a little complicated. Thus, it is feared that considerable complications will be encountered in the actual application.

In Japan, grid lines of 5 mm or 1 cm square are drawn on a working map with a scale of 1 : 20,000, a topographical map with a scale of 1 : 50,000 is also sometimes used for this purpose. The crossing points are intended to be used as the center of circular plots or the starting point of rectangle plots. However, the method of using transparent plates on which circular plots are engraved at regular intervals as used in America and Canada is superior and far more effective than the japanese method. In the case of taking sample plots, the number of sample plots to be chosen from each stratum is determined by the most popular formula $n=\frac{4AC^2}{e^2A+4aC^2}$. The method of determining the coefficient of variation ($C$) related to the stand volume or other standvariables directly from aerial photographs is far more effective than from the ground cruise.

The stratified sampling method or the proportional sampling method is recommended to the forest inventory of Hokkaido and the most important thing in this case is that the photo estimates must be corrected and recalculated by the factors obtained through double sampling procedures. As mentioned in CHAPTER 13, a photocruise together with sampling design was conducted to estimate the total volume of the Tomakomai Experiment Forest of Hokkaido University. The forest in question is located at the foot of Mt. Tarumae and while the terrain is partially irregular, as a whole it may be considered as a plain. Therefore, the variation in ground elevation was not taken into consideration. The sampling results were given as $163{,}910 \pm 5{,}381$ $m^3$. This is only an example of our study on aerial photogrammetry in Hokkaido.

### 6. Measurement of standvariables in each sample plot

Standvariables which are visible on aerial photographs are number of trees, tree crown closure, tree crown diameter, tree height, and some others. Especially at both edges of low-altitude continuous-strip aerial photographs, occasionally, tree with the entire stem is visible are seen. The diameter of such trees can be measured directly from the photographs. Sometimes, these standvariables are measured independently. However, these standvariables are generally measured as a function on which the determination of stand volume or stand volume growth is made.

It is obvious that measurement methods of these standvariables which are being used in America and Canada can be used even in Japanese forest inventory. However, some of the instruments used in American and Canadian forest inventory have a different measurement unit from that of Japan. Therefore, it is highly desirable to work out a conversion table.

With regard to the estimation of stand volume, there are 5 methods:

a) Aerial stand volume table
b) Aerial tree volume table
c) Stereogram
d) Coefficient compared against normal forest
e) Stand profile

Of the above 5 methods, the aerial stand volume table is the most popular. Thus, the prerequisite in the utilization of aerial photographs in Hokkaido forest inventory is to develop the aerial stand volume table in question. The author developed the aerial stand volume tables of hardwood in the Tomakomai Experiment Forest of Hokkaido University. Moreover, under the guidance of the author, Forestry Affairs Division of Hokkaido Prefectural Government has been developing all kinds of aerial stand volume tables to be used in the forests concerned.

The most difficult problem in Hokkaido forests, most of which are naturally generated, is to estimate the stand volume growth during a definite period. This problem may be solved by using **the photo method** as indicated in CHAPTER 12 SECTION 7. Namely, stand volume growth in an investigation area is obtained by repeating volume estimation at the same area with the same method at definite intervals. In this case, the amount of cutting during the period is added to the stand volume growth. The amount of cutting is generally calculated from a working book, this is also estimated from aerial photographs by a follow-up of the same procedure shown in the case of total stand volume.

Low-altitude continuous-strip aerial photography was one of the epoch making trials in advanced countries. Photo-interpreters would obtain much more information on standvariables by using such aerial photographs. Since the identification of small sized trees is possible on color aerial photographs with a fairly high accuracy, such photographs may be effectively used in the field of Silviculture.

### 7. Future of forest inventory by aerial photographs

Judging from the present stage of aeril photogrammetry in Hokkaido, a considerable amount of difficulties remain even in the case of black and white photographs, not to mention color photography. One of the most important things on hand is to emphasize the importance of gradually improving our photographic techniques and to endeavour to reduce the cost involved.

It is regretable that in regard to sampling method or sampling method plus aerial photogrammetry in present day forest inventory, there is a definite lack in the actual application or extension of the same. In other words, every effort should be made to bring about extension of the theory and in order to accomplish the above we are compelled to follow in the steps of advanced countries. It, therefore, seems vitally important to incorporate or otherwise innovate courses in studies on aerial photogrammetry into our present forestry education. By doing so, foresters may acquire advanced techniques in photo-interpretation. Further, foresters already in the service who lack knowledge in aerial photogrammetry should be re-educated under the guidance of either Forest Experiment Station or University. Finally, the author cordially expects that our aerial photogrammetry will be improved and to advanced so that when the time arrives foresters can readily change over to forest inventory based on aerial photographs.

# 航空写真による森林調査（摘要）

谷口信一

この論文では，航空測定学のとくに進歩しているといわれるアメリカ・カナダ等における林業面へのこれが応用の経緯，それにたいする日本の現状，さらに本学苫小牧演習林でなされた著者達の研究等をとおして，北海道における林業経営の基礎的資料を今後航空写真からどのようにもとめていくかにつき若干の考察をおこなつている。

まず航空写真は，簡単な実体鏡を併用することによつてその地被状態を立体模型として容易に机上に再現しうるので，大面積にわたる林分の分類，すなわち層化が可能である。この場合，小班界なり林班界なりにあまりに拘束されて林分の分類をおこなうと，層化の概念が複雑になつて，写真の十分な利用がさまたげられる。

航空写真上における林分の境界づけでは，樹種，樹種群，樹冠直径，樹冠の疎密度，樹高などがその基準となり，普通それぞれの林分の内容がコードシステムによつて表わされる。北海道における天然生林では，樹種の単木的識別が容易でないから，そこに優先する樹種のみを識別し，おおきく針葉樹林，針広混交林，広葉樹林，二次林程度に分け，必要に応じそれぞれの内容をコードシステムで表わすようにするとよい。

平地あるいはそれに近い林地の場合であると，分類されたそれぞれの林分面積は直接写真上で点格子を使つて査定できるが，それが山岳地帯である以上原則的には写真から菱形鎖をくみ，基本図を調製し，写真上の林分境界その他の重要地物もこの上に転位し，そこで面積査定をおこなうようにし，とりわけ地形にもとづく地位判定などもあわせおこなうことがのぞましい。

航空写真が大面積の森林調査にたいして効果的であるということは，すでに諸外国のおおくの研究によつて立証されている。ことに小数標本による統計的処理法を併用すると従来の森林資源調査法が著しく近代化されるであろう。北海道では，層化一段抽出法，あるいは比例抽出法が適当と考えられ，必要とする標本数はプロット材積の変動係数，目標精度，層面積，プロット面積の大きさなどからもとめられる。ことにプロット材積の変動係数は地上調査には比較すべくもないが，とにかく写真からだけでも推測できるので便利である。プロットの大きさは，それぞれの国の森林や林業の事情によつて区々であるが，写真上では航空林分材積表との関連性，抽出プロット数をできるだけ少なくするたてまえから1 haの円形プロットが適当である。苫小牧演習林において1 haの円形プロット13箇を地上に転位し判読諸数値を修正するための基準をもとめたさいは，プロット一箇につき6人

の調査員で 5.3 時間を要した。このように 1 ha の円形プロットすらさほどの困難をともなわずに，地上に転位が可能である。しかし起伏のおおい林地では，プロットの形状にとらわれることなく写真上のプロット面積の数分の一を地上で実測する。この場合土地の高低によつて局所的に写真縮尺に変化が表われるから，厳密にいうと標本合計面積の修正が必要である。

抽出された標本につき，写真上で直接査定できる林分要素は，本数，樹冠直径，樹冠の疎密度，樹高，ごくまれに直径などであるが，これらを介して，林分材積，林分材積生長量，林分の質などが間接的に査定される。苫小牧演習林において 0.2 ha の矩形プロット 44 カ所，1 ha の円形プロット 13 カ所，計 57 カ所につき，写真上の林分要素を判読し同時に地上調査をおこなつて，判読値の訂正因子を調査したところ，上層木の本数査定では 1.20，平均樹冠直径の査定では 0.85，平均樹高の査定では 1.15 となつた。かかる平均的表示による訂正因子を使用するほかに判読値から実測値を回帰推定する方法がある。とにかく二重抽出法における第二次抽出の地上調査値にもとづいて判読値をそれぞれ修正していく手続きは，航測の精度をたかめるうえにおいて不可欠の要件といえよう。個々のプロットにおける判読値と実測値との比較では，はなはだ不正確な結果もあらわれたが，調査箇所全体としてみると，それぞれのプロットの測定誤差がたがいに相殺され，より良い結果となる傾向があつた。

著者の 3 種類の航空林分材積表のうち，上層木本数，平均樹冠直径，平均樹高にもとづくものが，上層木本数と平均樹冠直径，上層木本数と平均樹高にもとづくものよりはるかに実測値に近い数値をあたえた。すなわち 44 箇所のプロットでは，全体の材積誤差率が 8.13%，13 箇所の 1 ha 円形プロットではそれが −8.4% であつた。ここでも相反する方向の測定誤差がたがいに相殺されていることを知る。いずれにしても，写真判読に熟練するまでは，使用する航空林分材積表につき予め十分なる内容の吟味をおこなつておくことが必要である。測定誤差をまつたく除去し，材積表自体にふくまれる誤差を 44 箇所のプロットで調べたところ，3 つの材積表ともにそれが 4% 以下であつた。

著者達は苫小牧演習林 2,771 ha につき，航空写真にもとづく森林調査をすすめているが，なかんずく広葉樹林 1,684 ha を調査の対象にえらび，必要とする 1 ha 円形プロット 133 箇を任意に抽出して，そのそれぞれにつき，上層木本数，平均樹冠直径，平均樹高を測定し，さきの訂正因子によつて判読値の修正をおこない，著者の 3 林分要素にもとづく航空林分材積表から林分材積をもとめ，比例抽出法による標本設計によつて事業区別の広葉樹林蓄積を査定した。演習林全体としてのそれは，163,910 $m^3$ であり，その標準誤差は ± 5,381 $m^3$ となつた。さらに 95% の信頼確率における抽出誤差は ±6.49% となる。プロット材積の変動係数は上幌内事業区が最大で 50.23%，幌内事業区が最小の 15.24% であつた。

大面積にわたる林分材積生長量の査定法を確立することは，測樹学における従来の課題の一つであつたが，航空写真にもとづくこれが新しい試みには今後大いに期待がかけられてよいと思う。さらに大縮尺の色彩写真を使用することによつて，樹種の識別・森林被害量の査定，林分の質の判読などにおける諸々の困難が克服されていくであろうことを信じている。

この論文の内容はいたつて不十分であるけれども，先進諸国における航空測定学との交流を盛んにする機運がこれによつていささかなりとも促進しうるとすればそれは著者の望外の幸なのである。

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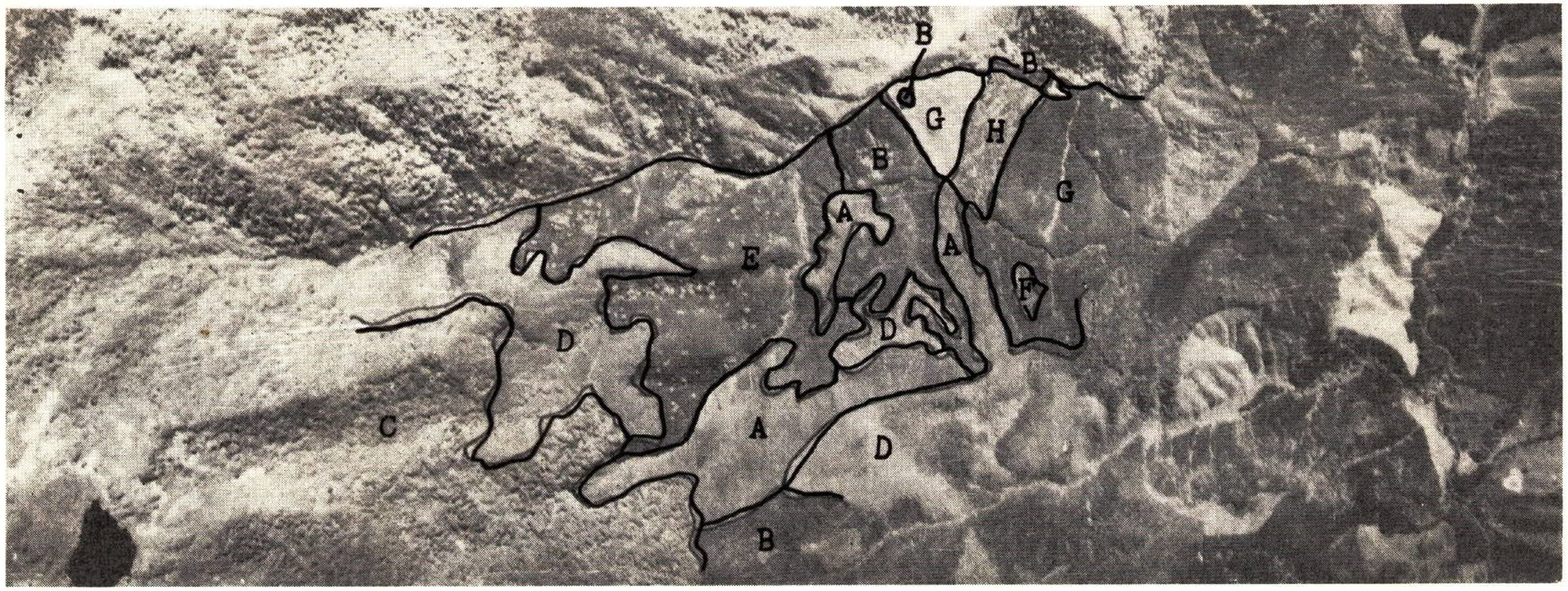
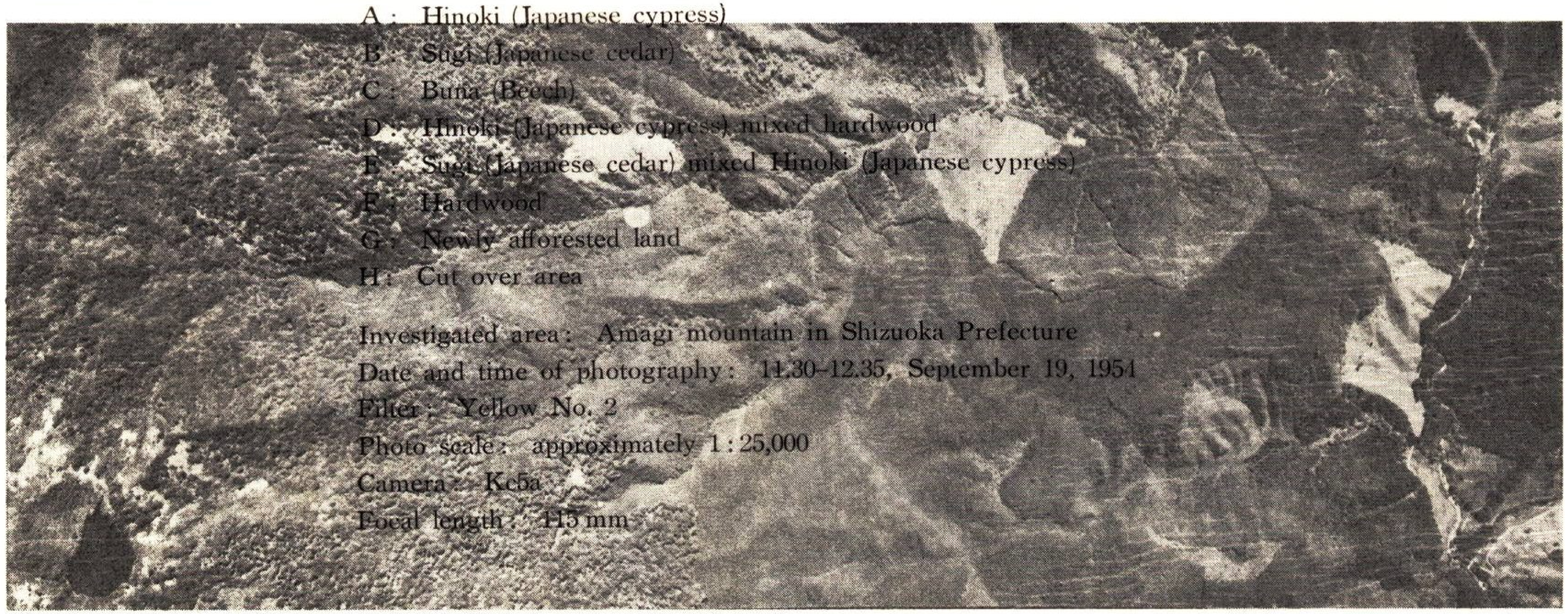
Comparison of infrared and panchromatic photography with regard to the separation of forest types
(Aerial photographs by Nakasone)

Explanation of investigated area delineated on aerial photograph

a.
*Infrared photography*




b.
*Panchromaitc photography of the same aera*



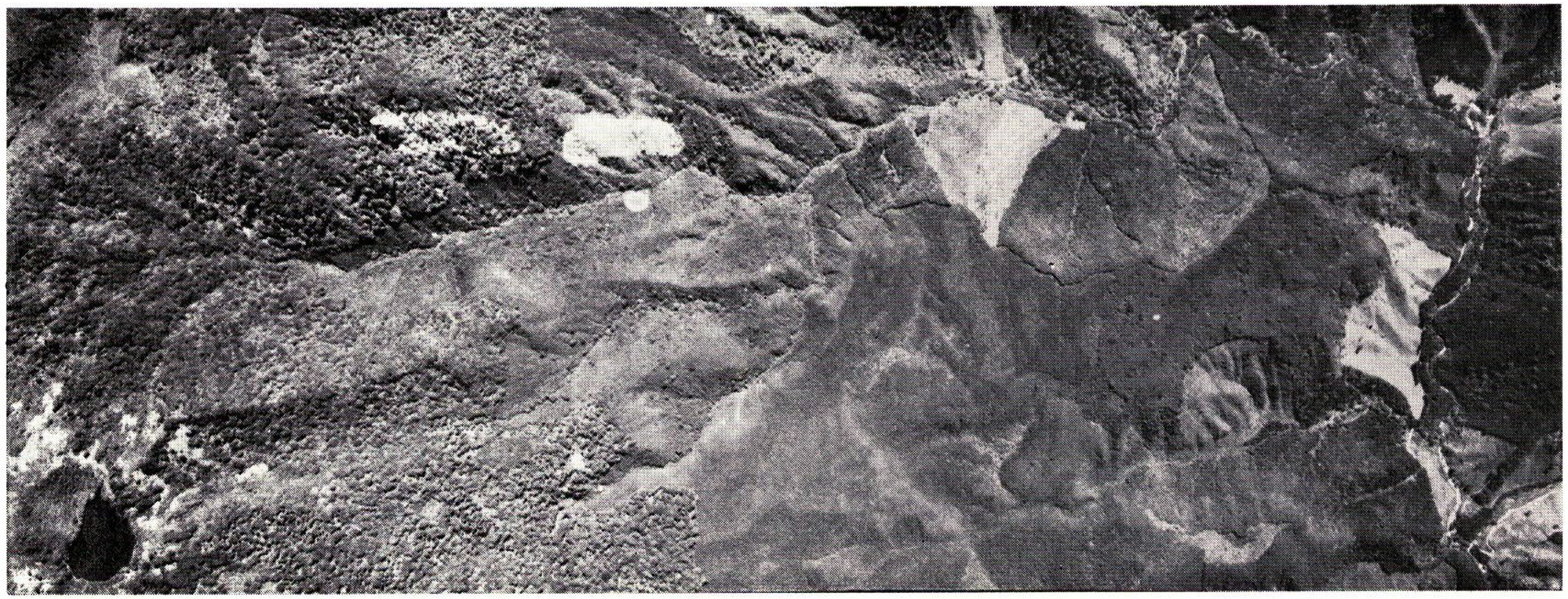
A: Hinoki (Japanese cypress)
B: Sugi (Japanese cedar)
C: Buna (Beech)
D: Hinoki (Japanese cypress) mixed hardwood
E: Sugi (Japanese cedar) mixed Hinoki (Japanese cypress)
F: Hardwood
G: Newly afforested land
H: Cut over area

Investigated area: Amagi mountain in Shizuoka Prefecture
Date and time of photography: 11.30–12.35, September 19, 1954
Filter: Yellow No. 2
Photo scale: approximately 1:25,000
Camera: Ke5a
Focal length: 115 mm

Plate 1

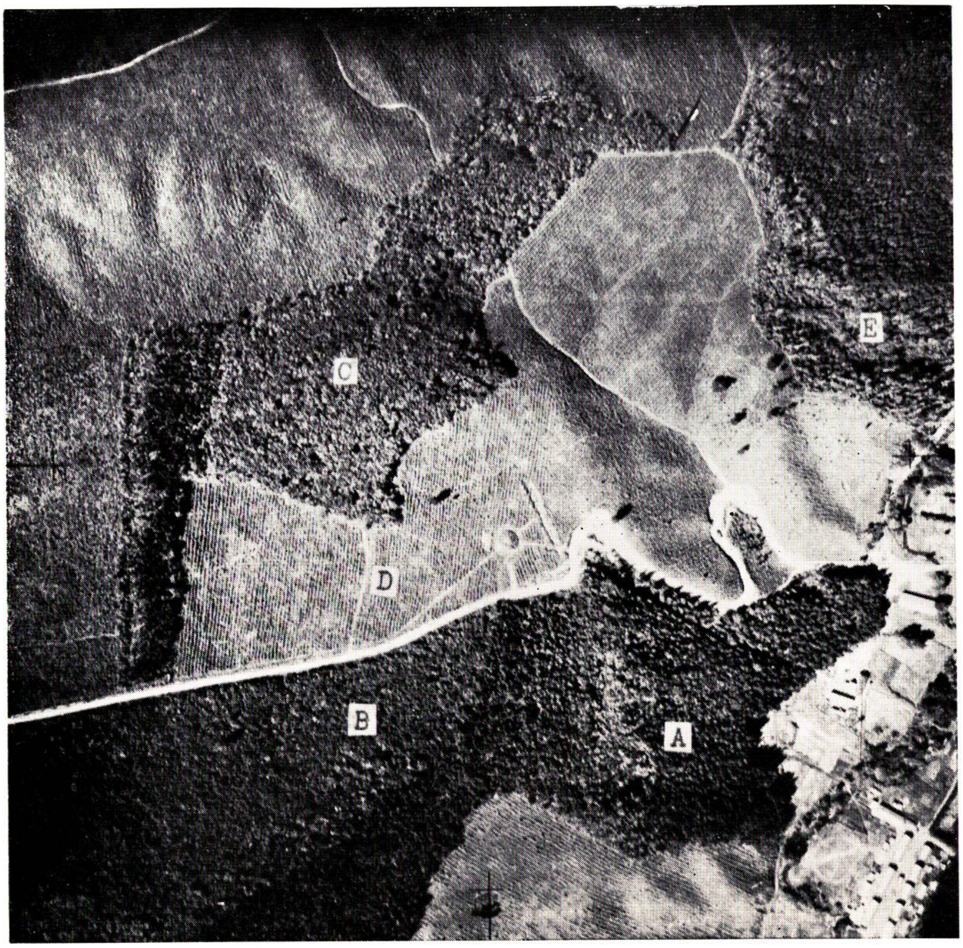
Comparison of infrared and panchromatic photography with regard to the separation of forest types
(Aerial photographs by Nakasone.)

a.
*Infrared photography*



b.
*Panchromaitc photography of the same aera*

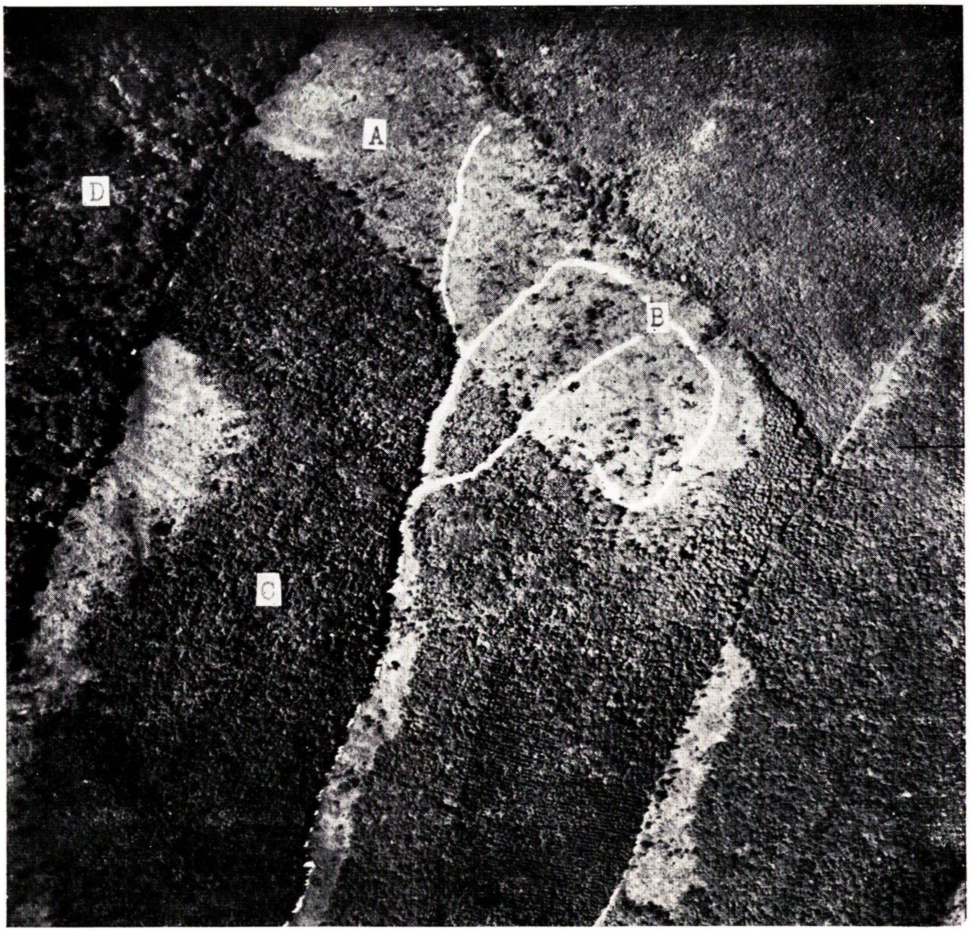
Afforested land patterns in Compartments (15, 20, 30), Horonai Working Unit, Tomakomai Experiment Forest, Hokkaido University. Negative scale 1:5,200, photographed by K-24 Camera with a 5″ focal length. Panchromatic summer photography.




A : Comparatively old aged afforested land of Spruce
B : Comparatively young aged afforested land of Spruce
C : Young aged afforested land of Spruce
D : Newly afforested land of Larch
E : Comparatively old afforested land of Larch

Where the planted trees are become old and are closely spaced, they are characteristically dark in color as compared with younger aged planted trees. Where the planted trees are young enough to expose the ground surface, rows of planted trees exhibit a characteristic texture. Larch gives us a lighter color than Spruce.

Cut over area, afforested land, and natural forest in Compartment 31 or near there, Yamanokami Working Unit, Tomakomai Experiment Forest, Hokkaido University. Negative scale 1 : 5,200, photographed by K–24 Camera with a 5″ focal length. Panchromatic summer photography.




A : Area which has been cleared recently

Remaining trees and stumps are recognized under a stereoscope.

B : Switchbacks on a transportation road

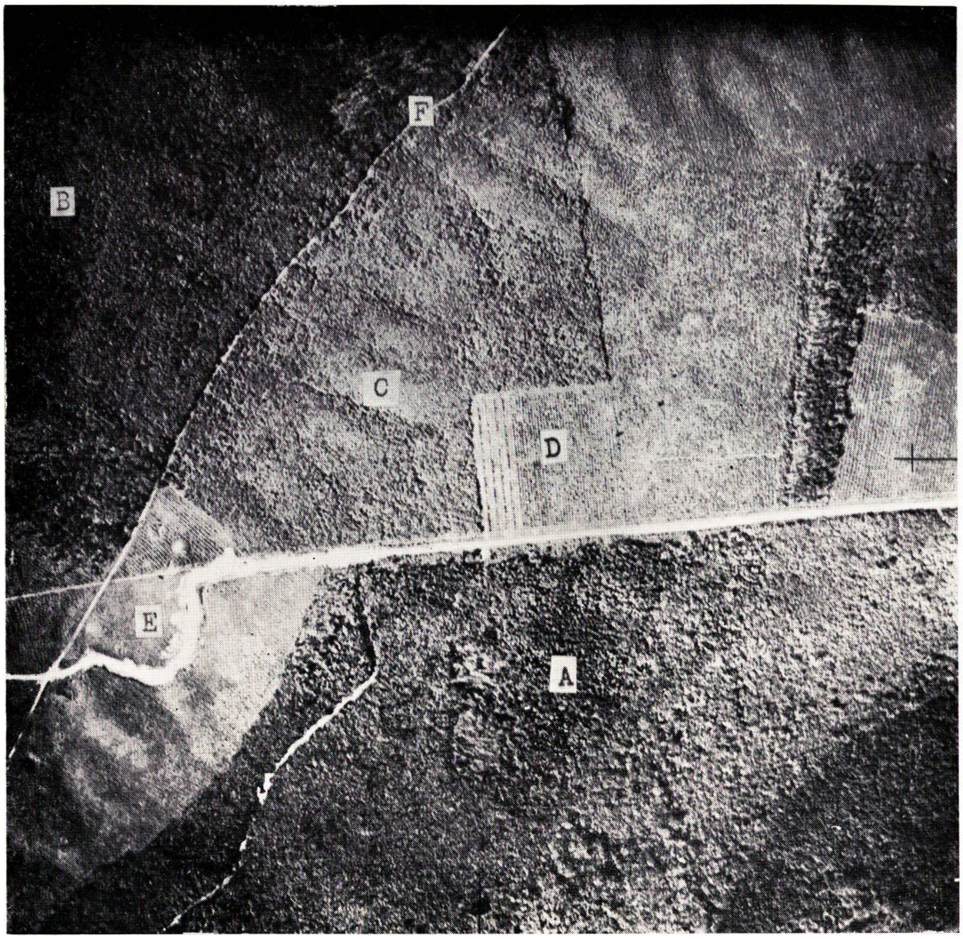
Color tone is very whitish because the road is surfaced with volcanic ash soil.

C : Comparatively young aged afforested land of Spruce.

D : Natural forest (Hardwood) devastated by "Typhoon 15" in 1954

In general, an afforested land exhibits the finest texture and the regular pattern as compared with other types of forest.

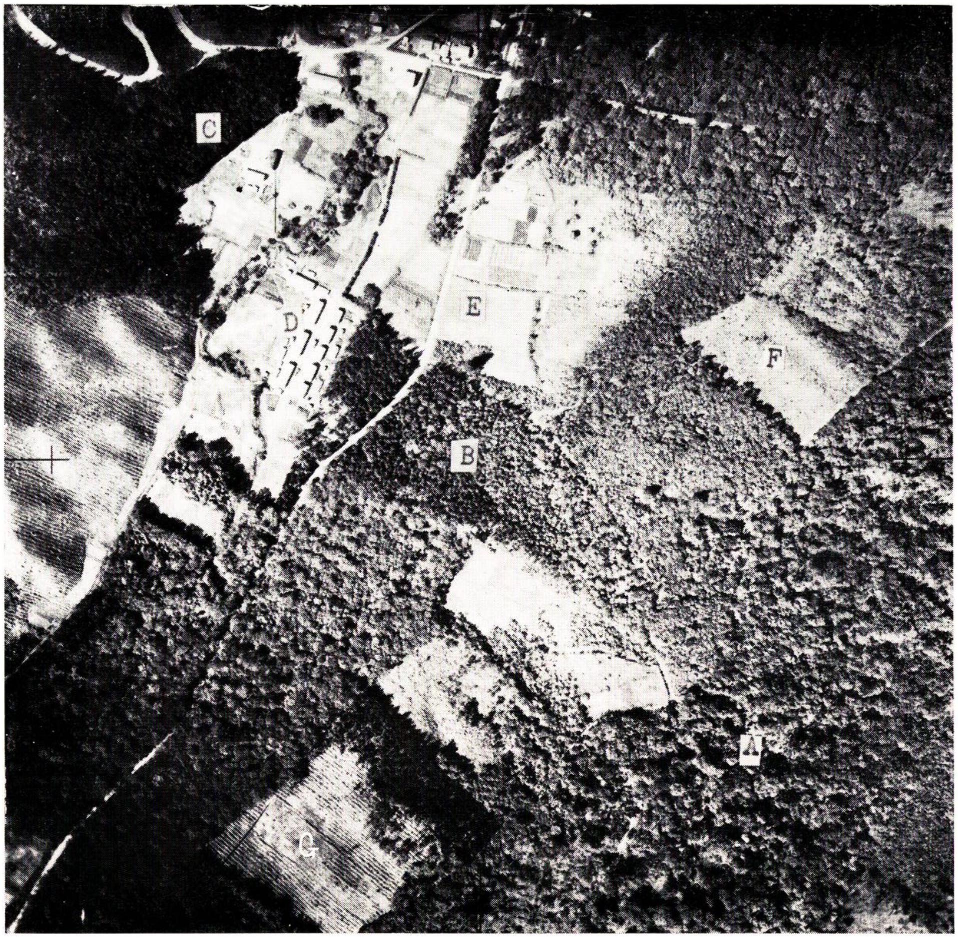
Secondary forest and afforested land in Compartments (15, 16), Horonai Working Unit, Tomakomai Experiment Forest, Hokkaido University. Negative scale 1 : 5,200 photographed by K–24 Camera with a 5″ focal length. Panchromatic summer photography.




A : Secondary forest consisted of Cherry, Oak, Maple, and others
B : Comparatively young aged afforested land of Spruce
C : Badly afforested land of Todo fir
D : Afforested land of Larch mixed with Todo fir
The texture of this afforested land slightly differs from that of Larch alone.
E : Small breaking places along the road
F : Path

Secondary forest in this area does not exhibit a regular photographic pattern as seen in other areas of Hokkaido, the forest in question has been constituted by small size trees which came into failed planted area.

Natural forest patterns surrounded afforested land and cut over area in Compartment 32, Horonai Working Unit, Tomakomai Experiment Forest, Hokkaido University. Negative scale 1 : 5,200 photographed by K–24 Camera with a 5″ focal length. Panchromatic summer photography.




A : Natural forest

B : Comparatively young aged afforested land of Spruce

C : Comparatively old aged afforested land of Spruce

D : Dwelling house

E : Farm

F : Cut over area
Rows of planted trees are invisible.

G : Afforested land

Natural forest generally exhibits a characteristic rough texture as compared with afforested land and secondary forest.

Man-made features and natural surface cover near or in Compartments (17, 18) Horonai Working Unit, Tomakomai Experiment Forest, Hokkaido University. Negative scale 1 : 5,200 photographed by K–24 Camera with a 5″ focal length. Panchromatic summer photography.


A : Man-made water way

B : Cultivated field

Cultivated field is characterized by a finely lineate and where different stages of cultivation are present, there will be contrasting bands of different color tone.

C : Grass land

D : Dumping ground

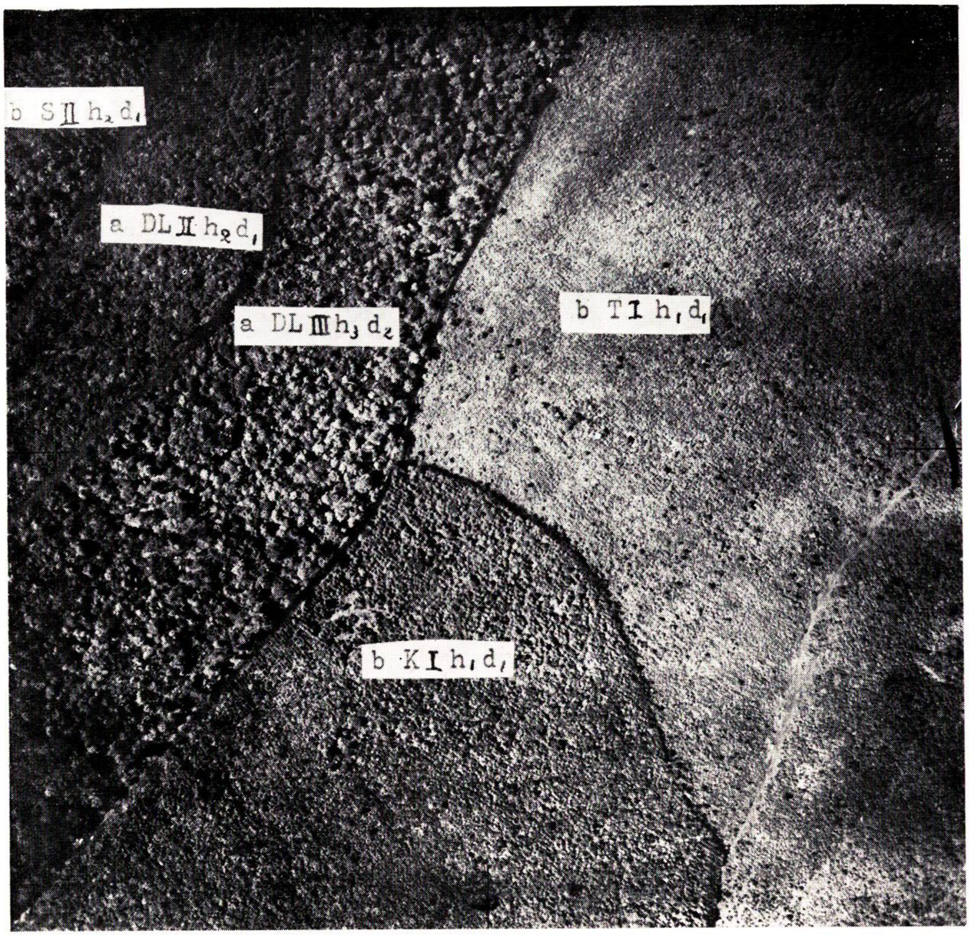
E : Shrub growth

Shrub growth is distinguished by its finer texture, where spare, by its peppery appearance.

F : Newly afforested land

G : Secondary forest

An aerial photograph showing the classification of vegetation cover based on code system.




For instance, $b\,TI\,h_1\,d_1$ in this Plate indicates the following content: Artificial forest; Tree species: Todo fir; Age: Up to 20 years; Height: Up to 8 m.; Diameter: Up to 10 cm.