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INVENTORY DESIGN FOR PLANNING
THE DEVELOPMENT OF IRANIAN
FOREST RESOURCES: WITH EMPHASIS
ON THE WESTERN FOREST REGION

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ABSTRACT

INVENTORY DESIGN FOR PLANNING THE DEVELOPMENT OF IRANIAN FOREST RESOURCES: WITH EMPHASIS ON THE WESTERN FOREST REGION

By

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Iran is geographically the central country of the Middle East. Iran is a little larger than Alaska and has an area of 163,600,000 hectares of which 12,000,000 hectares are forested. Forests as a national resource are second only to oil. Iran's need for timber is greater today than at any time in the past. The ratio of imports to exports has been constantly increasing since 1946. In 1971, Iran spent $65,300,000 for importing timber while exporting only $300,000 from this resource (FAO, 1973).

Iran has a population of 29,780,000 persons, with one of the highest growth rates in the world, 3.1 percent in 1966. Seventy percent of the population are illiterate. The demand for timber has been sharply increased due to the establishment of programs to make reading materials more widely available to solve this problem of illiteracy. The demand has also been increased due to the development in educational and housing systems to meet the needs of

increased population. Furthermore, the forest resources of Iran are limited and are largely undeveloped.

Iran's leadership needs to know what, where, and how much timber there is at any given time to develop more comprehensive plans for forest management and research in order to meet the domestic demands for forest products. This knowledge cannot be obtained unless satisfactory information about the forests is available. To obtain such information, a suitable inventory for each of the Iranian forest areas is necessary.

X The major Iranian forests are the Caspian and the Western Forests. The Caspian Forest covers 3,400,000 hectares and has excellent timber quality and growth. The Caspian Forest consists mainly of hardwoods, while the Western Forest consists of mixed species, but has the potential to produce good quality softwoods (Dr. Tregubov, 1969). X Softwoods are preferable for paper manufacturing. X The Iranian leadership has decided to educate 70 percent of the illiterate people, but does not have sufficient timber resources for the domestic pulp and paper demands this program would require. Likewise, there is very little information about the Western Forest. The objective of this study, therefore, was to formulate an inventory design which would provide the informational base for potential development of the Western Forest and establishment of a pulp and paper mill.

In this investigation, two plans have been recognized: first, the immediate or short-term plan; and, second, the long-term plan. In the short-term plan of investigation, promising conifer species were selected, after studying climatically similar forests in the world. Provenance testing of these species constitutes an urgent and immediate task. The execution of a suitable inventory design constitutes the second task. This task includes estimation of the present timber resources and determination of factors influencing the productivity of the Western Forest. A pilot survey using concentric point-sampling (i.e., three basal area factors from the same point) was conducted during the summer of 1974. The purpose of the pilot survey was to obtain a general knowledge of stand structure to aid in designing a suitable inventory plan. The results of analyzing these data indicate that the Western Forest is a balanced uneven-aged stand with a diameter distribution function of $y = e^{5.78 - 0.08x}$ where x is diameter in centimetres, y is the diameter frequency, and e is the base of natural logarithm. It has a height distribution function of $h = e^{4.58 - 0.19m}$ where h is height in half a metre and m is height frequency.

Ali A. Sarafraz

A cluster sampling design using variable-radius plots with nine plots per cluster is proposed, using basal area factor of 2 (in metric system). A total of 187 random samples are required for a precision of 10 percent of the basal area with a probability at the 95 percent level. Soil, slope and other ecological data are also recorded at each sample in addition to the data on tree parameters. A stem analysis on one tree in every sample is proposed to estimate defect and construct site index curves and volume tables. In the actual implementation of the inventory, the planning and management of manpower and logistics are crucial to the success of the inventory. As a result of the inventory, sufficient information should be available for planning the location and capacities of pulpwood mills and other wood-based industries. It is hoped that these proposals will in some way contribute to the welfare and economic well-being of the Iranian people.

INVENTORY DESIGN FOR PLANNING THE DEVELOPMENT OF IRANIAN FOREST RESOURCES: WITH EMPHASIS ON THE WESTERN FOREST REGION

By

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CHAPTER I

INTRODUCTION

Iran's need for timber will soon be much greater than it is today or has been at any time in the past. The Iranian demands for forest resources have increased sharply because of many factors such as population increase, housing improvement, and growth in the educational system. Also, Iran has one of the highest birth rates in the world (Plan Organization, 1968). The annual population growth rate was about 2.6 percent in 1959, and 3.1 percent in 1966. The Ministry of Development and Housing reported that the shortage of housing by 1971 was 798,313 homes. With respect to growth in the education system, the literacy rate was 15.9 percent in 1959, and by 1966 it was 29.4 percent, a 14 percent increase (Plan Organization, 1968). The distribution of exports and imports of timber for a period of twenty-two years, 1946-1967 is demonstrated in Figure 1. Iran will need more timber in the future. Furthermore, the forest resources of Iran are largely unexplored and undeveloped, with the Caspian Forest production being only $27,000,000 per year.

Figure 1: The Distribution of Exports and Imports of Lumber in 22 years in Iran, as reported in handbook no. 19, College of Natural Resources at Tehran University. Karaj, Iran.

The Ministry of Agriculture and Natural Resources of Iran is responsible for helping to meet present and future demands for goods and services from the national forests and related resources. In this undertaking, the Ministry has two main responsibilities:

1) To manage, protect, and develop the Iranian National Forest System.

2) To conduct basic and applied research in forestry and related fields.

If Iran's leadership knows what, where, and how much timber there is at any given time, they should be able to develop future plans for managing the forests and improving research on forest resources in order to meet the domestic demands for forest products. It is essential to recognize the need for intensive research on forest problems, particularly on those related to the production of paper.

Iran has only one paper mill, the Pars Paper Mill Company established in 1971. It has an annual output of 35,000 tons, while the domestic need will be 200,000 tons by 1981 (R. Pelttari, FAO advisor to Iran, 1964). Iran has two major forests: the Caspian Forest and the Western Forest. According to Dr. Tregubov, former FAO advisor to Iran, and Dr. Mobayen, professor at the College of Sciences, Tehran University, 1970, the Western Forest species indicate that this forest zone is a suitable area for introducing more profitable conifers. The major objective of this study is to provide a basis for the rational utilization of the Western Forest which is a part of the overall Iranian National Forest system. Useful production from this forest will require preparation and execution of a comprehensive program. Inevitably, part of such a program must involve forest inventory, which has not yet been planned for the Western Forest. Conducting this inventory will provide the necessary inputs to an information system for the Western Forest. The inventory design developed for this forest will be helpful for Iran's leadership as one of the fundamentals for forestry planning and for pre-investment decisions related to the possible establishment of wood processing plants (e.g., paper manufacturing plants) in the Western Forest. In designing the inventory plan, careful consideration must be given to the two main decision variables of precision and inventory operation costs, and also the circumstances of the forest such as geography, management, policies etc. In addition to the Western Forest, the other important Iranian forest is the Caspian Forest. This forest is the most extensive hardwood area. The Caspian Forest inventory which has already been conducted by Rogers and Williams and proposed plan for the re-inventory will be presented.

National forest inventories not only help in regulating yield, but they are essential in national land-use planning. National inventories which provide general estimates such as species and diameter distribution are usually satisfactory for general planning purposes. Such information indicates what, where, and how much forest production is available for any given time. These are important in deciding forest policy and general planning of forest industries development. Hopefully this study, with slight modification, will also be useful to other developing nations of the world.

This study begins with a review of general information about Iran in relation to the forest resources and present study areas. The current situation of forest industries in Iran is discussed in Chapter III. A serious campaign against illiteracy, along with the high rate of population growth and modern life in Iran have brought a sharp increase in all varieties of timber consumption. The Iranian forest resources are limited to two hardwood forests, but Iranian carpenters prefer to work with softwood. Softwood is easy to work and has more uniform quality than local hardwoods even though it is more expensive. Because of this demand, *Picea* has been imported for construction from the USSR. Since there is a projected shortage of 165,000 tons of paper by 1981, the feasibility of establishing paper manufacturing plants in the vicinity of the Western Forest is discussed in Chapter III.

Chapter IV describes the types of requirements and information needed for establishing paper manufacturing in the Western Forest, such as determining the location of manufacturing plants, plant capacity, kinds of timber supplies and inventory information for present stand.

In Chapter V, a review of forest inventory methods used for developing countries is made. These methods include "Selected Line Method," "Dawkins' Method," "Loetsch's Method," "Rollet's Method," "Wheeler's Method," and the "Strip Method."

In Chapter VI, the existing Caspian Forest Inventories are presented. It is also determined that a pilot survey is helpful in designing a suitable inventory plan for the Western Forest.

Chapter VII describes a pilot survey conducted in the Western Forest and the analysis of data.

On the basis of the pilot survey findings, a suitable inventory plan for the Western Forest is proposed in Chapter VIII.

Finally, summary and conclusions are made concerning utilization of all Iranian Forests with emphasis on the Western Forest.

CHAPTER II

GENERAL INFORMATION ABOUT IRAN AND ITS FOREST RESOURCES

Iran is located in southwest Asia and geographically is the central country of the Middle East. Iran is bordered by U.S.S.R. and the Caspian Sea on the north, Iraq and Turkey on the west, Afghanistan and Pakistan on the east, and the Persian Gulf and the Gulf of Aman on the south. The capital city is Tehran with a population of 3,500,000. The area of Iran is 163,600,000 hectares which is almost four times the size of France, a little larger than Alaska, or one-fifth the size of the United States (Hejazi and Tabatabai, 1967-1968). It extends for about 2,600 kilometres from north to south and about 2,100 kilometres from east to west. The population of Iran is 29,780,000.

Iran can be classified into five major land catagories as follows (Hejazi and Tabatabai, 1967-1968):

1. Agricultural lands, towns and irrigated areas, 22,500,000 hectares;
2. Range, 16,000,000 hectares;
3. Desert, 81,600,000 hectares;

4. Subdesert areas, but capable of cultivation, 31,500,000 hectares;

5. Forests, 12,000,000 hectares.

Information regarding elevation, climate (Ganji, 1955), vegetation, average annual precipitation, and population distribution (Geographical Handbook Series about Persia) are given in Figures 2, 3, 4, 5, and 6, respectively. Most of the soils in Iran, especially those of limestone and sandstone origin, are highly erodable.

The first forest law was passed by the Iranian Parliament in 1943, and a forestry administration (Bongahe Jangle) was set up in the Ministry of Agriculture in 1949. Although this forest bureau was supposed to be responsible for planning, protecting, and all other aspects for all forests, the bureau was only concerned with issuing cutting permits and collecting revenues. In 1963, the Iranian Cabinet approved a decree calling for the nationalization of all forests.

According to Dr. Tregubov, former United Nations professor of silviculture at the College of Natural Resources at Tehran University, 1967, the distribution of the size of Iranian forests on the basis of the location of key species is shown in Table 1 and also on the map in the back pocket.

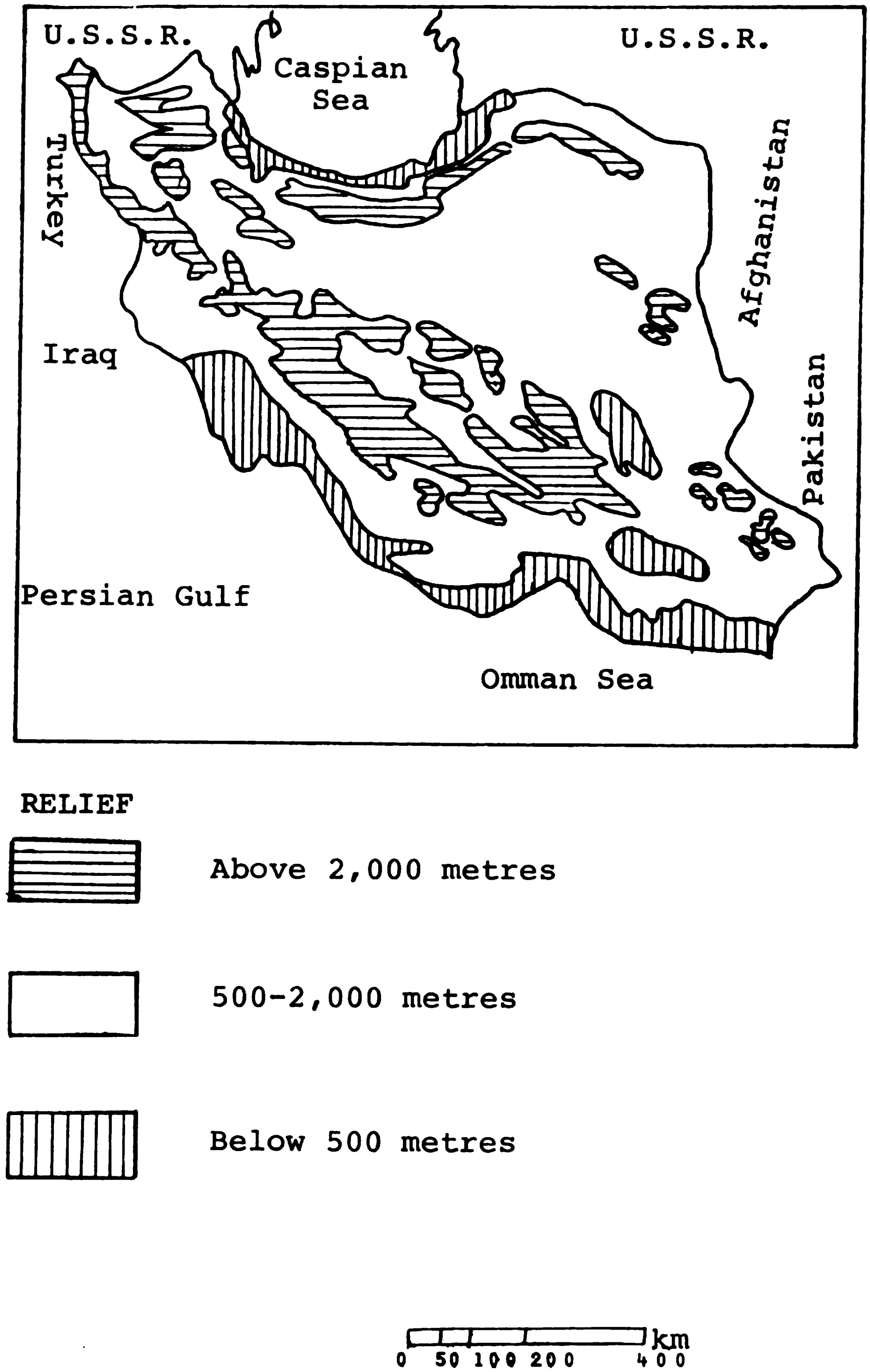
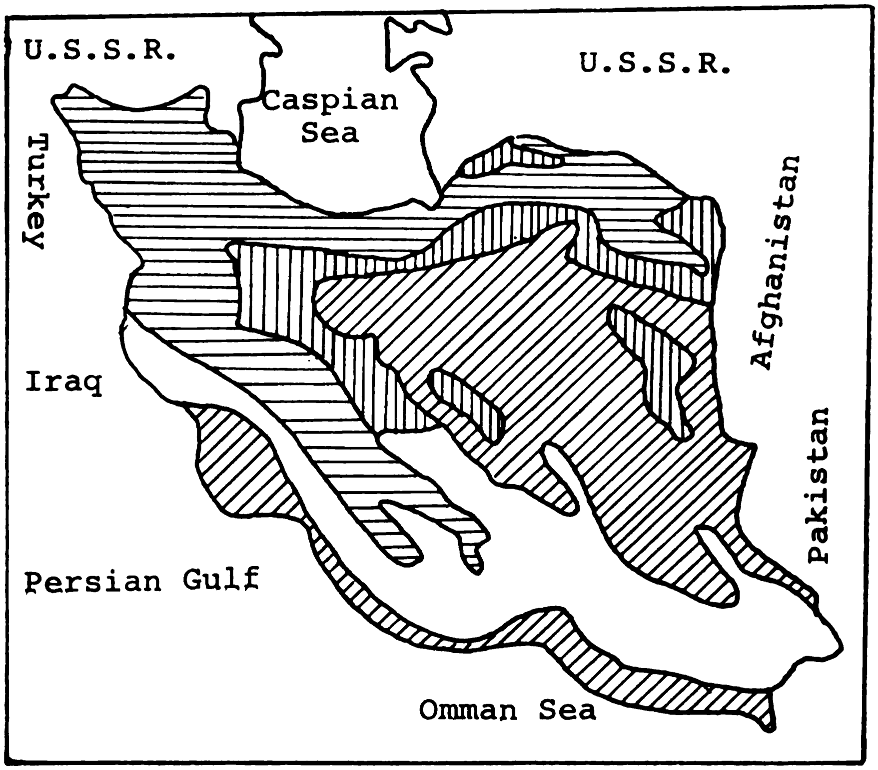


Figure 2: Iran-Elevation
(scale 1:5,000,000)



Note: The abbreviations below are explained on the following page. (scale as Fig. 2)

Figure 3: Climatic Map of Iran
(Koppen system, Ganji, 1955)

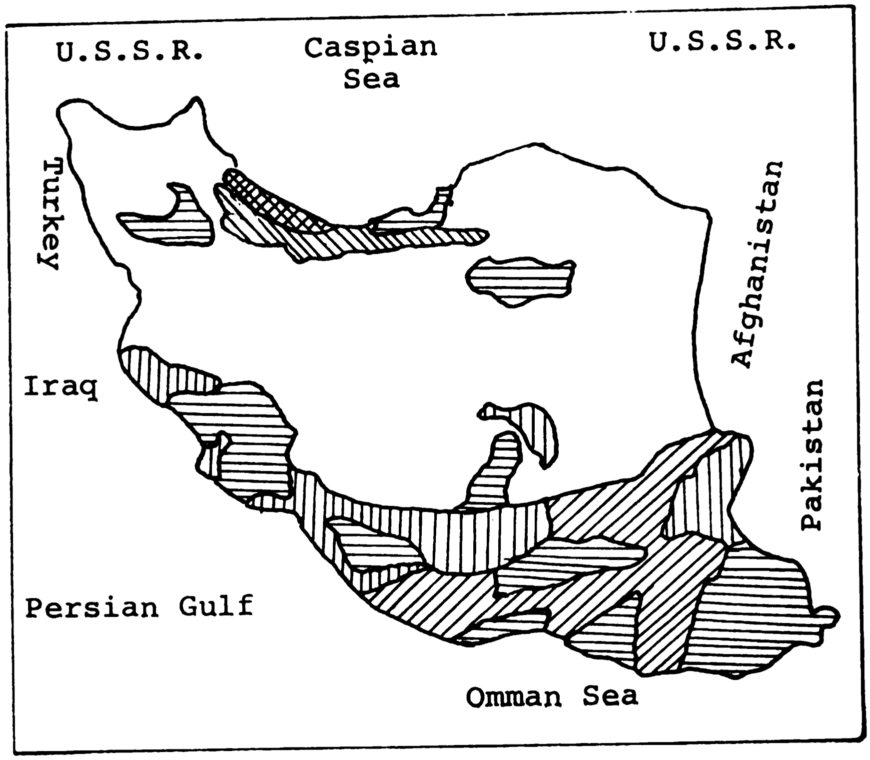
Note: Some of the more important abbreviations used in the climatic map of Iran (Figure 3) are as follows:

BSC sa - steppe, warm temperature, rainy climates. The average coldest temperature is between 3 and 18, and the average hottest is above 10 degrees of centigrade.

BS sah - semiarid climate or steppe or dry grassland and it rains at least three times in the driest summer months.

BW sah - arid climate or desert and it rains at least three times in the driest summer months.

C sa - warm temperature rainy climate in hot summer over 21.7 degrees centigrade.



Artemisia, Astragalus

Acacia segal

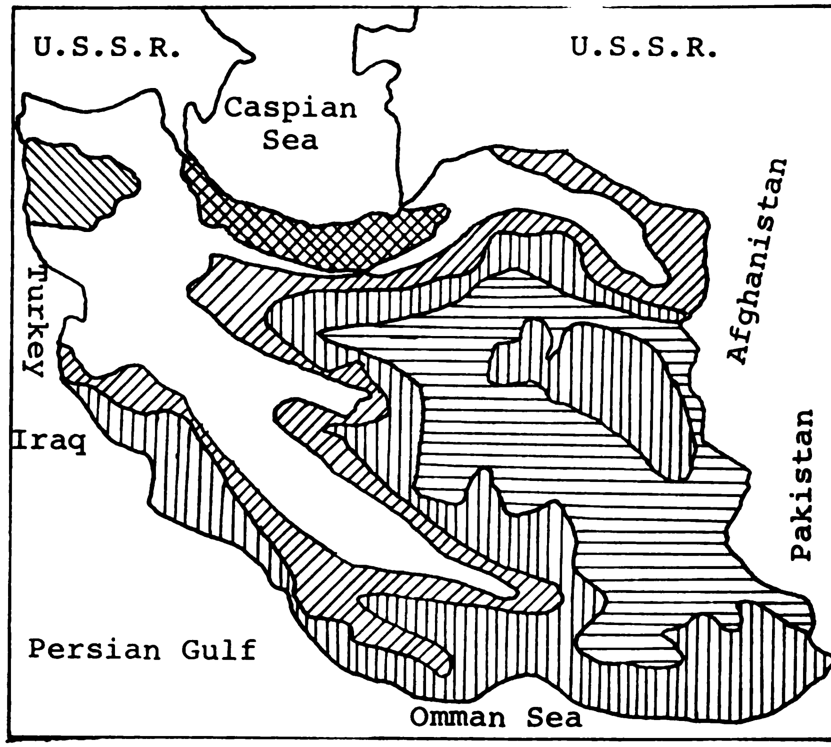
Halophile

Ziziphus spina - christi prosopis spicigera

Fagetum hyrcanum

Auerco-Buxetum

Figure 4: Iran Vegetation
(scale as Fig. 2)



200 centimetres

100 centimetres

40 centimetres

30 centimetres

20 centimetres

10 centimetres

Figure 5: Average Annual Precipitation in Iran (centimetres)
(scale as Fig. 2)

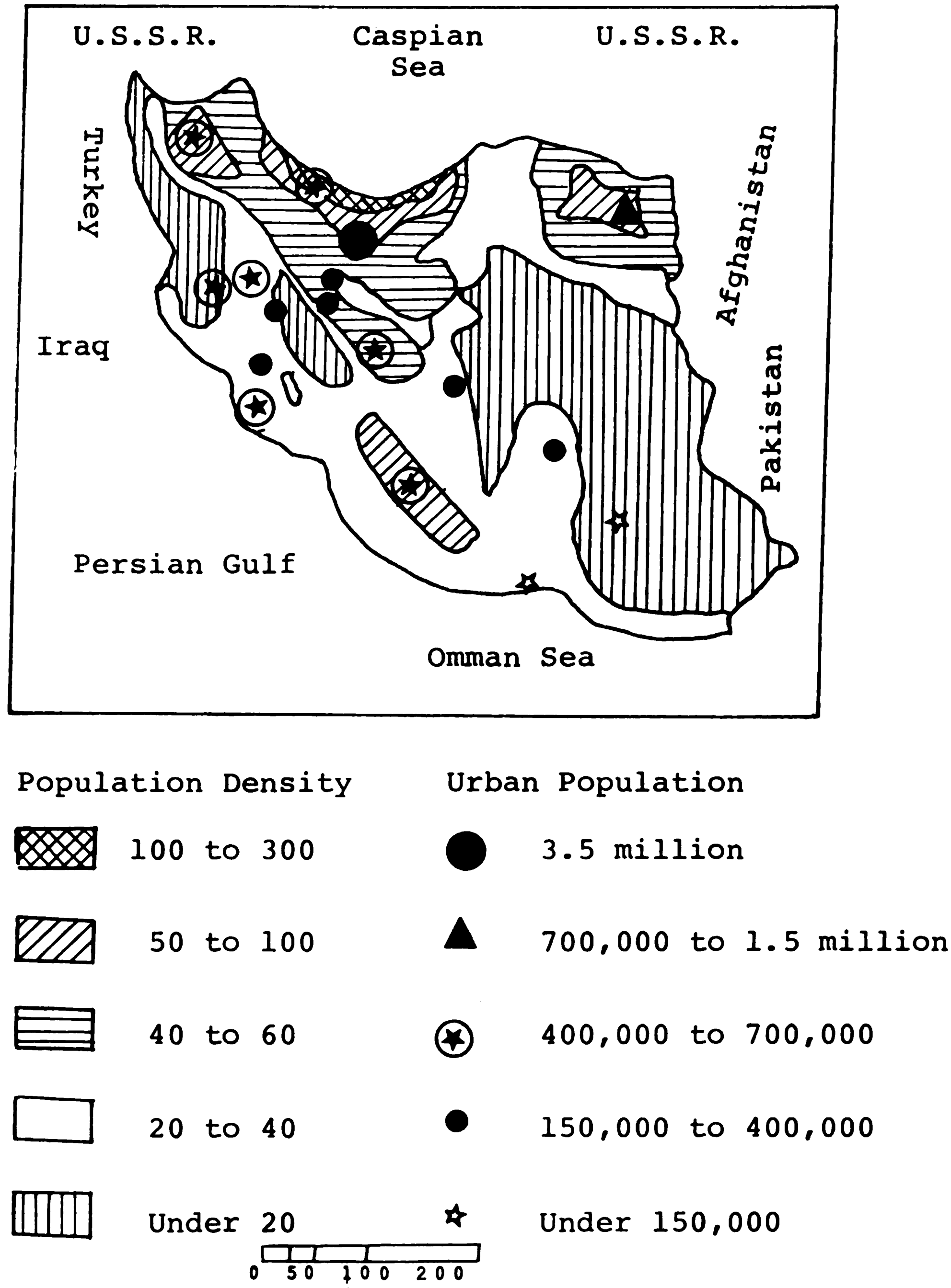


Figure 6: Population Distribtuion of Iran
(per kilometre square)

Historically, forest management has usually started rather late in the economic development of any country. Generally, periods of reckless clearing and exploitation for agricultural lands take place and then lumber is utilized later. Forest management starts with a period of protection and conservation of remaining forests, and of reforestation of cut stands. Subsequently comes a period of limited utilization according to a long-term management plan on a sustained-yield basis. Carrying out the management plan regulates the forest production with resultant improvement of the quality of stands and subsequently the value of the forest.

Table 1.--Distribution of Iranian Forests

Forest Name and/or Key Species	Area (ha.) x 10^6
The Caspian Forest: *Carpimetum orientalis* & *Quercus macranthera*, *Fagetum hyrcanum*, *Parrotio-Carpinetum*, *Querco-Carpinetum*, and *Querco-buxetum*.	3.4
Western Forest: *Quercus persica*, *Q. infectoria*, and *Q. libani*, *Acer cinerascens*, *Platanus orientalis*, *Salix aegyptica*.	5.0
Pistacia mutica and *Pistacia vera* Forest	1.5
Juniperus excela Forest	1.1
Others: *Tamarix articulata* and *Avicennia officunalis*.	1.0
TOTAL	12.0

Source: Handout at the College of Natural Resources, Tehran University, provided by Dr. Tregubov, former FAO advisor.

The period of Iranian recklessness has passed, and the period of protection is in progress. Reforestation is one of the current improvements. However, there are many difficulties in development of Iranian forest resources such as the variability in rainfall distribution. Water in Iran is a limiting factor in tree growth and human development. Fresh running water is found only in isolated areas: the northern border lands, the Zagros valleys, and ports. Elsewhere many of the streams are short, intermittant, or salt-laden. Their waters often are absorbed into some kind of grasses that covers so many of the valley bottoms, and life is dependent on springs, wells, or artificial devices and dams for water.

> The pattern of the drainage basins is remarkable, and is directly related to rainfall and the structure of the terrain. In the North, where considerable precipitation is caused by moist northerly winds, mountain torrents plunge down the northern slopes of the Alburz ranges to the Caspian Sea. In the West and Southwest of Iran, where the Zagros Mountains receive much rain and snow, a succession of river basins succeed one another from north to south, each having an outlet carved through the hills, by which the collected waters reach Mesopotamia through the Persian Gulf. Rainfall decreases southward and eastward, so that beyond the Alburz and Zagros Mountains almost the whole country lies in a vast "rain shadow." (Movahed, 1974)*

That is a reason for selecting the Caspian Forest and the Western Forest as the study areas. These forests are the first and second most valuable Iranian forest resources.

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*Citation was granted by the author.

Present Study Areas

The two most important Iranian forests, the Caspian Forest and the Western Forest, have been selected as the study areas for this investigation.

The Iranian Caspian Forest

This forest is located in a narrow strip about 1,000 kilometres long, on the northern slope of the Alburz mountains along the Caspian shore. According to Kernan (1956):

> The Caspian Forests, a heavily wooded area of unrivalled excellence in the Middle East, is created by the combination of high rainfall, mild climate, and a long growing season. The timber is of superior quality. The quality of timber of soundness, size and form is very good. Reproduction is abundant, growth is rapid and the net volume growth runs high (up to 50,000 board feet to the acre).

This growth estimate is based on a few observations and Kernan's judgement. The Caspian Forest covers 3,400,000 hectares with an average elevation of 560 meters. The annual rainfall in the Caspian Forest occurs between early September and late June with an average of about 1,500 millimeters. The ownership pattern on the forest is mostly public domain and some private ownership such as Royal Domain. The inaccessible areas of the Caspian Forest are only 3.5 percent of the total forest. For the remainder of the area access is most limited to pack animal (Tahbaz, 1966).

+ The Caspian Forest consists of four important forest types according to elevation (see the bottom diagram on the forest type map, in the back pocket, Figure 7). The key species are listed as follows:

1. Querco-Carpinetum and Querco-Buxetum located on elevations of less than 200 metres.

2. Parrotio-Carpinetum located on elevations between 200 and 800 metres.

3. Fagetum hyrcanum located on elevations between 800 and 2,000 metres.

4. Carpinetum orientalis and Quercus macranthera located on elevations between 2,000 and 2,800 metres.

More than 80 percent of the trees in the Caspian Forest are hardwood (Dr. Tregobuv lecture). Thirty percent of the Caspian Forest is virgin and unexplored, and 5.9 percent is not operationally feasible for management or production (i.e., too hilly and rocky). Nine percent is specified for soil protection according to the law (H. Hambleh's handout, in forest policy, FAO professor at the College of Natural Resources at Tehran University, 1964). According to H.A.M. Gläser, 1960; United Nations' expert, about two-thirds (2 million hectares) of the

Caspian Forest have been devasted and from these parts only fuelwood and charcoal can be expected. The rest of the Caspian Forest is untouched and is not easily accessible because of high mountains. According to Glaser, 1960, this portion of the Caspian Forest contains a considerable quantity of fuelwood. However, overmature and partly rotten trees and thinning residuals yield on an average 50 percent of fuelwood.

The Western Iranian Forest

The Western Forest species indicate that this forest zone is suitable area for introducing more profitable conifers (Dr. Tregubov and Dr. Mobayen, 1970). Considering the inadequate amount of paper manufacturing in Iran, the Western Forest has been selected as the major study area.

The Western Forest is located in the Zagros region. This region comprises the great and wide ridge of the Zagros of approximately 1,600 kilometres in length. This territory has almost submediterranian, moderately arid climate.

The Western Forest consists of three important forest types. The key species for the three forest types are listed below:

1. Quercus infectoria, and Quercus Libani.
2. Quercus persica, Lonicera persica, Pyrus

glabra, and *Pistacia* *khindjuk*.

3. *Amygdalus* *scoparia*, and *Daphine* *angustifolia*.

These forests receive 40-50 centimetres of moisture annually due to their nearness to the Persian Gulf. This moisture preserves the rather thin xerophytic forest. These forests have been devasted by severe overcutting, mainly for fuel and native uses. However, about half of these forests have been preserved on account of the nomadic Kashkai tribes who use acorns in making their bread (Dr. Tregubov and Dr. Mobayen, 1970).

CHAPTER III

POTENTIAL DEVELOPMENT OF FOREST INDUSTRIES IN IRAN

In 1971, in Iran $65,300,000 was spent on timber imports, while only $300,000 was obtained from timber exports (FAO, 1973). Iran, however, has 12,000,000 hectares of forest resources of which most are unexplored or are not properly utilized. Availability of funds as a result of the development of oil exports provides a good basis for developing the Iranian forest resources. The fact is that forest resources are second only to oil as the nation's primary resources in terms of dollar value. It is the author's opinion that the development of forestry and forest industries should follow from the present national economy. This could result in a more favorable balance of trade in the forest sector of the economy.

Over a million persons are engaged in Iranian handicraft industries which have a tradition of many centuries (e.g., 400,000 are engaged in carpet weaving). The number of workers engaged in handicrafts is almost three times more than the workers employed in other industries (Iran Almanac, 1971).

Iran has not been a major industrial country in the past. Most of the major forest industries were established after 1960 and are mainly operated under methods all but obsolete. As a result, their products, from logs to furniture, do not meet standard specifications and are the main forms of lumber available on the market. The status of the forest industry can be illustrated by the following information.

Sawmill Industry

Sawmilling is relatively an old industry in Iran. The traditional Iranian lumbers are sawn or hewn by hand in the forest into sizes ranging between 200-260 centimetres in length, 20-40 centimetres in width, 12-20 centimetres in thickness and are called "alvars, travers, and kondaks." These squared pieces are sawn to desired sizes in the joinery or resaw mills. In 1969, the total production of sawmilling units in Iran was 2,239,000 cubic metres, of which 304,000 cubic metres were from the Caspian Forest (FAO, 1969). The major species used for large sawmill units are hardwoods. Twenty thousand of these sawmills are very small units (workshop); the larger ones are described as follows:

(a) Assalem

Assalem is the largest sawmilling unit in Iran with 300,000 cubic metres per year (FAO, 1969). This unit was established about 30 kilometres northwest of Bandar Pahlavi in 1961. All equipment and machinery, costing $250,000, was imported by the United States Operations Mission (FAO, 1960). The sawmill consists of a vertical bandsaw (12 centimetres wide) with edgers, trimmers, log chains, green chains, and conveyers. The main products are sleepers and large size squared timber. Sleepers are used mainly for the expansion of the Iranian railroad system. Since the growth of forests near the mill cannot produce enough wood for its full capacity, the mill works only one shift and consequently produces 150,000 cubic metres annually.

(b) Golband

This unit was established in 1956 in the Caspian area. The mill consists of five vertical saws each 8-10 centimetres in width. The production capacity of this unit is 30,000 cubic metres per year and produces only sleepers.

(c) Emamzadeh Ebrahim

This unit was established in 1960 in the north-western part of the Caspian area. The mill consists of two Iranian-made vertical saws 8-10 centimetres in width. The unit produces 20,000 cubic metres of sleepers yearly.

(d) Lavij

Lavij was established in 1954 in Tehran. The mill consists of two vertical saws with 5 and 10 centimetre saw-belts. The annual production capacity is 3,000 cubic metres of sleepers.

(e) Fishery Company

This mill was established in 1952 in Bandar Pahlavi. It consumes about 6,000 cubic metres of pine timber (imported by rafting from Russia), domestic oak and poplar to produce boxes and barrels for packing fish, pickles and caviar. This is an excellent plant suitable for demonstration purposes (FAO, 1960).

(f) FAO Sawmill

This mill was established in 1969 in the Caspian area (Nekah). The unit operates with two horizontal band-saws of 12 centimetres in width. The production capacity of this mill is 15,000 cubic metres annually.

In addition to the above sawmills, there is a unit under establishment directed by a Romanian project. The building is under construction (1974). Other integrated wood industries such as veneer, particle board, etc. will be incorporated. The capacity of this unit is expected to be 93,000 cubic metres of alvar, 5,000 cubic metres of boxes, 68,000 cubic metres of parquet, 12,000 cubic metres of plywood, 4,000 cubic metres of veneer sheets, 18,000 tons of particle board, and 5,000 cubic metres of windows annually.

There was another sawmill, Tamishan which was abandoned by the Iranian government in 1959. This unit was too large and completely outdated. The unit was in operation for sixty years and the Tamishan and Suldeh forests were destroyed because of overcutting to keep the mill in operation (FAO, 1960).

Plywood Industry

The Iranian plywood industry has been developed mostly in the last decade. In 1969, the total capacity of plywood mills was 12,360 cubic metres (FAO, 1969). There are five plywood units, four of which are located in Tehran. The mills are operating at 15 to 35 percent capacity due to the long distance between the mills and the Caspian Forest (FAO, 1960). The mills in Tehran are at least 300 kilometres distance from the forest. This results in high transportation cost for logs and deterioration of the quality of the logs during the time between felling and delivery to the mills; consequently about 40 percent of domestic consumption is imported. The five plywood units are described below.

(a) Sherkateh Sahami Sanyehe Ckub

This unit was established in 1975 in the Caspian area (i.e., Nokhodchar in Gilan). The capacity in one shift is 6,800 cubic metres per year. However, the current production is 3,400 cubic metres annually, consisting of 3,000 cubic metres of plywood and 400 cubic metres of doors and blackboards. The unit uses mainly hardwood.

(b) Sella Fiber Company

This unit was established in 1956 in Tehran. The unit produces 1,880 cubic metres of plywood and 1,000 cubic metres of veneer.

(c) Tesella Company

This unit was established in 1958 in Tehran. The annual production, at 40 percent capacity, is 1,880 cubic metres.

(d) Takhteh Fanar Company

This mill is located in Tehran and was established in 1962. The capacity of the unit is 2,000 cubic metres. However, since 1969 it has operated at only 50 percent of its capacity due to being too large.

(e) Messrs. Bani Hashemi

This unit was established in 1969 in Tehran. The unit has a capacity of producing 3,600 cubic metres of plywood and 3,600 cubic metres of veneer. However, the unit is too large and produces at only half capacity.

Fiberboard Industry

The consumption of fiberboard in Iran seems to be high for furniture and door-making. No statistics on the actual quantity of fiberboard consumption are available. However, consumption seems to justify the establishment of more factories, especially since the mill can be operated mainly on the waste of forest industries or raw material of low quality. The total capacity of the units, working at full capacity, was 33,000 tons in 1969. There are three fiberboard units in Iran, all of which are producing only compressed fiberboards by the wet process. The units are described below.

(a) Babolsar

This unit was established in the mid-east of the Caspian area (i.e., Babolsar) in 1966. The mill has a capacity of about 7,500 tons annually. The unit is usually in operation for three eight-hour shifts.

(b) Khoy

This unit was established in 1967 in the northwest of Iran (i.e., Tabriz). The unit produces 7,500 tons of fiberboard annually.

(c) Hassan Road

Hassan Road fiberboard mill was established in 1968 in the western Caspian area (i.e., near Rasht). This unit produces 18,000 tons of fiberboard annually.

Veneer Industry

The veneer industry has been developed mostly in the last decade and its consumption is abnormally high as compared with the consumption of plywood. The Iranian customs' law are in favor of importing Formica although more economical types would be better for some uses (FAO, 1964). There are only four mills with total capacity of 28,200 tons per year. Three of them are located in Tehran. The available information regarding these units is summarized below.

(a) Sella Fiber Company

This unit is the oldest one and was established in 1961 in Tehran. The mill capacity is 1,000 cubic metres annually.

(b) and (c) Bani Hashemi and Messrs. Yazdanian

Both of these units were established in Tehran in 1969. Each has a capacity of producing 3,600 cubic metres of veneers annually.

(d) Messrs. Sherkateh Sahami Velux Iran

This is the largest veneer unit in Iran with a capacity of 20,000 tons yearly in a one-shift operation. The unit was established in the Caspian area (i.e., Rasht) in 1969. It uses wood waste, alder and plantation wood.

Particle Board Industry

The consumption of particle board in Iran is very low. The total capacity of all particle board mills in Iran is about 28,000 tons annually. The particle board mills in Iran are described below (FAO, 1969).

(a) Messrs. Djurabchi Company

This unit is located in Chamkaleh (near Lahijan) in the Caspian area. The capacity of the mill is 1,200 tons per year. The mill machinery is a complete Hildebrand design for one-layer flat-pressed wood-particle-board with low compression. Poplar is the main raw material.

(b) Messrs. Tavakoli Company

The mill was established in 1963 in Tabriz (northwest Iran). The unit has an annual capacity of 9,000 tons after expansion in 1969.

(c) Particle Board Factory of Messrs. Khoy

This unit was established in 1964 in Tabriz. The mill capacity is 3,240 tons per year. The raw material is wood.

(d) Particle Board Factory of Messrs. Sadaghiani

This mill was established in 1966 in Tabriz. The capacity of the unit is 7,500 tons each year, after installation of a new machine in 1969.

(e) Particle Board Factory (no specific name)

This unit was established in 1968 in the Caspian area (i.e., Hadji Kalateh near Gorgan). The mill capacity is 4,500 tons annually. The raw materials used are cotton and poplar.

(f) Messrs. Hakimzadeh Industry

This mill was established in 1969 in Khorramshahr. The unit has 3,000 tons capacity annually. The raw material is palm.

Other Wood Industries

Other wood products manufactured in Iran include parquet, bobbins, and barrel staves. According to Pelttari, 1964, the United Nations' expert, the two existing parquet mills in Iran are well equipped to satisfy domestic demand. The two parquet mills and others are described as follows.

(a) BW-Parquet Company

The mill is located on Makhsops Road between Karadj and Tehran. The unit has 75,000 square metres capacity per year. It has complete BM-machinery for making parquet.

(b) Iran Company Parquet Factory

The unit is located in Tehran Pars Road Javadije. The mill has 70,000 square metres capacity annually. The unit has complete Schroeder machinery for manufacturing parquet and wood-working machines for door and furniture manufacturing.

(c) Bobbin Factory

This mill was established in 1964 in Tehran. The capacity of the unit is 2,000 bobbins a day. The machinery of the unit is Hempel semi-automatic.

(d) Iranian Timber Company

This unit is located in Gonbad, east of the Caspian area. The mill produces barrel board. The mill has two band saws with hydraulic carriage and two circle saws for re-sawing. The unit has not operated for a long period.

Pulp and Paper Industry

The pulp and paper industry is the youngest industry in Iran. Since neither pure cellulose nor paper is being manufactured in Iran, there are a few small mills which are only making cardboard. Cotton is the most important raw material for cellulose in Iran. The total production of crude cotton in Iran is about 30,000 tons per year. This consists of 10,000 tons of pure cotton and the remainder is seed and scrap (UNESCO-FAO, 1962). In addition the mills use waste paper, straw and agricultural residues as raw material. Iranian forests mainly consist of broad-leaved forests, hence it is only possible to produce semi-chemical pulp for wrapping paper.

There are seven paperboard mills in Iran with small capacities ranging from less than 1 to 15 tons annually. All of them are located in the suburbs of Tehran. Four of them have home-made cylinder machines. More description of paperboard mills is given below.

(a) Papeterie Gemayel

The unit is located in Kahrizek, Qum Road, 25 kilometres from Tehran. The mill has 12-15 tons annual capacity. It has three cookers (uses soda) and Belgian fourdrinier.

(b) Cartonnerie Mimosa

This mill is close to Papeterie. The capacity of the unit is 5 tons each year. The mill has two cylinder machines which are French made.

(c) Shargh Cardboard Company

The unit is located in Ghassem-Abad which is 18 kilometres from Tehran. The mill has 3 tons annual capacity with home-made fourdrinier.

(d) Iran Cardboard Company

This unit is located in Karadj which is 30 kilometres from Tehran. The capacity of the mill is 1.5 tons annually. The cylinder machine is home-made.

(e) Karaj Cardboard Company

This unit is located in Karaj with 2.5 tons capacity each year. It has a cooker using soda and a cylinder machine.

(f) Tapeh Seif Cardboard Company

This unit is located on Saveh Road near Tehran with 1.5 tons capacity annually. The mill has a home-made cylinder machine.

(g) Karbassi Cardboard Company

This unit is also located on Saveh Road near Tehran. The mill has a 0.8 ton capacity each year. It has a cylinder machine.

In addition to the above paperboard mills, there is only one paper mill, called the Pars Paper Mill Company. The mill was established in 1971 and is located at Haft Tappeh in Khuzistan, southwestern Iran. The annual capacity of the mill is 35,000 tons, however, the remainder of domestic consumption is imported, which constitutes 1.8 percent of total foreign imports (Iran Almanac, 1971). Raw material for the mill comes from the Haft Tappeh Sugar Mill in the form of the residue left over from the sugar-cane used in the mill. The current output consists of white writing paper and off-set printing paper. The mill cost about $26,000,000 (1,780 million Rials), however, the unit is saving $10,000,000 of Iranian foreign exchange each year (Iran Almanac, 1971). The main shareholders include the Plan Organization, the Oil Consortium, the

Imperial Organization for Social Services, the Industrial Credit Bank and the Industrial Mining and Development Bank of Iran.

It has been noted in the introduction that high population growth rate, modern life in Iran and a serious campaign against illiteracy have brought a sharp increase in paper consumption of all varieties from stationery to cigarette paper. More production at home and better wrapping and packing also resulted in an increase in the demand for heavier papers and cardboards. The Ministry of Economy, 1971, reported that 93,884 tons of paper were imported in 1967. Pelttari, 1964, has predicted that Iranian paper consumption will be 200,000 tons by 1981. Considering that Iran has only a single paper mill with 35,000 ton capacity and an annual import of $65,000,000 of timber indicates the need for a better alternative than importation. Iran has twelve million hectares of forests of which only the Caspian Forest has been under investigation. The Caspian Forest consists primarily of hardwood, which is not suitable for producing the types and qualities of paper which softwood can produce (Hejazi, 1964). So far, almost all experts from different agencies such as the United Nations and the United States have been asked to visit and make comments about development of the Caspian Forest. Dr. Tregubov, the United Nations' expert and the Foreign Dean of the Forestry College (at Tehran University in 1969), was the first foreign expert to visit the Western Forest and he remarked that this forest has potential for producing conifers economically. Therefore, in order to evaluate the potential of the Western Forest, an inventory of existing timber volumes, and production potential should be conducted. Only then can one design a plan suitable for the Iranian need considering the ability for conifer production in the Western Forest. One of the alternatives for utilization of this forest seems to be the establishment of forest industry unit(s) to produce paper. The preliminary investigation is described in the following chapter.

CHAPTER IV

RESOURCES AND INFORMATION NEEDED TO DESIGN, LOCATE, AND OPERATE A PAPER PLANT

In the previous sections, it was noted that a substantial domestic market already exists for paper products in Iran. There is no doubt that the market will continue to develop rapidly keeping pace with national economic growth. Imports of paper products are only a temporary solution and the cost is likely to be high. Therefore, in the long run, the Iranian industry and the government will have to depend on the development of their own forest resources and industrial capacity. Establishing a pulp and paper industry in the vicinity of the Western Forest is an opportunity for the Iranian industrial sector. Prior to the establishment of such an industry, a thorough investigation is required of factors such as availability of forest resources and development of a work plan for experimentation to determine suitable species; expected levels of consumption by the population to be served by the pulpmill; the availability of water supply, labor and transportation; sources of capital for investment, and the cost of a suitably sized mill.

Reasonable assurance of a continuing and stable supply of wood in terms of different classes for the pulp-mill is critical. How well this assurance may be offered depends upon the quality of the timber information available. An estimation of the presently available timber in terms of species and diameter class distribution above 8 centimetres at the 5 percent level of precision (because this level is reasonable), the proportion of area (or the acreage) suitable for plantations, and projection of future growth in the Western Forest might be made by conducting a suitable inventory design.

It is known that conifers are preferable over hardwoods for operating a paper industry. However, the lack of extensive areas of conifers is a limiting factor in the Western Forest which therefore creates an additional problem for the present study. Planting of appropriate species in suitable areas is a possible solution to this problem. Two questions would have to be resolved if planting were to be carried out:

1) What pulp species are suitable for the region, and,

2) how much plantable area for these species is available?

These questions, as well as other information needed, could be answered by executing a suitable inventory design to determine the necessary site parameters.

The term "site" in forestry refers to the environment of a forest. Forest site quality is defined as the sum total of all of the factors affecting the capacity to produce forests or other vegetation. Integration of all various site factors provides an estimation of the region's quality. These include climatic factors, edaphic factors, and biological factors (in particular, natural vegetation). In order to introduce the most suitable species, an assessment of the Western Forest site quality should be included in the inventory task.

The climatic and edaphic factors of a site have a predominant influence on forest form and growth. Information relating to climatic conditions are: average rainfall including total and seasonal distribution; average rainfall in January; and June-July temperatures. This information can be obtained from the weather bureau of Iran.

The edaphic factors relate to soil conditions which directly affect forest vegetation. The primary source of information with respect to soil is a soil-map. A soil-map usually is constructed by using a combination of aerial photographs and ground sampling. Since aerial photographs from the Western Forest are not available, taking pictures from four directions of each sample plot is recommended. These photos can be considered as a rough source of information. Slope, soil texture, bulk density, organic matter, and depth are the other factors which should be determined to furnish a sampling base and allow correlation with a vegetation map. Soil textural classes refer to three broad and fundamental groups: sands, loams, and clays. The sand group includes all soils in which the sand portion separately makes up 70 percent or more of the material by weight. Two specific classes are recognized--sand and loamy sand. Clay soil must contain at least 35 percent clay. Different classes of clay soils are sandy clay and silty clay or the most common of all, simple clay. The loan group contains many subdivisions and is difficult to explain. An ideal loam may be defined as a mixture of sand, silt, and clay particles which exhibits light and heavy properties in about equal proportions (Brady, 1974). The loam groups are good for agriculture. The classes of loam include loams, silt loams, silty clay loams, and clay loams. The depth of the portion of the soil that is either occupied or capable of being occupied by the roots of the tree is an important matter in the evaluation of soil (i.e., the effective depth of the soil). Among the soil factors most frequently found important are, the depth of the A horizon above a compact subsoil, the depth of the least permeable layer (usually the B horizon), and thickness of the soil mantle over bedrock (Coile, 1952).

Ground vegetation is an important source of information in assessing site quality. A ground vegetation study is usually carried out prior to forest inventory because it is quite time consuming. However, for the present purpose, the ground vegetation study can be done on nested sub-sample plots rather than on the whole sample plots.

Actual forest productivity is generally measured in terms of gross volume of bole per unit area per year over the normal rotation (mean annual increment). Determination of the mean annual increment is quite time consuming and is expensive. To be useful as an index, however, the indicator factor should be capable of simple and inexpensive measurement and should furthermore be highly correlated to forest productivity. The relationship of total height-growth to total age, called site index, is a commonly used indicator of site quality. By sampling height and age of dominant and codominate trees in the given stand and then making a comparison with predetermined site index curves, one can determine the quality of the site under investigation. The height-growth method is applicable if certain conditions are met: (1) if the forest has not been devastated or overcut several times; (2) if several predetermined site-indices are available from similar regions; (3) if there is no desperate need for introducing exotic species. (If there is such a need, there might be enough evidence of existing correlation between native species and several exotic species in order to select the suitable species by using the total height-growth index.) However, for assessing the site quality of the Western Forest, none of these conditions is met: the forest is overcut and the trees mostly chopped off, there is no study with respect to the determination of site index in similar areas and there is a desperate need to introduce suitable species for which no study has been done to indicate the existing correlation (if there is any) between exotic and native species. Consequently, a possible alternative is stem-analysis. Several dominant trees which have not been chopped should be selected for a complete stem-analysis. Total height, and height to live crown, should be recorded after felling the trees. To confirm the position of the terminal point of each year's height growth, sectioning should be done at intervals small enough that sections could be taken between 80-90 percent of all whorls (e.g., for Ponderosa pine). In the United States, sectioning has been done at 30 centimetre intervals to a height of 15 metres and thereafter at 15 centimetres. If the height growth is plotted over age, the pattern of growth for a considerable number of years can be studied. The factors affecting the growth also can be investigated. If a composite study of all factors described above in conjunction with stem-analysis, is done the results provide a good basis for assessing the site quality of the Western Forest. In other words, if one knows that a given species needs a certain site quality to grow and one can match that site quality with some parts of the Western Forest, there would be a good possibility of success in introducing the species for those areas.

Classification of site quality into different groups, for the present study, includes two methods. The rough method of site quality classification can be made by determining the indirect factors such as the availability of certain amounts of different elements in the soil, climatic conditions, and ground vegetation. The other method is based on the height-growth of introduced trees as a supplement to the other information sources in the rough method of site quality classification mentioned earlier: this would involve planting the new species in different areas, measuring, and recording the height-growth for several years and studying the indirect factors which provide better evidence for the site quality classification. However, the rough method, e.g., into three groups (good, medium, and poor), provides quicker results and may be accurate enough for the decisions to be made. The combination of both methods is recommended for the present study in conjunction with stem-analysis. The results obtained from different methods (rough, height-growth, and stem-analysis) could be the same or different. If there are similarities, a finer determination of classification can be made by continuing the height-growth study. If similarities are not found, the reasons for the contrast should be explored. In any event, height-growth classification provides better and more reliable evidence than the other source of information for the introduced species. Stem-analysis provides a good basis for the historical growth of the existing trees.

Introduction of exotic species is considered as an experiment and also requires a work plan. Several informationally important factors are described in the preceding paragraphs. Information on these factors takes a considerable amount of time to obtain and should be collected for a prospective plan in the future. However, climatic site factors are generally useful in providing a rough index of regional forest productivity. In particular, rainfall and temperature data may be used to compare forest growth, both potential and actual, in various geographical regions, assuming soil conditions whithin the regions are closely related to climate. Both precipitation and the temperature regime influence the distribution and growth of the forest. This fact in a broad sense has been illustrated in terms of existing rough correlation between climatic classifications and the occurrence of forest types. There are several climatic classifications such as Merriam, Koppen, and Thornthwaite. According to climatic, temperature, and precipitation charts of the world, provided by Koppen and the U.S. Air Force, 1960, the Western Forest has a climate similar to the Mediterranean or dry summer subtropical. The summer temperature is above 20 degrees centigrade with a cold winter below zero degrees centigrade. Precipitation is about 40-50 centimetres. This information helps to determine roughly the species which might be good candidates for the experiment by determining the most adaptable species in similar regions of the world such as Mexico and the United States. Some candidate softwood species for the Western Forest are listed in Table 2.

Table 2.--Potentially Promising Species for Pulp and Other Products Found in the United States of America and Most Areas in Mexican Forests*

Arizona state, United States:

1. *Pinus flexillis*
2. *Pinus chihuahuana*
3. *Pinus ponderosa*

Most areas of Mexican forests:

1. *Pinus montezumae*
2. *Pinus oocarpa*
3. *Pinus pseudostrobus*

Chihuahua state, Mexico:

1. *Pinus arizonica*
2. *Pinus ayacahuite brachyptera*
3. *Pinus cembroides*
4. *Pinus chihuana*
5. *Pinus durangensis*
6. *Pinus durangensis quinquefoliata*
7. *Pinus leiophylla*
8. *Pinus lumholtzii*

Table 2.--Continued

Oaxaco state, Mexico:

1. <u>Pinus ayacahuite</u>	11. <u>Pinus Patula longepedunculata</u>
2. <u>Pinus douglasiana</u>	12. <u>Pinus pringlei</u>
3. <u>Pinus herrerai</u>	13. <u>Pinus pseudostrobus coatepecensis</u>
4. <u>Pinus lawsoni</u>	14. <u>Pinus pseudostrobus oaxacana</u>
5. <u>Pinus leiophylla</u>	15. <u>Pinus strobus chiapensis</u>
6. <u>Pinus michoacana</u>	16. <u>Pinus rudis</u>
7. <u>Pinus michoacana f. tumida</u>	17. <u>Pinus tenuifolia</u>
8. <u>Pinus michoacana cornuta</u>	18. <u>Pinus teoccote</u>
9. <u>Pinus montezumae</u>	
10. <u>Pinus oocarpa</u>	

*Martinz, 1948.

Obtaining the seeds from the same species, but different areas which already grow those species constitutes the next step (i.e., provenance testing). The steps in a provenance test include assigning seed lot number in the nursery (or nurseries in different locations of the region), planting, measuring the heights, and recording for several years (e.g., 3 years). Planting 2-3 trees from the same species to an easily accessible field with better site, making a map of the tree locations and recording the growth are the last actions which should be taken.

In order to make an evaluation of potential opportunities for the Western Forest resources, one might review the pulping technology in relation to the adaptability of the forest species (i.e., combination of hardwoods and softwoods) to the processes which produce some kind of paper. This review would yield information on the most desirable paper and paperboard grades that could be made from the available wood supply in the Western Forest. The processes which are capable of utilizing the widest range of raw materials are bio-chemical processes (A.D.L., 1965). The feasibility study would take place before the final decision making processes.

Determination of pulp and paper plant locations is a critical matter which needs particular attention (A.D.L., 1965). The need for large quantities of clean water for process use and dispersal of mill effluent is an important consideration in pulp and paper mill location. Another aspect of choosing a suitable location for a pulp and paper mill is accessibility to the existing transportation for receiving raw materials from the forest and for shipping the products from the mill to the markets. A chosen area should be large enough for primary treatment of the wood. Another factor related to the pulp and paper location is the proximity of the mill to towns, for employee residence. If the mill belongs to private owners, the area description, topography, surface condition of the soil, and related conditions should be determined.

Capital investments and operating costs should be considered in the establishment of the pulp mill in the Western Forest. An investor needs to have an estimate of capital costs and operating costs of the mill prior to making his decision. Operating costs include cost of wood, chemicals, operating labor, factory overhead, maintenance, utilities, operating and packing supplies, depreciation, taxes and insurance, interest and lending rates, sales and transportation.

The production capacity of the mill is another matter. As previously noted, Iranian paper consumption by 1980 is expected to be 200,000 tons per year. Thus the new mill will be competing for a market of this size which has Iran as a market.

CHAPTER V

REVIEW OF FOREST INVENTORY DESIGNS FOR DEVELOPING COUNTRIES

The main objective of initiating an inventory in developing countries is to provide a basis for the rational utilization of forest resources. The details and the cost of the inventories are governed by the special requirements of each case. For instance, a management plan for a given forest cannot be prepared unless the allowable cut has been determined. This must be based on a properly conducted inventory. One of the special input requirements of the allowable cut calculation is an estimate of growth for different species in the forest, which require ground work in addition to using aerial photographs. However, an estimation of crown density does not require ground examination, since aerial photographs provide a sufficiently accurate estimation for planning purposes.

The different types of inventories, such as a national and local inventories, cannot be effected arbitrarily. The national inventory is naturally desirable to have first, especially when connected with a general plan of land use. However, this is not the case for many developing countries. In many developing countries, local forest inventory takes place before national inventory until the forestry practices reach a certain stage of development. The forest inventories in developing countries usually have been carried out by assistance from the Food and Agriculture Organization (i.e., FAO). The methods described generally were used to determine stand conditions of the forest. The principles of these techniques, specific purposes, and their applicability to Iranian forest conditions are described in this section. The methods are usually named after the FAO experts who used them. This does not necessarily mean that the persons named developed the method.

Selected Line Method

The selected line method has been used in some developing countries (e.g., Ceylon and Amazon Valley in Brazil) as well as in Canada for forest inventory. The method involves prior stratification of the forest into usually three forest zones (i.e., wet, dry, and intermediate) with the aid of aerial photographs. In addition a preliminary map is drawn. Identifiable points on this map are selected as the starting points of the survey lines or as reference points for locating the starting points. Usually, identifiable points are required at both ends of the planned survey lines, and a straight line joining identifiable map features is drawn through the forest class to be sampled. Sample plots are then established along this line according to certain pattern designs appropriate to the requirements of the survey. Often the sample plots are measured systematically at equal distances. The intensity of sampling varies with the importance of the strata, and on the variance of the basal area of total growing stock on the measured plots. The variance is computed from sample plots in the course of the work. Sampling is discontinued as soon as the number of sample plots seems sufficient to satisfy the pre-determined precision (i.e., type of sequential sampling). Undoubtedly, this method of estimating the variance is not a proper way because it represents the variance of only that portion of population sampled, not the whole. A pilot survey of the entire population is advisable which provides a more precise estimate of the variance in the population.

In general work, a road is laid out to provide a motorable track into the areas it is desired to sample. The location of this track is taken from the map after consulting aerial photographs. The ground samples are taken along the transects, mostly samples are one hectare in size, i.e., 10 metres in width and one kilometre in length, or the plots are drawn by wedge prisms or Bitterlich's relascope. Roads constitute an important factor governing the selection of location and care is taken to have the transects evenly distributed throughout the entire area.

The purpose of selected line method surveys is primarily to gather information about the topography of the country and its forest cover necessary for the drawing of topographic and vegetation maps by using photo-interpretation (based on field-checking) and to explore the area of forest as much as possible (FAO, 1961). This technique would be applicable for Iranian forest resources if aerial photographs were available. However, since forest maps and topographic maps are available, but not airphotos, this method is not highly recommended.

Dawkins' Method

Dawkins' method (FAO, 1961), has been designed for tropical forests, such as occur in Uganda. The first phase of this method consists of stratification on aerial photographs to produce a photo type-map. This is worthwhile even if the map does no more than separate the swamps, thickets, grassland, and other areas to be excluded from sampling. The forest area is divided into 10-30 blocks. The shape of blocks is rectangular: "2 x f," 20 metres (i.e., one chain) in width and from 0.8 (i.e., half a mile) to 4.8 (i.e., 3 miles) or 6.4 kilometres (i.e., 4 miles) in length. The "f" is the sampling fraction. The larger the size of the forest, the smaller the value of "f", for example, for forests with sizes 2.56 (i.e., 1 square mile), 12.8 (i.e., 5 square miles), 51.2 (i.e., 20 square miles), and 256-512 (i.e., 100-200 square miles) square kilometres, the "f" values would be 0.20, 0.10, 0.03, and 0.01, respectively. The sampling fraction for a given precision of an estimate can not be settled unless the variance of that estimate is known. To obtain the sampling error, Dawkins has proposed to start at a low sampling fraction (5 or 6 blocks) with large blocks and calculate the sampling errors before proceeding to a higher level. The shape of the sampling unit is a narrow strip with one chain (about 20 metres) width and the same length as the block length. However, using a small recording unit of 0.5 hectares (i.e., 0.2 acres or 2 chains x 1 chain), the number of samples (transects) could be reduced after knowledge of the sampling error. The use of such a small unit must be considered advantageous, particularly because sub-division into plots allows sub-sampling of the more abundant or less important data. The selection of one pair of strips in each block is made randomly. Strips should start from roads or other access routes which can be traced on the aerial photographs.

The required results are usually to produce a forest type-map, but revised to show silvicultural, economic or any other classifications, stand tables of all important species or species groups, and reliable minimum estimate (i.e., mean minus the sampling error) of volume, basal area, or stems for any desired tree population. It seems that this method of forest inventory would be applicable for Iranian forests if proper aerial photographs could be provided.

Loetsch's Method

This method was used in five of the northern teak-bearing provinces of Thailand. Aerial photographs (with scale 1:48,000) were used for the stratification (FAO, 1961). To obtain the area of these strata, their percentages were sampled on the aerial photographs according to the tract-line system. Since the scale of the photograph was small, neither the dot-grid system, nor the delination system were found satisfactory. The tract-line system consisted of a square, 5.5 x 5.0 centimetres, on a plate of glass with millimetre graduations along the sides. The plate was placed on the photograph. With a mirror stereoscope and 4x magnification, the interpreter followed the sides of the square, divided into two pairs of two adjacent sides each, and marked the boundaries between recognized strata on a special form. The sum of the length of each strata in millimetres gave the percentage of each stratum.

In ground sampling the camp-unit system was used. The basis of this system is a circular sample plot of 0.05

hectare (radius 12.61 metres). The arrangement of these plots in the field is shown in Figure 8.

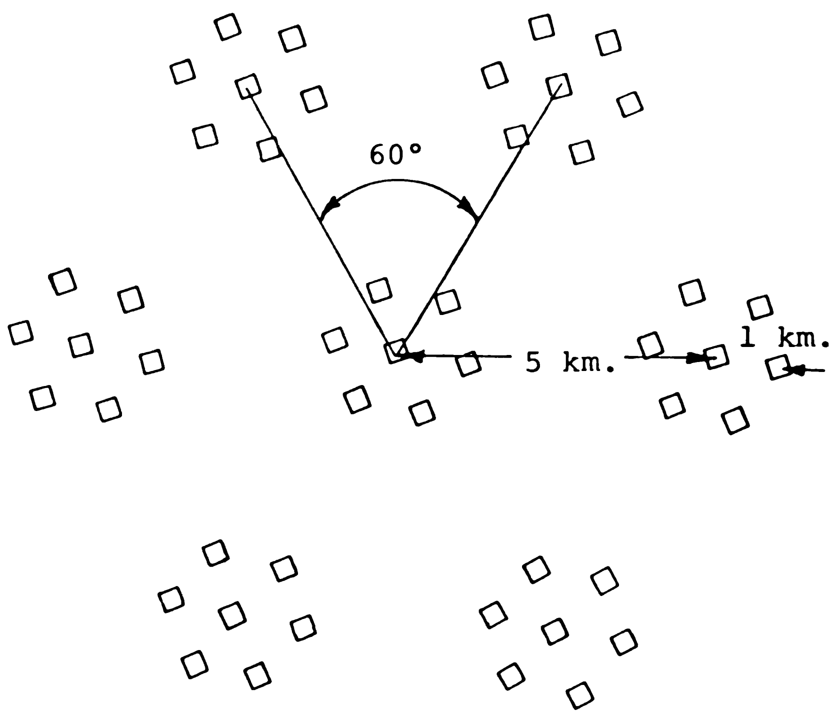


Figure 8: Location of 7 Camp Units

The camp was composed of seven camp units, and each unit of seven tracts. The distance from the camp center to the farthest sample plot was 5 kilometres, and the distance from the unit center to the first corner of a tract was 1 kilometre. One photograph was selected at random from each group to locate the reference camp. The photographs were subdivided into several groups of equal size, following the numbered order of runs and photographs. Thus, a restricted random distribution was used. The unit centers were then found on the photograph by means of a celluloid disk, and later located in the field from the photographs with a pocket stereoscope.

Field sampling was carried out by crews consisting of two officers and two workers. Each crew measured a tract or forty-eight sample plots a day (in Thailand), which was considered an advantage to the method. One camp staff consisted of seven crews plus a camp leader and his aide. Their daily work thus yielded seven tracts or one camp unit.

The data measured or estimated inside the sample plots were tree species, basal area at breast height, factors for calculation of the merchantable volume, and some additional observations. The diameter growth of important species was measured by increment borings and the site class determined by measuring the circumference: height ratio of dominant tree within a 25 metre radius of the center sample plot.

Loetsch's method would seem to be a suitable method for the Iranian forest inventory if aerial photographs were available. Loetsch's method is relatively quick and sufficiently accurate. More accurate detail can be obtained if the scale of the aerial photograph is about 1:20,000.

Rollet's Method

This method (FAO, 1961), was used in eastern Cambodia. Stratification was performed from aerial photographs to produce a type-map and checked against a few ground strips of the forests under investigation. Scale of the aerial photographs was 1:40,000. Photographs were assembled into mosaics, and a pattern of temporary coordinate squares was formed using rubber bands arranged on top of the mosaic similar to grids on the map. By shifting the rubber bands, variations in the scale of mosaics could be seen against the general map. Subsequently, the stratification visible on the photo mosaics could be transferred by hand onto the general map, square by square. The proportionate areas of the strata were computed by the dot-grid system.

For ground sampling, the preliminary calculations were based on both earlier enumerations and the results of a pilot survey. Three bases were employed in the classifications: forest type, group of species, and groups of diameters. The sample plots, 6 x 5 = 30 plots, with the size one hectare each spaced one kilometre apart represents a single camp. A camp is selected at random. Each one hectare sample plot was divided into quarters for tree enumeration. In one of the quarter plots, the trees were further entered by its quarters, i.e., 1/6 hectare plots. Since local one-way volume tables (dbh and volume) were available by regions, only diameters were measured in the initial stages of the work. For growth studies, the sample plots of each camp were designed as permanent sample plots after giving special consideration to accessibility. In addition to the sample plots considered so far, another sixteen 1 hectare sample plots located at 0.5 kilometre intervals were measured and used in the analysis of the results. Rollet's Method could be applied to Iranian forests if aerial photographs of Iranian forests and volume table for different species were available. However, since neither of the two are available, the method does not seem applicable.

Wheeler's Method

This method was used in Cambodia (FAO, 1961). The preliminary classification was made from aerial photographs (with scale 1:40,000). Strips about 2 kilometres wide were photographed on a scale of 1:10,000 at intervals of 16 kilometres. However, location of sample plots was independent of stratification as this was done using a 16 x 16 kilometres equidistant grid. Aerial photographs were also used for identifying grid locations, measuring the size of forest, and improving the precision of the inventory. Tree heights, crown width and crown closure were measured on the photograph and correlated with ground total volume measurement.

The ground measurements were on a 16 x 16 kilometres equidistant grid. Field plots in each of the basic grid locations were measured by a wedge prism. Four point samples were taken equidistant within a square of one hectare, as shown in Figure 9.

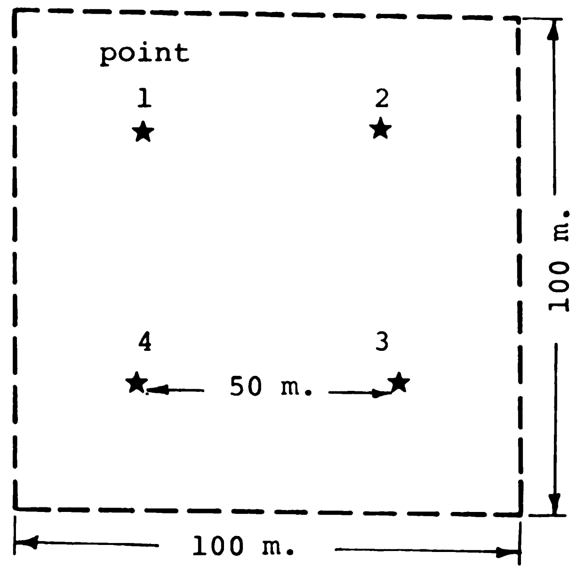


Figure 9: Wedge Prism Points at each Grid Location in Wheeler's Method

Point 1 is the point arrived at by compass and chain from the nearest identifiable point on the aerial photos. Diameter, double bark thickness at breast height, merchantable height, and total height were measured for each tree selected in the sample. Form class, which is the percentage relationship between the diameter inside bark at the top of the first 5-metre log and the dbh outside bark, was also measured. In addition to the measurements by tree species and species groups, timber cut estimates were given special attention, as were measurements of all stumps within the one quarter hectare bounded by points 1-4 (Figure 9), and all stumps of trees estimated to be one metre and larger within the hectare. In order to determine growth and mortality, permanent plots were established using every sixteenth basic grid plot which is measured periodically. Aerial photographs are not necessary using Wheeler's method. Considering that there are no aerial photographs available for the Iranian forests, this method could be recommended with slight modification. The present study will determine the suitable size of BAF for the Western Forest with respect to precision and cost. The basic grid used can be at 8 x 8 kilometres intervals rather than 16 x 16 kilometres in order to obtain more detailed information for some areas.

Strip Survey

Strip surveys are very often used in forest surveys in developing countries. This method is not bound in any way to aerial photographic coverage, but a large-scale map is required for the survey work. The method involves equidistant parallel strips running at right angles to the prevailing topography of the country. For instance, a strip distance of 2 kilometres and width of 20 metres for an area with size 40,000 hectares gives a 1 percent survey.

This percentage is often used in Indonesia on areas of more than 10,000 hectares (FAO, 1961).

The strip method is applicable for the Iranian forests because aerial photographs are not necessary.

CHAPTER VI

DESCRIPTION OF CASPIAN FOREST INVENTORIES

In 1959, a survey of the Caspian Forest, 3,400,000 hectares, was begun, under the direction of Earl J. Rogers, ICA Forest Survey Advisor, and was conducted over the next few years. A second survey was designed by Alva B. Williams in 1973, but has not yet been published; it is currently in progress. The two surveys are explained briefly in the following sections.

Rogers' Design

The plan is basically a triple sample design. The first phase consists of selecting 124,146 photo points with each point classified as either forest or non-forest. The second phase consists of interpreting 23,103 points on 0.1 hectare photo-plots for two independent variables, crown-density and average total height of three tallest trees. From these measurements on each photo-plot the average crown-density and average tree heights is calculated. The third phase of the forest inventory consists of selecting 753 points out of 23,103 points for ground plots. The 753 points are the actual numbers used in survey, not the proposed ones (Williams, 1973). Data collected from these ground plots are the same as required in the usual forest survey. Volumes from ground plots and the photo estimates of tree height and crown density are used to make a regression estimate by least square method as shown below:

$$V_t = P_f \, (a + b_1 X_1 + b_2 X_2)$$

where,

V_t = mean volume-per-hectare of gross land area

P_f = portion of forest land to gross land area interpreted from photo-points, and the measurement is assumed to be free of error.

a = constant,

b_1, b_2 = partial regression coefficients

X_1 = average of the mean total height of three tallest trees measured on all forest photo-plots

X_2 = average crown-density measured on all forest photo-plots.

The variance of V_t includes the contribution from four sources: measurement of heights and crown density, measurement of the forest area, and contribution from regression coefficient estimates which are shown in the first, second, third, and fourth terms of the right side of the following equation respectively:

$$S^2_{\bar{v}t} = \frac{P_f^2 \, S^2_{v1.2}}{N_g}$$

$$+ \frac{P_f^2 \quad (b_1^2 \, S_{x1} \;+\; b_2{}^2 S_{x2}{}^2 \;+\; 2b_1 b_2 \mathrm{cov}.X_1 X_2)}{N_p}$$

$$+ \frac{\bar{v}_f^2 \; P_f Q}{N} + P_f^2 \quad \{S^2_{\bar{v}1.2} \quad (C_{11}\bar{\alpha}_1^2 \;+\; C_{22}\bar{\alpha}_2^2 \;+\; 2C_{12}\bar{\alpha}_1^2 \; \bar{\alpha}_2^2)\}$$

Which may be coded as follows:

$$S^2_{\bar{v}} = \frac{A}{N_g} + \frac{B}{N_p} + \frac{C}{N} + D \text{ where:}$$

$S^2_{\bar{v}}$ = variance of mean volume-per-hectare of gross area,

$S^2_{\bar{v}1.2}$ = variance of independent of regression of mean volume-per-hectare estimated by regression,

S^2_{x1} = variance of average tree-height (3 tallest trees) in metres per 0.1 hectare of forest land,

S^2_{x2} = variance of crown-density per 0.1 hectare of forest land,

Cov X_1X_2 = covariance of X_1 and X_2,

$\bar{v}_f$ = mean volume-per-hectare of forest land,

Q = portion of non-forest land area to gross land area,

C_{11}, C_{22}, C_{12} = C multipliers,

d_1 = difference between means of tree-heights for N_p plots and N_g plots (all measured on photos),

d_2 = difference between means of crown-density for N_p plots and N_g plots (all measured on photos),

N_g = number of ground-plots,

N_p = number of photo-plots, and

N = number of photo-points.

The number of ground-plots, photo-plots, and number of photo-points required to meet a given accuracy are given in the following formulas respectively:

1. Ground-plots

$$N_g = \frac{\sqrt{A}}{S_{\bar{vt}}^{2}\ C_g} [\sqrt{AC_G} + \sqrt{BC_P} + \sqrt{CC_f}]$$

2. Photo-plots

$$N_p = N_g \frac{\sqrt{BC_g}}{AC_p}$$

3. Photo-points

$$N = N_g \frac{\sqrt{CC_g}}{AC_f} \quad \text{where,}$$

C_g = cost of ground-plot,

C_p = cost of photo-plot, and

C_f = cost of photo-point.

The above three formulas are taken from Chapman's triple sample design, 1947.

<u>Williams' Design</u>

The objective of Williams' plan is to update the previous survey for the Caspian Forest by using the concept of 3P-sampling. The probability of selection of a tree in the sample is proportional to estimated height. Point sampling with a prism of diopter 3.03 was used in the plots established in the previous survey in order to select trees for running 3P-sampling. Not all the plots established in the previous survey were used. Only 300 plots were used, based on acceptable error (E = 5%), measuring a small part of forest (Tavalash) coefficient of variation (CV = 91%), and using the formula $N = t^2\ CV^2$.

In addition to the error from point sampling, 5 percent, another sampling error is involved by using 3P-sampling. This is the variation in the ratio of actual to estimated heights. This coefficient of variation usually runs from 15 percent to 25 percent for experienced and inexperienced estimators respectively. Given CV = 25%, the sampling error will be = 2%. Therefore, the total sampling error objective (according to Williams) for this inventory will be = $\sqrt{5^2 + 2^2} = 5.4\%$.

As Williams reported, point-sampling with two sampling points per plot and a prism with 3.03 diopter has been used. The question may be raised here as to how this basal area factor was selected. Considering the negative consequences of using an unsuitable size of BAF, this point might bear further investigation. Another question regarding Williams' proposal is how many sampling points per plot would be advisable. This question can be explored by conducting further research into the logistics of point sampling while the inventory is in progress.

It has been stated in the introduction that there is no reliable knowledge about the Western Forest resources. Planning wisely for development of the Western Forest for any purpose requires satisfactory information about the forest. This information is provided by conducting a suitable inventory design. A suitable inventory can be more appropriately designed when some preliminary information of the forest is available. The preliminary information can be obtained by carrying out a pilot survey. Therefore, a pilot survey was carried out for designing a suitable sampling procedure for the Western Forest. The pilot survey and analysis of the data collected are discussed in the following chapter.

CHAPTER VII

PILOT SURVEY OF THE WESTERN FOREST

A suitable inventory procedure for a forest can be designed if some parameters of the forest population have been predetermined. If these parameters are not known, a pilot survey is highly recommended. The main objective of a pilot survey (i.e., pre-survey) is to estimate variance and the coefficient of variation in the population. Analysis of data collected provides a better understanding of population parameters such as the diameter, height, and spatial distributions. The results derived from the analysis of data collected in the pilot survey help the designer to propose an inventory procedure which can be easily executed within the desired precision at least cost (i.e., three objectives: practicality, precision, and cost).

The Western Forest pilot survey took place in the summer of 1974, and consisted primarily of two tasks. The first was to collect existing information about all Iranian Forests (including the Western and Caspian Forests) from various offices; and, the second was to collect raw data from the Western Forest for a proposed inventory design. The details of these two tasks are described below.

Assembling Information

The first task for summer, 1974, was to obtain available information from different sources related and useful to this study about the Western and Caspian Forests specifically and about the other forested areas in general. For example, in order to select several random point-locations on each forest section, a map of the study area was needed. The offices contacted and related materials obtained are described as follows:

a. After leaving the United States of America for Iran in summer, 1974, the investigator stopped in Rome to visit the head of forest inventory of FAO (Dr. J. P. Lanly). Copies of all papers written about Iran by the FAO were obtained. The list of these publications is given in Appendix A.

b. The College of Natural Resources at Tehran University was one of the offices that the investigator contacted continually for consultation, gathering existing information, and borrowing forest inventory equipment such as relascopes and chains. The information obtained includes an Iranian Vegetation Map in sixteen copies; Caspian Forest Survey Program Instructions, 1960, by

Rogers; and the text about the Western Forests called "Iranian Western Oak Forests," 1966, by Tabatabai and Javanshir.

c. The Ministry of Agriculture and Natural Resources, Department of Forestry, was another office contacted. This office provided a copy of the Caspian Forest Survey, 1973, by Williams, transportation from the cities to the field, and one technician as an assistant to collect data from the Western Forest. All forestry offices in the Western Forest areas also helped the investigator in this respect.

d. The Iranian Army, Division of Geography, was also contacted and a copy of the Iranian Army Map (with scale 1/250,000) was obtained.

e. The office of the Statistical Center provided a copy of the Western Topography Map (with scale 1/100,000).

f. The Ministry of Advanced Education was contacted for supporting the transportation expenses between provinces.

In addition to the above offices, several other Iranian offices, such as banks, which might have some sort of related information were contacted. The Earth Resources Observation Systems (EROS) Data Center, in the United States, was also contacted to obtain the existing imagery of western Iran taken by satellite.

Data Collection

The second task of summer, 1974, consisted of collecting raw data from the 2,850,000 hectares of the Western Forest. Since this task could not be completed by the investigator alone, a team of personnel was employed. The field organization consisted of the investigator, one forestry technician, and a driver. The qualification of the driver was that he should be familiar with the specific part of the study area. The technician was taught the nature of the research design, field duties and related materials. He was also trained how to use the measuring instruments (e.g., relascope) and how to take care of the difficulties in the field such as borderline, boundary, and leaning trees. Transportation in the field was only on foot. A car was absolutely necessary to move from one area to another. The car was a heavy duty vehicle (i.e., landrover).

Collection of data was done by a concentric point sampling technique, which is a modification of conventional point-sampling described in Appendix B. Concentric point sampling is the use of several angle guages with different basal area factors from the same point. Concentric point sampling is justified because it is a time-saving method of application and because trees were sampled with probability proportional to frequency and size (i.e., basal area) rather than only to frequency.

The common practice in countries using point sampling on the metric system (e.g., European countries) is to apply BAF's with sizes 1, 2 or 4. However, it should be noted that point-sampling is not well-known in Iran. Since the suitable size of BAF has not been carefully studied for the Western Forest, "Concentric point-sampling" with BAF's 1, 2, and 4 was used. Through analysis of the data, a suitable BAF for the Western Forest was determined. The Western Forest stand structure (distribution of diameter and height, their means and variances, and tree spatial distribution) were studied.

To apply concentric point-sampling for the Western Forest, the following steps were taken:

a. Selection of a series of random points on the map of the Western Forest by using pairs of random numbers.

The number of random points was mainly dependent on the funds available to the project. One technician and a car were available to the investigator for a limited period of time; hence it was possible to examine thirty-three random points. The forest under investigation is relatively pure and homogenous with respect to species (mainly *Quercus*). Considering this point and the other circumstances mentioned above, the number of random points is deemed to be accepted for the present pilot survey.

b. Location of a sample point in the field.

c. Tree tally by an observer (i.e., the investigator) for the three BAF's at each point.

When a tree was viewed through the relascope at breast height and simultaneously seeing the trunk of the tree directly, then a comparison between the diameter at breast height and width of each of the three bands 1, 2, and 4 were made. The tree would be in the sample if the dbh was larger than the width of a given band. Then the observer informed his partner to number the selected trees for the sample sequentially for each sample point. If the tree dbh was exactly equal to a given width of band, the most accurate procedure would be to include or exclude the tree for sample by measuring the distance from the tree to the center point. For purposes of the pilot survey, however, decisions on borderline trees were made on the basis of a coin toss. If the tree dbh was smaller than a given width of a band, the tree was not selected for the sample.

d. Measuring the diameter and height of the trees included in the sample and their distances to the center point by the technician and recording of data by the investigator on the tally sheet provided.

A sample tally sheet is shown in Table 3. Thirty-three points were examined in the Western Forest. Five of these points were located in an area which has been overused. Since no measurable trees were available for these five points, pictures were taken. These pictures are filed for future reference. Therefore the remaining twenty-eight points constitute the raw data. A listing of number of trees measured at each point is given in Table 4 in terms of different BAF's. The data collected including frequency distributions of diameter and height, and spatial distributions are given in Appendix C. The description of the data analysis follows.

Data Processing and Analysis

Data processing is the major link between data collection and proposing a prospective forest inventory system for the Western Forest. In addition, the process for the other Iranian forests, which will be done by the investigator in the near future, should be similar to the Western Forest. Editing and data reduction is the first step in analysis. It is essential that the treatment of the data be considered as an integral part of the present pilot survey, because data processing and analysis serves as a tool of proposed forest inventory systems.

As the sample tally sheet indicates, sampled trees were recorded by species and different sizes of BAF.

Table 3a.--A Sample Pilot Survey Tally Sheet for BAF = 1

Point No.: 12 BAF = 1 Date: July, 1974

Name of Crew: 1. R. Rajabzadeh, 2. A. A. Sarafraz

Location: Howrezeh, Azarbaijan Gharbie

Tree No.	Species Quercus dbh	ht.	dist.	Tree No.	Species Quercus dbh	ht.	dist.
1	25	5	18	13	29	4	19
2	25	4	23	14	17	33	6
3	36	7	25	15	22	4	11
4	45	6	27	16	20	5	6
5	25	3	8	17	20	4	13
6	16	3	8	18	27	4	10
7	22	3	8	19	18	3	3
8	18	4	5	20	22	3	9
9	18	4	3	21	29	4	14
10	16	4	4	22	24	4	7
11	27	4	10	23	16	2	2
12	18	2	11	24	16	3	11
				25	29	5	18

1. dbh measured in centimetres
2. height measured in half-metres
3. distance measured in half-metres

Table 3b.--A Sample Pilot Survey Tally Sheet for BAF = 2

Point No.: 12 BAF = 2 Date: July, 1974

Name of Crew: 1. R. Rajabzadeh, 2. A. A. Sarafraz

Location: Howrazeh, Azarbaijan Gharbie

Tree No.	Species Quercus dbh	ht.	dist.	Tree No.	Species Quercus dbh	ht.	dist.
1	25	3	8	7	17	3	6
2	22	3	8	8	20	5	6
3	18	4	5	9	27	4	10
4	18	4	3	10	18	3	3
5	16	4	4	11	24	4	7
6	27	4	10	12	16	2	2

1. dbh measured in centimetres
2. height measured in half-metres
3. distance measured in half-metres

Table 3c.--A Sample Pilot Survey Tally Sheet for BAF = 4

Point No.: 12 BAF = 4 Date: July, 1974

Name of Crew: 1. R. Rajabzadeh, 2. A. A. Sarafraz

Location: Howrezeh, Azarbaijan Gharbie

Tree No.	Species Quercus dbh	ht.	dist.	Tree No.	Species Quercus dbh	ht.	dist.
1	18	4	3	4	18	3	3
2	16	4	4	5	16	2	2
3	20	5	6				

1. dbh measured in centimetres
2. height measured in half-metres
3. distance measured in half-metres

Table 4.--Number of Trees in the Sample for Different BAF's at 33 Pilot Survey Points

Point No.	BAF = 1	2	4	Point No.	BAF = 1	2	4	Point No.	BAF = 1	2	4
1	-	-	-	13	15	7	4	25	12	7	3
2	-	-	-	14	9	6	3	26	6	3	1
3	36	30	11	15	14	7	4	27	6	3	2
4	31	18	8	16	10	4	1	28	8	3	1
5	-	-	-	17	9	5	2	29	4	2	1
6	-	-	-	18	14	6	3	30	6	3	2
7	38	18	8	19	9	5	2	31	7	4	3
8	12	7	2	20	19	7	5	32	7	4	2
9	19	10	5	21	10	6	3	33	7	2	0
10	13	9	6	22	6	2	2				
11	19	11	5	23	-	-	-				
12	25	12	5	24	21	10	5	TOTAL	392	201	99

Diameter (in centimetres), height (in half-metres) and distance from the sample point (in half-metres) were recorded for each tree. The data were brought back to Michigan State University in the fall of 1974. Data were classified by one centimetre diameter classes, half-metre height classes, and species for determining diameter and height distributions.

An estimation of the number of trees in each diameter class (i.e., one centimetre) per hectare for a given BAF is made by the following steps:

1. Estimation of Basal Area (BA) per hectare by the formula:

$$(BA/ha.) = \frac{\text{No. of tallied trees}}{\text{No. of sample points}} \times BAF$$

2. Determination of Basal Area per hectare for each diameter class which is:

$$(BA/ha.)_j = BAF \times (1/n) \sum_{i=1}^{n} n_{ij} \text{ or}$$

$$\frac{\text{No. of counted trees in each diameter-class}}{\text{No. of sample points}} \times BAF$$

where n_{ij} is the number in class "j" from sample point "i" and "n" is the number of sample points.

3. Dividing the $(BA/ha.)_j$ obtained from item (2) by basal area at midpoint of each diameter class, D_i, which provides an estimate of the

number of trees in each diameter class per hectare, N/ha., (i.e., stand table).

$$(N/ha.) = (BA/ha.)_j \ /[\pi (D_i/2)^2 \times (1/10{,}000]$$

This procedure for one centimetre classes was used for all three BAF's in order to estimate the number of trees in each diameter class. The results in 5-centimetre classes on a per hectare basis for three BAF's are shown in Table 5.

An estimation of the number of trees in each height-class (i.e., half-metre) per hectare for a given BAF is to take the sample trees in each height-class, nj, (half-metre) and compute:

$$BAF \times \sum_{j=1}^{n_j} \frac{1}{BA_j}$$

The results in 1.5-metre classes for three BAF's are presented in Table 6.

An estimate of basal area, in square metres per hectare, and its standard deviation for different BAF's is presented as follows:

$$\text{For BAF} = 1 \left\{ \begin{array}{ll} BA_1 & = 14.00 \\ s_1 & = 9.13 \end{array} \right.$$

$$\text{For BAF} = 2 \left\{ \begin{array}{ll} BA_2 & = 14.36 \\ s_2 & = 9.81 \end{array} \right.$$

$$\text{For BAF} = 4 \left\{ \begin{array}{ll} BA_4 & = 14.14 \\ s_4 & = 10.01 \end{array} \right.$$

Table 5.--Diameter Frequency Distribution in 5-Centimetre Classes for Different BAF's From Pilot Survey Data

dbh Class Midpoint cm.	Number of Trees per Hectare BAF = 1	BAF = 2	BAF = 4
13	30	26	42
18	68	75	77
23	41	50	46
28	25	21	18
33	22	18	17
38	15	14	13
43	10	10	8
48	6	6	5
53	3	3	3
58	2	2	2

Table 6.--Height Frequency Distributions for Different BAF's From Pilot Survey Data

Midpoint of Height Class (metres)	Number of Trees per Hectare BAF = 1	BAF = 2	BAF = 4
2.5	34	55	54
4.0	47	39	27
5.5	51	51	56
7.0	23	19	26
8.5	26	24	31
10.0	22	12	14
11.5	8	9	3
13.0	5	8	2
14.5	6	5	2
16.0+	4	3	5

Diameter and Height Distributions and Determination of Departure From the Balanced Condition in the Western Stand

In planning the regulation and/or the silvicultural treatment of the Western Forest, the forester needs to know the distributions of tree diameter and height. According to the observations by the investigator, the Western Forest is an uneven-aged forest since trees of different sizes and ages were observed with large and small trees intermixed singly or in small groups. The question raised here is whether the Western stand is balanced or unbalanced and if the stand is unbalanced, to what degree. A balanced uneven-aged forest is one in which the current growth can be removed annually or periodically while maintaining at the same time the structure and initial volume of the forest. First the question of balance will be investigated by using two methods. Then the diameter and height distributions are studied.

A forest is balanced if the quotients between numbers of trees in successive diameter classes, remains constant over the range of diameter classes (Meyer, 1952). Two methods are available for examining these quotients and both are used here. First, in order to determine whether the diameter distribution of the Western Forest is balanced or not, the number of trees over dbh is plotted on a semi-logarithmic paper (for three BAF's) in Figure 10. Not taking into account the first diameter class (i.e., 13-centimetre), the plots are nearly a straight line. Therefore, the diameter distribution is nearly balanced (Meyer, 1952). In a second approach, the quotients between number of trees in successive diameter classes is plotted over class midpoint (for three BAF's). For example, if the number of trees in 15.5, 25.5, and 35.5 centimetre diameter classes are 98, 66, and 37, respectively, the quotients, Y, would be 98/66 = 1.48, and 66/37 = 1.79. The quotients are transformed into a linear function, i.e., $y = a + bx$ where a is intercept and b is slope. The regression functions are plotted in Figure 11 and computation is in Table 7. Since the slope, b, is close to zero (0.05 i.e., the quotient remains constant), the Western Forest is nearly balanced. The value of a and b are calculated by use of least-square technique. Leak (1964) suggested that the quotient curve could easily be straightened out by using 10-centimetre classes instead of 5-centimetre classes. By the latter method one can accurately determine any uneven-aged diameter distribution by the slope b and intercept a. However, the expression of diameter distribution does not specify stand density.

Although the stand is nearly balanced, there is a shortage of pole size timber (i.e., 13 centimetre diameter class) resulting from excessive local uses.

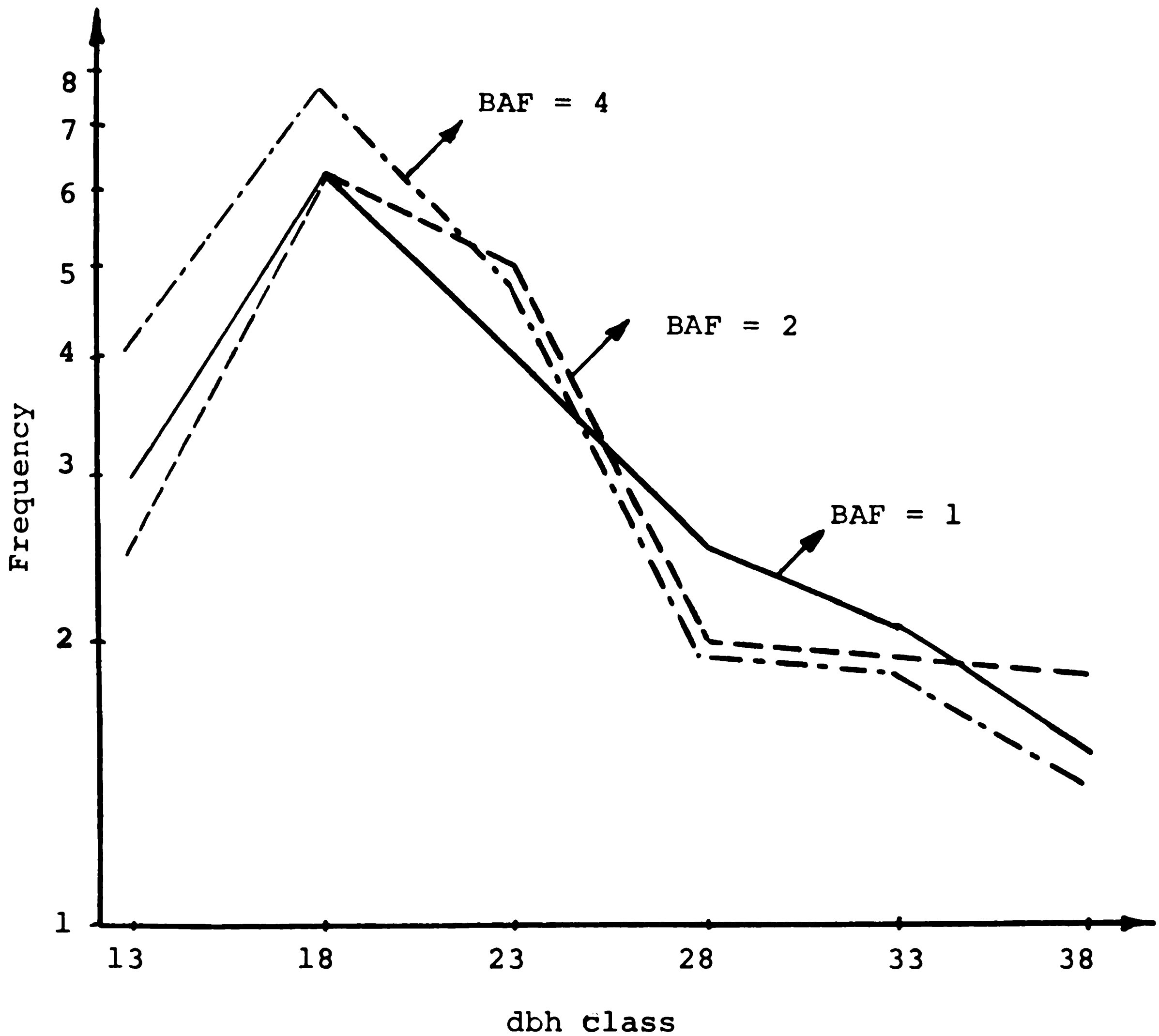


Figure 10: dbh Frequency Distributions on Semi-logarithmic Scale

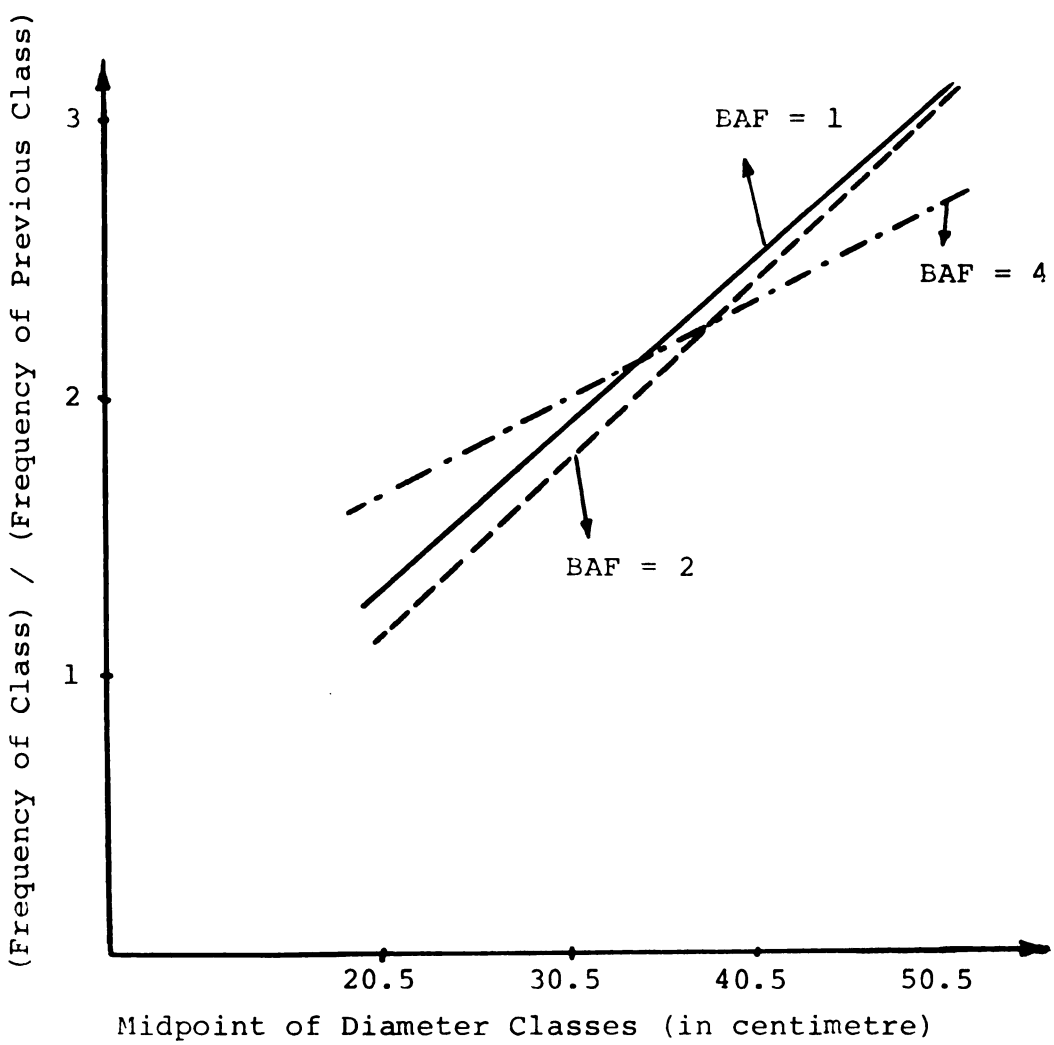


Figure 11: Transformed Functions of Quotients Between Number of Trees in Successive Diameter Classes (Y) Over Class Diameter Midpoints (X)

Table 7-a.--The Regression Function of Quotients Between Number of Trees in Successive 10-Centimetre dbh Classes, Y, Over Midpoints, X, for BAF = 1

Midpoint of 5-Cm. dbh Class	No. of Trees	Midpoint of 10-Cm. dbh Class	No. of Trees	Quotients Y	Midpoint Between 10-Cm. Classes X
13	30				
		15.5	98		
18	68				
				1.48	20.5
23	41				
		25.5	66		
28	25				
				1.79	30.5
33	22				
		35.5	37		
38	15				
				2.31	40.5
43	10				
		45.5	16		
48	6				
				3.20	50.5
53	3				
		55.5	5		
58	2				

Calculation

$n = 4$

$\Sigma X = 142$ $\qquad \Sigma Y = 8.78$

$\bar{X} = 35.5$ $\qquad \bar{Y} = 2.20$

$\Sigma x^2 = 500.00$ $\qquad \Sigma xy = 28.3508$

$MSE = 0.5662$ $\qquad \sqrt{MSE} = 0.7525$

$b = \frac{\Sigma xy}{\Sigma x^2}$

$a = \bar{Y} - b\bar{X}$

s.e. of a = 0.1262

s.e. of b = 0.0001

Function

$$Y = 0.1834 + 0.0567X$$

where: MSE is mean square error,

$\sqrt{MSE}$ is the stand error of estimate,

s.e. of a is the standard error of intercept, and s.e. of b is the standard error of slope.

Table 7-b.--The Regression Function of Quotients Between Number of Trees in Successive 10-Centimetre dbh Classes, Y, Over Midpoints, X, for BAF = 2

Midpoint of 5-Cm. dbh Class	No. of Trees	Midpoint of 10-Cm. dbh Class	No. of Trees	Quotients Y	Midpoint Between 10-Cm. Classes X
13	26				
		15.5	101		
18	75				
				1.42	20.5
23	50				
		25.5	71		
28	21				
				2.21	30.5
33	18				
		35.5	32		
38	14				
				2.00	40.5
43	10				
		45.5	16		
48	6				
				3.20	50.5
53	3				
		55.5	5		
58	2				

Calculation

$n = 4$

$\Sigma X = 142$ $\quad \Sigma Y = 8.83$ $\quad b = \frac{\Sigma xy}{\Sigma x^2}$

$\bar{X} = 35.5$ $\quad \bar{Y} = 2.21$

$\Sigma x^2 = 500.00$ $\quad \Sigma xy = 25.65$ $\quad a = \bar{Y} - b\bar{X}$

$MSE = 0.5494$ $\quad \sqrt{MSE} = 0.7412$ $\quad$ s.e. of a = 0.4605

s.e. of b = 0.0003

Function

$$Y = 0.3863 + 0.0513X$$

where: MSE is mean square error,

$\sqrt{MSE}$ is the stand error of estimate,

s.e. of a is the standard error of intercept,
and s.e. of b is the standard error of slope.

Table 7-c.--The Regression Function of Quotients Between Number of Trees in Successive 10-Centimetre dbh Classes, Y, Over Midpoints, X, for BAF = 4

Midpoint of 5-Cm. dbh Class	No. of Trees	Midpoint of 10-Cm. dbh Class	No. of Trees	Quotients Y	Midpoint Between 10-Cm. Classes X
13	42				
		15.5	109		
18	77				
				1.70	20.5
23	46				
		25.5	64		
28	18				
				2.13	30.5
33	17				
		35.5	30		
38	13				
				2.31	40.5
43	8				
		45.5	13		
48	5				
				2.60	50.5
53	3				
		55.5	5		
58	2				

Calculation

$n = 4$

$\Sigma X = 142$ $\quad \Sigma Y = 8.74$ $\quad b = \frac{\Sigma xy}{\Sigma x^2}$

$\overline{X} = 35.5$ $\quad \overline{Y} = 2.18$

$\Sigma x^2 = 500.00$ $\quad \Sigma xy = 14.4000$ $\quad a = \overline{Y} - b\overline{X}$

$MSE = 0.1421$ $\quad \sqrt{MSE} = 0.3769$ $\quad$ s.e. of a = 0.0159

s.e. of b = .00001

Function

$$Y = 1.1626 + 0.0288X$$

where: MSE is mean square error,

$\sqrt{MSE}$ is the stand error of estimate,

s.e. of a is the standard error of intercept, and s.e. of b is the standard error of slope.

This is a constraint to sustained yield management which should be further investigated before extensive harvesting is carried out. Special care to ensure adequate regeneration following harvesting must be taken. Because the volume per hectare is low and generally in poor condition, harvesting on a sustained yield basis might be carried out by selective partial cutting. Since the expression of diameter distribution, described above, does not specify stand density, the following procedure is used.

Uneven-aged tree diameter distributions tend to follow an inverse J-shaped distribution. The inverse J-shaped can be considered as a special case belonging to the exponential family of distributions and is sometimes called the negative exponential distribution. Thus determination of tree diameter distribution for the Western Forest was done in the following manner:

1. Plot number of trees in each diameter class, y, over dbh, x, on millimetre square paper for each BAF.

2. The general exponential function of the form $y = e\ a + bx$ describes the diameter distribution for each BAF where e is the base of natural logarithms, a and b are constants which characterize the Western Forest structure.

3. To obtain the values for a and b, natural logarithms for y values are obtained from logarithm tables and the exponential functions are transformed into linear function (i.e., log y = a + bx).

4. After the values of a and b (intercept and slope) for each BAF are estimated, the function of the diameter distribution is written in the form of $y = e^{a + bx}$.

The calculations are presented in Table 8 and the graphs in Figure 12.

Similar procedures were used for determination of height distribution. The computations and graphs are presented in Table 9 and Figure 13, respectively.

The diameter and height distributions for different BAF's are similar. However, BAF of 1 has the least standard error of estimate for basal area estimation and diameter distribution, and BAF of 2 for height distribution. These would imply that different basal area factors are best for estimation of different parameters.

Spatial Distribution

The space arrangement of trees is an important phenomenon from the silvicultural viewpoint. In fact,

Table 8.--Diameter Regression Functions for Different BAF's

BAF = 1	BAF = 2	BAF = 4
r = -0.9919	r = -0.9897	r = -0.9898
b = -0.0853	b = -0.0868	b = -0.0870
a = 5.7793	a = 5.8173	a = 5.7427
MSE = 0.3147	MSE = 0.5042	MSE = 0.4932
$\sqrt{MSE}$ = 0.5610	$\sqrt{MSE}$ = 0.7101	$\sqrt{MSE}$ = 0.7023
s.e. of a = 0.7065	s.e. of a = 0.7171	s.e. of a = 0.6989
s.e. of b = 0.0003	s.e. of b = 0.0003	s.e. of b = 0.0003
Σx = 342	Σx = 342	Σx = 342
Σx^2 = 14,496	Σx^2 = 14,496	Σx^2 = 14,496
Σy = 22.83	Σy = 22.67	Σy = 21.93
Σy^2 = 69.0133	Σy^2 = 68.6413	Σy^2 = 65.0237
Σxy = 739.5900	Σxy = 731.2600	Σxy = 702.8400

Functions

BAF = 1	BAF = 2	BAF = 4
$y = e^{5.78 - 0.08x}$	$y = e^{5.81 - 0.08x}$	$y = e^{5.74 - 0.08x}$

where:

x is diameter,
y is frequency,
e is the base for natural logarithms,
r is the correlation of coefficient,
b is the slope,
a is the intercept,
MSE is the mean square error,
$\sqrt{MSE}$ is the standard error of estimate,
s.e. of a is the standard error of intercept,
s.e. of b is the standard error of slope,
Σx^2 and y^2 are the sum of squares, and
Σxy is the sum of cross-products.

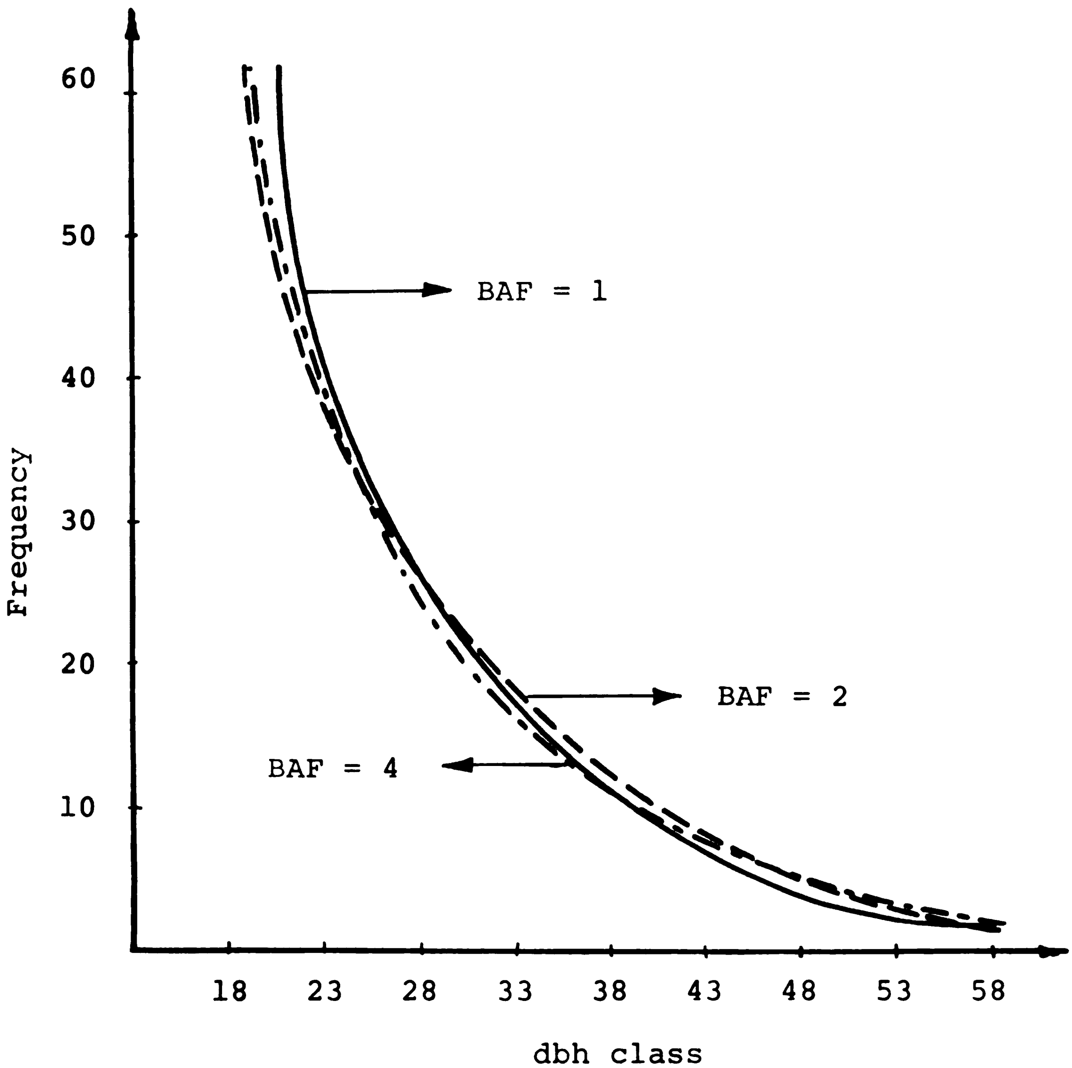


Figure 12: Diameter Distributions for Different BAF's

Table 9.--Height Regression Functions for Different BAF's

BAF = 1	BAF = 2	BAF = 4
r = -0.92579	r = -0.97609	r = -0.8738
b = -0.1955	b = -0.2117	b = -0.2548
a = 4.5849	a = 4.6804	a = +4.835
MSE = 14.0178	MSE = 1.7162	MSE = 139.3758
$\sqrt{MSE}$ = 3.7440	$\sqrt{MSE}$ = 1.3100	$\sqrt{MSE}$ = 11.8057
s.e. of a = 0.8803	s.e. of a = 0.5372	s.e. of a = 0.6180
s.e. of b = 0.0046	s.e. of b = 0.0047	s.e. of b = 0.0054
Σm = 92.5	Σm = 92.5	Σm = 92.5
Σm^2 = 1041.25	Σm^2 = 1041.25	Σm^2 = 1041.25
Σh = 27.76	Σh = 27.22	Σh = 24.78
Σh^2 = 85.3440	Σh^2 = 82.8276	Σh^2 = 77.1861
Σmh = 220.48	Σmh = 212.48	Σmh = 181.90

Functions

BAF = 1	BAF = 2	BAF = 4
$h = e^{4.58 - 0.19m}$	$h = e^{4.18 - 0.21m}$	$h = e^{4.83 - 0.25m}$

where:

m is height,
h is frequency,
e is the base for natural logarithms,
r is the correlation of coefficient,
b is the slope,
a is the intercept,
MSE is the mean square error,
$\sqrt{MSE}$ is the standard error of estimate,
s.e. of a is the standard error of intercept,
s.e. of b is the standard error of slope,
Σm^2 and h^2 are the sum of squares, and
Σmh is the sum of cross-products.

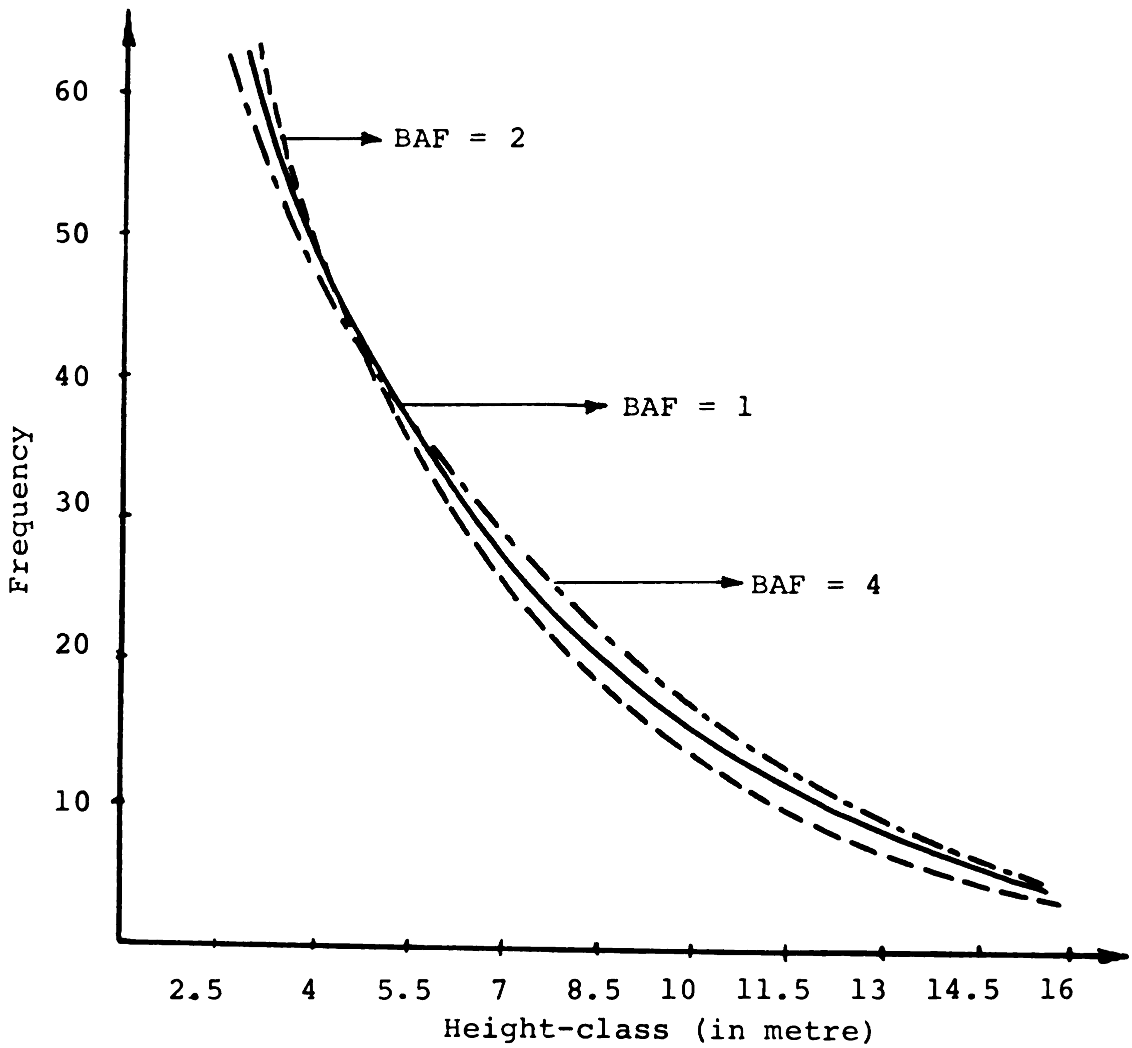


Figure 13: Height Distributions for Different BAF's

silvicultural fellings are nothing more than the rearrangement of the spacing between trees for a given area and species. It is therefore, apparent that forests cannot be tended and grown properly unless those influences which decide the space arrangement of the trees are well-known (e.g., root competition for the water and food in the ground). The factors that influenced the space arrangement of the Iranian Western Forest can be considered as a separate, future silvicultural research study and were not fully investigated in the present study. The present study, however, provides some preliminary information for further silvicultural research which might be very helpful.

Trees in a forest may be distributed according to one of three broad patterns: random, uniform (regular), and clumped (aggregated, irregular, and non-random). Several methods have been introduced for determination of spatial distribution. Accuracy and practicality of different methods are not the same, of course. For example, in addition to the greater convenience of measuring from points (i.e., tree to tree), random point-to-plant measurements also have a theoretical advantage. As has been shown by Greig-Smith (1957), a non-random population may exhibit patchiness of several scales, thus if plants are clumped, they may often be present not merely in simple clumps but also in clumps of clumps, and so on. When this is so, an index based on plant-to-plant distances will indicate only the smallest scale of non-randomness present, whereas one based on point-to-plant distance will be affected by most, if not all, the levels of non-randomness in the population. Therefore, a method of random point-to-plant distance was employed for the present study. The same random points are used for spatial distribution as used for the original pilot survey.

Greig-Smith, 1957, suggested that the condition under which a Poisson distribution in biological population applies is when the number of individuals of a species in the area is low relative to the possible number that could grow in that area. The relative factors affecting stand growth in the Western Forest indicate that such an assumption is reasonable. Different methods have been proposed to test and to measure the degree of departure from randomness. Variance: mean ratio (i.e,, relative variance) was used for all sample points and different BAF's. This test made use of the equality of mean and variance of the Poisson distribution. If the ratio of variance to mean is less than one, a regular distribution is indicated and if greater than one, a clumped distribution. The index of dispersion, i.e., I = (variance) x (degrees of freedom) is presented for all BAF's used in Table 10. The values of the index of dispersion are high for all three BAF's, which indicates that the spatial distribution of the stand is contagious. This corresponds with the indications given by the ratio of variance: mean figures. Contagion or clumping is to be expected since the sampling points are widely distributed in space; i.e., spatial distribution of the forest as a whole is being examined, rather than spatial distribution within stands.

Table 10.--Variance: Mean Ratio and the Index of Dispersion for Sample Trees Using Different BAF's

	Variance	Mean	(Var.)/(Mean)	Index = (Var.)(d.f.)
BAF = 1	83.3334	14.00	5.95	2,250.00
BAF = 2	96.3122	14.36	6.71	2,600.43
BAF = 4	100.1270	14.14	7.08	2,703.43

In order to determine the spatial distribution, two general cases can be recognized: uniform versus clustered (clump can be considered as a special case of cluster). The general test is to assume the distribution and then test the expected numbers versus the actual numbers taken from field measures. Since the parametric test has certain requirements such as normality and homogenity of variance, a non-parametric test has been suggested, such as the Kolmogorov-Smirnov test (Conover, 1971). Because of insufficient data, this test has not been carried out.

Test of Skewness and Kurtosis of the Diameter and Height Distributions

A measure of the amount of skewness and kurtosis in the Western Forest for diameter and height distributions are presented by their third moment, M_3, and the fourth moment, M_4, about their means, respectively. To render the measures of M_3 and M_4 independent of the scale on which the data are recorded, they are divided by δ^3 and δ^4, respectively (where δ = standard deviation). The sample estimates of these can be denoted by b_1 and b_2, respectively.

The estimation of skewness and kurtosis for different BAF's, for both diameter and height distributions, are expected to provide similar results hence the estimations can be made for BAF of 1. The computation of b_1 and b_2 for the diameter and height distributions are shown in Table 11 and Table 12, respectively. Since b_1 and b_2 are dimensionless, the whole calculation can be done in the coded scale, without no need to decode.

If the sample comes from a normal population, $\sqrt{b_1}$ is approximately normal with mean zero and standard deviation $\sqrt{6/392}$. Since $\sqrt{b_1}$ for diameter distribution

Table 11.--Computations for Test of Skewness and Kurtosis of the Diameter Distribution

d_i*	Coded d_i D_i**	Freq. f	D_i^2	D_i^3	D_i^4
18	-4	68	16	-64	256
23	-3	41	9	-27	81
28	-2	25	4	-8	16
33	-1	22	1	-1	1
38	0.0	15	0.0	0.0	0.0
43	1	10	1	1	1
48	2	6	4	8	16
53	3	3	9	27	81
58	4	2	16	64	256

*d_i = diameter class in 5-centimetre

**D_i = reduced deviation from the mean of the diameter classes

Test of skewness

$n = 192$

$\Sigma fD_i = -428$ $\qquad$ $ED = \Sigma fD_i \;/\; n = -2.23$

$\Sigma fD_i^2 = 1,672$ $\qquad$ $ED^2 = \Sigma fD_i^2 \;/\; n = 8.71$

$\Sigma fD_i^3 = 5,414$ $\qquad$ $ED^3 = \Sigma fD_i^3 \;/\; n = 28.20$

$$M_2 = ED^2 - (ED)^2 = 8.71 - (-2.23)^2 = 3.74$$

$$M_3 = ED^3 - 3(ED)ED^2 + 2(ED)^3 = -28.20 + 58.27 - 22.18 = 7.89$$

$$b_1 = M_3 \;/\; M_2 \sqrt{M_2} = 7.89 \;/\; 3.74 \sqrt{3.74} = 1.09$$

Test of kurtosis

$\Sigma fD_i^4 = 22,012$ $\qquad$ $ED^4 = \Sigma fD_i^4 \;/\; n = 114.64$

$$M_4 = ED^4 - 4(ED)(ED^3) + 6(ED)^2(ED^2) - 3(ED)^4 =$$
$$114.64 - 251.54 + 259.88 - 74.19 = 48.79$$

$$b_2 = M_4 \;/\; M_2^2 = 48.79 \;/\; 3.74^2 = 3.49$$

Table 12.--Computation for Test of Skewness and Kurtosis of the Height Distribution

h_i*	Coded h_i H_i**	Freq. f	H_i^2	H_i^3	H_i^4
4.0	-4	47	16	-64	256
5.5	-3	51	9	-27	81
7.0	-2	23	4	-8	1
8.5	-1	26	1	-1	1
10.0	0.0	22	0.0	0.0	0.0
11.5	1	8	1	1	1
13.0	2	5	4	8	16
14.5	3	6	9	27	81
16.0	4	4	16	64	256

*h_i = height class in 1.5 metre,
**H_i = reduced deviation from the mean of the height classes

Test of skewness

$n = 192$

$\Sigma fH_i = 361$ $\qquad$ $EH = \Sigma fH_i \;/\; n = 1.88$

$\Sigma fH_i^2 = 1{,}475$ $\qquad$ $EH^2 = \Sigma fH_i^2 \;/\; n = 7.68$

$\Sigma fH_i^3 = 4{,}129$ $\qquad$ $EH^3 = \Sigma fH_i^3 \;/\; n = 21.50$

$M_2 = EH^2 - (EH)^2 = 7.68 - 3.53 = 4.15$

$M_3 = EH^3 \; 3(EH)(EH^2) + 2(EH)^3 = -21.50 + 43.32 -6.64 = 15.17$

$b_1 = M_3 \;/\; M_2 \sqrt{M_2} = 15.17 \;/\; 4.15 \sqrt{4.15} = 1.80$

Test of kurtosis

$\Sigma fH_i^4 = 18{,}155$ $\qquad$ $EH^4 = \Sigma fH_i^4 \;/\; n = 94.56$

$M_4 = EH^4 - 4\,(EH)(EH^3) + 6(EH)^2(EH^2) - 3\,(EH)^4 =$

$94.56 - 161.68 + 162.87 - 37.48 = 58.27$

$b_2 = M_4 \;/\; M_2^2 = 58.27 \;/\; 4.15^2 = 3.39$

(i.e., $\sqrt{1.09} = 1.04$) is nearly six times larger than its standard deviation (i.e., 0.177) and eight times for height distribution, positive skewness is confirmed.

For the normal distribution, the value of b_2 is 3. If b_2 exceeds 3, there is usually an excess of values near the mean and far from it, with a corresponding depletion of the flanks of the distribution curve. The results show this case for both diameter and height distributions.

The pilot survey, consisting of thirty-three point samples, indicated that the Western Forest is an uneven-aged, approximately balanced forest with a mean stand density of 192 trees per hectare and mean basal area per hectare of 14 square metres. The diameter distribution showed a large range from 15 to 61 centimetres as did the height distribution, which was from 2.5 to 17.5 metres. The main species present were largely members of the genus Quercus with a few other minor species in the lower diameter classes. The quality of the trees was highly variable with some trees chopped off at the top by early human disturbances. Three BAF's were used, which all gave similar diameter and height distributions. Both diameter and height distributions exhibit positive skewness and kurtosis with an excess of values near the mean and far from it.

CHAPTER VIII

PROPOSED INVENTORY DESIGN FOR THE WESTERN FOREST

Without an adequate knowledge of the Iranian forest resources, it is difficult to make any rational plan either for regulation or development. Therefore, to provide a sound and firm basis for planning of forestry and forest industries, a well designed inventory of the forest resources is necessary and important.

The stocking of the Western Forest is low (i.e., only 14 square metres per hectare for basal area), and many trees have been chopped off at the top or completely cut down because of local uses. Considering that the Western Forest has a potential of producing more profitable conifers (Dr. Tregubov, 1969), planting of fast growing softwoods to increase the forest productivity is essential. Consequently the present inventory design must have a strong emphasis on gathering information regarding factors influencing forest productivity rather than just estimating the existing volumes.

The first step of an inventory design is to identify the parameters of interest. These parameters for the Western Forest inventory are listed below:

1. Edaphic factors: slope, soil texture, bulk density and organic matter;
2. Climatic conditions: average rainfall including total and seasonal distribution; average rainfall in January and temperatures in June and July;
3. Site quality by stem analysis;
4. Vegetation maps including both ground and forest vegetation for purposes of determining area and location data;
5. Volume of timber on commercial forest land;
6. Volume of annual net growth;
7. Availability of clean fresh water and suitability for the establishment of pulp and paper mills.

Additional information on capital investments and operating costs including cost of wood, chemicals, operating labor, factory overhead, maintenance, utilities, operating and packing supplies, depreciation, taxes, insurance, interest and lending rates, sales and transportation, should also be examined for planning purposes.

The second step of the inventory is to divide the area into manageable inventory units. This classification might be based either on existing political or administrative boundries or on watershed boundaries. Such units should be related to future management, taking into consideration topography and geographical layout. For these purposes, the latest topographic maps, available from the Iranian Army, Division of Geography, and existing forest map (Dr. Tregubov and Dr. Mobayen, 1970) are very useful. These units can be revised after the inventory planning process to include industrial development.

Selection of sampling units can be done in two general methods, random or systematic. The Western Forest is located in hilly topography and the use of too many sampling units is costly and time consuming. On the other hand, the precision of estimates depends on the number of independent sampling units in the sample. These two factors must be balanced in determining the number of sampling units.

The proposed design does not make use of aerial photographs, but it would certainly be beneficial if aerial photographs could be obtained. These photos could be used for more accurate stratification of forest types which would make sampling more efficient. Aerial photographs would also enable a more accurate and speedy mapping of the forests and could be used in location of field plots and subsequent management. Experience in other countries has clearly illustrated the advantages and usefulness of this tool. Therefore, it is highly recommended that it be made available for projects like this.

Inventory Design

The design of the samples can be either by clusters or simple plots, randomly or systematically located. Likewise, the plot could be fixed or variable size. The layout of these plots and the design chosen must be compatible with the terrain and forest condition.

Experience from the pilot survey indicates that variable plot sampling (i.e., point-sampling) is an efficient method to use. This is primarily because of hilly terrain conditions and the high expenses to get to a point. A cluster of variable plots is proposed as shown in Figure 14. Each cluster is laid out in a north-south direction with the distance between each plot being 100 metres. Experience from the pilot survey indicates that with a BAF of 1, 2, and 4, the maximum distance of an included tree is always less than 50 metres. Each plot is numbered consecutively from 1 to 9 as shown in Figure 14. These clusters will be located on the forest type map by random selection of number pair, respectively, of latitude and longitude. That selected point is the location of the center of plot number 1.

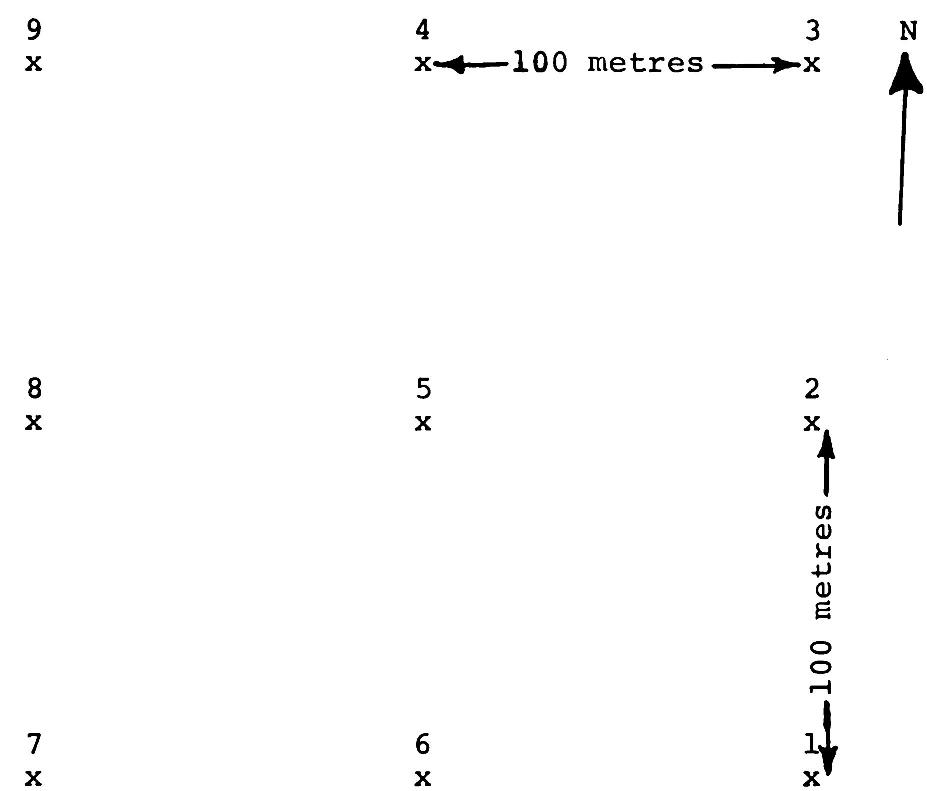


Figure 14: Layout of a Cluster of 9 Center Plots

The forest type map (Figure 7 in the back pocket) shows broad stratification of the forest by groups of the most important species. Lack of aerial photographs prevents more detailed stratification of the forest prior to layout of plots. It is for this reason that the existing forest type map is used. The Western Forest, 2,850,000 hectares, consists of three important forest types including: Quercus infectoria and Quercus libani, 1,410,750 hectares; Quercus persica, 285,000 hectares; and Amygdalus scoparia and Acer cinerascens, 1,154,250 hectares.

These three forest types as given in the forest type map are used as the basic strata for the allocation of sampling points and subsequent analysis.

If simple random sampling without stratification were used, the number of samples required to meet a certain level of precision is given by the formula:

$$n = \frac{z^2\ (CV)^2}{a^2}$$

where:

n = number of clusters required for accuracy a, with the probability level implied by the value of z.

z = standard normal, in the usual case either 1 (for probability = 0.68, i.e., "one standard error") or 2 (for probability = 0.95, i.e., "two standard errors") are sufficiently good approximations.

CV = coefficient of variation obtained from the pilot survey (e.g., for BAF of 2 CV is 68.31):

$$CV = \frac{100\ (\text{standard deviation})}{\text{average}}$$

a = a stated percentage accuracy desired for the average basal area.

For example, if one specifies that the estimated average basal area should be within plus or minus 10 percent of the true basal area unless a one-in-twenty chance has occurred (probability level = 0.95, which implies that z = 2), and since CV for basal area, for example, using BAF of 2 is CV = (100 x 9.81) / 14.36 = 68.31, then

$$n = \frac{(2)^2\ (68.31)^2}{(10)^2} = 187$$

If more funds and personnel had been available for the pilot survey, optimal allocations with respect to the variance and inventory cost operation would be used for allocating samples to strata. Since estimates of CV by strata are not available, however, a proportional allocation by area is proposed. Using this method of allocation, the total samples, 187, should be allocated proportional to the area of each stratum as shown below:

Since the area of each stratum is already known, the proportion to the total area can be calculated i.e.,

w_1 = 1,154,250 / 2,850,000 = 0.405

w_2 = 285,000 / 2,850,000 = 0.100

w_3 = 1,410,750 / 2,850,000 = 0.495

therefore, since n is already estimated, n_1, n_2, and n_3 can be calculated as below:

$n_i = n\ w_i$ where i = 1, 2, and 3

specifically,

$n_1 = 76$, $n_2 = 19$, and $n_3 = 92$.

Due to the random location of sampling points, it would be conceivable that some may fall in non-forested areas. In such cases, based on the assumption that non-forested areas are excluded from the population of interest, additional sampling points will be required to replace these that fall in non-forest areas. It is, therefore, advisable to select additional random points at the beginning of the inventory, which could be used as replacements if so required. While the proposed design is in progress, the required number of samples should be recalculated against the one which is proposed, 187, by calculating the basal area and variances of the three strata. In order to estimate $\overline{BA}$ to, for example, within $\pm$ 10 percent of the true basal area per hectare (i.e., $\overline{BA} \pm (10\ /\ 100)\ \overline{BA}$) with 95 percent confidence interval (i.e., z value is about 2), the following procedure is required:

$$\overline{BA} \pm 0.10\ \overline{BA} = \overline{BA} \pm t\ s_{\overline{BA}}$$

or $t\ s_{\overline{BA}} = 0.10\ \overline{BA}$

or $$2\sqrt{w_1 \frac{s_1^2}{n_1} + w_2 \frac{s_2^2}{n_2} + w_3 \frac{s_3^2}{n_3}} = 0.10\ \overline{BA}$$

Since $n_i = w_i\, n$, the last formula can be written as:

$$2\sqrt{\frac{w_1}{n}\, s_1^2 + \frac{w_2}{n}\, s_2^2 + \frac{w_3}{n}\, s_3^2} = 0.10\ \overline{BA}$$

or $$n = \left(\frac{2}{0.10}\right)^2 \times \left(\frac{w_1\, s_1^2 + w_2\, s_2^2 + w_3^2\, s_3^2}{\overline{BA}^{\,2}}\right)$$

Then $s_{\overline{BA}}$ is minimized for total sample size n if

$$n_i = n \frac{w_i\ s_i}{\sum_{i=1}^{3} w_1\ s_i}$$

This procedure is called optimal allocation (Cochran, 1963).

In order to obtain a more reliable estimate of the actual CV in each stratum and to verify the number of samples required to meet a certain precision, running calculations of CV should be maintained as the survey progresses. However, it should be pointed out that the <u>Quercus persica</u> forest has more valuable timber resources than the other forest types (Dr. Tregubov and Dr. Mobayen, 1970). Therefore, it might be desirable to specify a higher precision for this stratum.

From the pilot survey, the mean value of basal area per hectare obtained from all three BAF (1, 2, and 4) are very similar. Although the BAF of 1 has the least standard deviation, standard deviations for both 1 and 2 are very similar. The use of BAF of 1 requires measuring an average of 14.0 trees per plot whereas the use of BAF 2 requires only 7.2 trees. Also, the possibility of introducing bias due to hidden trees increases if BAF 1 is used (Beers and Miller, 1964). If BAF 4 is used, the average number of included trees per plot is only 3.5. In some terrain with low density, the number of trees will be too small to yield reliable results. Therefore, BAF 2 is proposed.

Measurement Procedure

For each plot, the following procedure will be carried out:

1. Determine included trees with a relascope, using BAF of 2.
2. Measure diameters of all included trees to the nearest centimetre with a diameter tape.
3. Measure the tree height using the relascope to nearest quarter metre.
4. Record the species, and quality (i.e., top chopped off or not).
5. Check for boundary trees by measuring the distance from the trees to their plot centers.

6. Measure distances and directions between points in a cluster using a 50 metre tape and a compass.

For plot number 5, additional information for edaphic and ecological conditions will be obtained, as listed below:

1. Slope with the percentage clinometer scale of the relascope;

2. Soil p^H with p^H paper;

3. Texture using the hydometer method;

4. Core samples collected for bulk density and organic matter determination;

5. Pictures taken from four cardinal directions with a camera for general references;

6. Ground vegetation.

Stem-analysis from an uninjured tree for every sample taken from plot number 5 is suggested. (In case such a tree is not found in plot number 5, the tree is selected from the other four plots, numbers 6 to 9 respectively.) This amounts to cutting off a tree and sectioning into different disks for measuring the annual diameter growth to the nearest millimetre, height growth data, defect estimation, and construction of site index curves, and

volume tables. Stem-analysis includes both field and office work. The field work consists of recording tree species, total height, outside defect, and the ground condition. Then the tree should be cut off and sectioned into 50 centimetre logs. From the top of each log, a disc of 2-3 centimetres thickness should be cut. The top disc will be number one, the second from top is number two, and so on. The bottom disc will be cut off flush with the ground (Husch, et al., 1972). These discs will be put in a plastic bag which will be numbered and taken to the office for analysis. For each tree that is cut for stem-analysis, the species, total height and total age are recorded together with internal and external defects. Office work includes measuring the annual diameter growth to the nearest millimetre on each disc after sanding off the unnumbered side of the disc. The height growth for any period of time can also be estimated by determining the difference in number of rings between two consecutive discs and distance between discs. The tree growth can be shown graphically by recording the disc number and counting the rings for each disc. These data are then plotted on a graph (see Figure 16) where the horizontal axis represents distance from the pith. The distance from the pith is recorded with a dot for each ring on a disc and then these points are jointed across discs to indicate graphically the tree growth.

In soil sampling, from plot number 5 of each cluster, two things should be determined: the texture of the A and B horizons and the thickness of these horizons. The soil horizons can be distinguished from each other on the basis of color, texture, structure, and consistancy differences. Drainage can be roughly determined by the amount of gray mottling. The more gray mottling, the poorer the drainage. The availability of fresh water should also be recorded as the inventory is in progress because it is important for treatment of timber in pulp mills.

Since it is also proposed to initiate growth determination by a method of sampling with partial replacement, a proportion of sample plots will be marked as permanent plots, where every included tree will be marked with paint, to enable future measurement for growth. These samples will be selected based on forest types and accessibility, respectively. For this purpose, diameter is recommended to be measured every five years with a diameter tape.

The tally sheets for each plot cluster consist of three separate pages; one for edaphic factors and ground vegetation for plot number 5, one for stem-analysis, and one for recording the species, diameter, height, stem form, external defect, and quality (e.g., that a tree has been chopped off at the top or not) of included trees in the sample for all nine plots. The appropriate tally sheets are shown in Figures 15, 16, and 17, respectively.

The field organization should be carried out by crews, each group consisting of one officer and six technicians. Three technicians will be responsible for collecting stem-analysis data and taking the samples on edaphic factors from plot number 5, and the other three will be responsible for carrying out point-sampling for all nine points. A heavy duty vehicle and a driver familiar with the area, for each group, is absolutely necessary.

Form No. 1

Sample No.______ Plot No.______

Location__________________________ Date ______________

Crew Chief__________________________

Slope	%	Aspect	Elevation (metres)	Horizon	Soil Textural Class S	L	C	Depth
0.0	10	N	0.0-500	A				
10	20	S	500-1000	B				
20	30	E	1000-1500					
30	40	W	1500-2000					
40	50	N-E	2000+					
50	60	S-E						
60	70	N-W						
70	80	S-W						
80	90							
90	100							
	100+							

S = Sands, L = Loams, C = Clays

Soil Sample Number ____________

Notes on

ground vegetation, availability of fresh water and other related information.

Figure 15: A Tally Sheet for Edaphic Factors and Ground Vegetation

Form No. 2

Point No.______

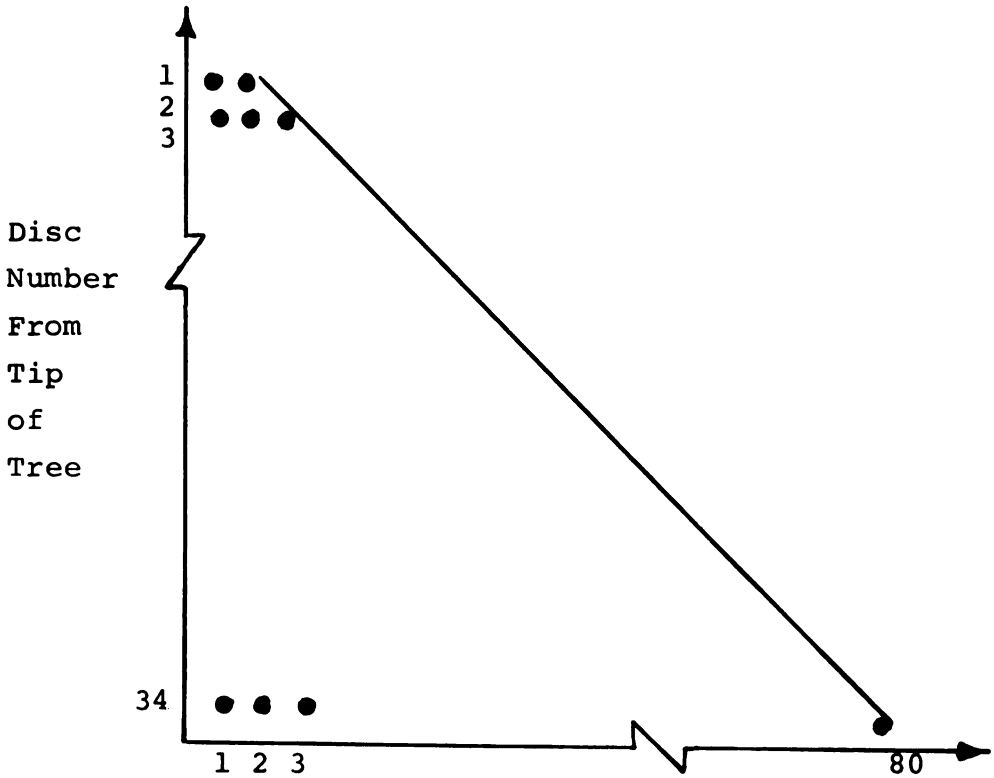
Location:__________________ Date:________ Crew Chief_______

Species____________________ Total Height___________________

Total Age__________________ Ground Condition_______________

Defect: Inside____________

Outside____________



Distance from pith to outer edge of ring, for each ring on disk. Every tenth ring shown as circle, intermediate rings shown as dots.

Figure 16: Stem-Analysis Form

Form No. 3

Sample No._______ Location______________________________

Forest Type______________ Crew Chief_____________ BAF = 2

POINT NUMBERS

1							2						
Tree No.	Species	dbh, cm.	Height, m.	Quality g p	Stem Form 1 2 3	External 4 5	Tree No.	Species	dbh, cm.	Height, m.	Quality g p	Stem Form 1 2 3	External 4 5

Quality: g = good, full crown, p = poor, chopped off.
Mean BA:
Stem Form: 1 = good, round clear bole, 2 = medium, and 3 = poor, crooked, branchy bole.
External Defect: 4 = with visual defect, 5 = with no visual defect. Note nature of external defect indicators on reverse side of tally sheet.

Figure 17: A Tally Sheet for Recording Tree Measurements

Form No. 3

Sample No._______ Location______________________________

Forest Type______________ Crew Chief_____________ BAF = 2

POINT NUMBERS

3							4						
Tree No.	Species	dbh, cm.	Height, m.	Quality g p	Stem Form 1 2 3	External 4 5	Tree No.	Species	dbh, cm.	Height, m.	Quality g p	Stem Form 1 2 3	External 4 5

Figure 17--Continued

Form No. 3

Sample No.________ Location______________________________

Forest Type________________ Crew Chief__________ BAF = 2

POINT NUMBERS

5							6						
Tree No.	Species	dbh, cm.	Height, m.	Quality g p	Stem Form 1 2 3	External 4 5	Tree No.	Species	dbh, cm.	Height, m.	Quality g p	Stem Form 1 2 3	External 4 5

Figure 17--Continued

Form No. 3

Sample No.________ Location______________________________

Forest Type_______________ Crew Chief___________ BAF = 2

POINT NUMBERS

7							8						
Tree No.	Species	dbh, cm.	Height, m.	Quality g p	Stem Form 1 2 3	External 4 5	Tree No.	Species	dbh, cm.	Height, m.	Quality g p	Stem Form 1 2 3	External 4 5

Figure 17--Continued

Form No. 3

Sample No.________ Location________________________________

Forest Type_________________ Crew Chief____________ BAF = 2

POINT NUMBERS

9						
Tree No.	Species	dbh, cm.	Height, m.	Quality g p	Stem Form 1 2 3	External 4 5

Figure 17--Continued

Analysis of Data

Since some of the trees are chopped off at the top and the probability of selecting a tree in the sample is proportional to basal area, the most reliable and accurate estimate of present stocking is basal area per hectare. The mean basal area per hectare for a given cluster will be calculated as follows: If BA_j is the mean basal area per hectare at cluster j, and the total number of trees included in nine points of cluster j is k_j, then:

$$BA_j = \frac{BAF}{9} \quad k_j .$$

And if n_i is the number of clusters for the i^{th} stratum, then the mean basal area per hectare for that stratum will be:

$$\overline{BA}_i = \frac{BAF}{9} \quad (\sum_{j=1}^{n_i} k_j) / n_i$$

Likewise, the mean basal area per hectare for the whole forest will be:

$$\overline{BA} = \sum_{i=1}^{3} w_i \ \overline{BA}_i$$

where w_i = the proportion of the area of the i^{th} stratum to the total area. The variance of mean basal area per hectare, for the i^{th} stratum will be:

$$s^2_{\overline{BA}_i} = [\sum_{j=1}^{n_i} (BA_j - \overline{BA}_i)^2 / (n_i - 1)] / n_i .$$

Consequently the variance of the mean basal area per hectare for the entire forest with three strata having variances $s^2_{\overline{BA}_1}$, $s^2_{\overline{BA}_2}$, and $s^2_{\overline{BA}_3}$ will be:

$$s^2_{\overline{BA}} = \sum_{i=1}^{3} w_i^2 \, s^2_{\overline{BA}_i} .$$

Since a volume table for the Western Forest is not currently available, data from the stem-analysis will be used to construct a two-way table of Volume : Basal Area Ratios, VBAR's, in the form of an equation using height and diameter at breast height, i.e., v = f (h, dbh). For this purpose, if the number of trees are insufficient, additional trees may have to be fallen. Additional information could also be obtained by taper measurements on standing trees using a relascope. In such a case, these measurements on standing trees must be closely supervised to ensure reliable and accurate measurements. In the stem-analysis, volume will be calculated in sections using the Huber formula, (Avery, 1967), i.e.,

$$v = h \left(\frac{A_b + A_u}{2}\right) = h \text{ (average cross-sectional area)}$$

where:

v = volume,

h = height,

A_b = cross-sectional area at base, and

A_u = cross-sectional area at top.

An estimate of volume per hectare at the q^{th} relascope point will be:

$$V_q = BAF \sum_{\ell=1}^{t_q} (VBAR)_\ell .$$

where l denotes a given tree in the q^{th} relascope point, and t_q is the total number of trees in the q^{th} relascope point.

And an estimate of mean volume per hectare for the j^{th} cluster will be:

$$\bar{V}_j = \frac{1}{9} \sum_{q=1}^{9} V_q .$$

Consequently an estimate of mean volume per hectare for the i^{th} stratum will be:

$$\bar{V}_i = \sum_{j=1}^{n_i} \bar{V}_j \; / \; n_i .$$

Finally, for the entire forest with the three strata, an estimate of mean volume per hectare will be:

$$\bar{V} = \sum_{i=1}^{3} w_i \bar{V}_i$$

The variance of the mean volume per hectare for the i^{th} stratum will be:

$$s^2_{\bar{V}_i} = [\sum_{j=1}^{n_i} (\bar{V}_j - \bar{V}_i)^2 \; / \; (n_i - 1)] \; / \; n_i .$$

Consequently the variance of the mean volume per hectare for the entire forest containing three strata with variances

$s^2_{\bar{V}_1}$, $s^2_{\bar{V}_2}$, and $s^2_{\bar{V}_3}$ will be:

$$s^2_{\bar{V}} = \sum_{i=1}^{3} w_i^2 s^2_{\bar{V}_i}$$

An estimation of the number of trees per hectare at the q^{th} relascope point will be:

$$N_q = BAF \sum_{\ell=1}^{t_q} \frac{1}{BA_\ell}$$

where BA_l denotes the basal area of the l^{th} tree in the q^{th} relascope point.

And an estimate of the mean number of trees per hectare for the j^{th} cluster will be:

$$\bar{N}_j = \frac{1}{9} \sum_{q=1}^{9} N_q$$

Consequently an estimate of the mean number of trees per hectare for the i^{th} stratum will be:

$$\bar{N}_i = \sum_{j=1}^{n_i} \bar{N}_j \; / \; n_i$$

Finally, an estimate of the mean number of trees per hectare for the whole forest will be:

$$\bar{N} = \sum_{i=1}^{3} w_i \bar{N}_i .$$

The variance of the mean number of trees per hectare for the i^{th} stratum will be:

$$s^2_{\overline{N}_i} = [\sum_{j=1}^{n_i} (\overline{N}_j - \overline{N}_i)^2 / (n_i - 1)] / n_i .$$

Consequently the variance of the number of trees per hectare in the forest containing three strata with variances

$s^2_{\overline{N}_1}$, $s^2_{\overline{N}_2}$, and $s^2_{\overline{N}_3}$ will be:

$$s^2_{\overline{N}} = \sum_{i=1}^{3} w_i^2 s^2_{\overline{N}_i}$$

An estimation of the undamaged trees per hectare for a relascope point, a cluster, a stratum, and/or for the whole forest can be made by a similar procedure to that for number of trees per hectare except including an indicator variable in the formulas listed below:

1. At the q^{th} relascope point:

$$U_q = BAF \sum_{\ell=1}^{t_q} \frac{x_\ell}{BA_\ell}$$

$$\text{where } x_i = \begin{cases} 1 & \text{if the } 1^{th} \text{ three in the } q^{th} \text{ relascope point is not chopped off, and} \\ 0 & \text{if the tree is chopped off.} \end{cases}$$

2. for the j^{th} cluster:

$$\bar{U}_j = \frac{1}{9} \sum_{q=1}^{9} U_q$$

3. for the i^{th} stratum:

$$\bar{U}_i = \sum_{j=1}^{n_i} \bar{N}_j \; / \; n_i, \text{ and}$$

4. for the entire forest:

$$\bar{U} = \sum_{i=1}^{3} w_i \bar{U}_i$$

The variance of the mean number of undamaged trees per hectare for the i^{th} stratum will be:

$$s^2_{\bar{U}_i} = [\sum_{j=1}^{n_i} (\bar{U}_j - \bar{U}_i)^2 \; / \; (n_i - 1)] \; / \; n_i \; .$$

And the variance of the mean number of undamaged trees per hectare in the forest containing three strata with variances

$s^2_{\bar{U}_1}$, $s^2_{\bar{U}_2}$, and $s^2_{\bar{U}_3}$ will be:

$$s^2_{\bar{U}} = \sum_{i=1}^{3} w_i^2 s^2_{\bar{U}_i}$$

Similar procedures will be employed to estimate the mean number of damaged trees per hectare and the variance.

A stand table will be constructed using the following procedure:

1. For each species and for each diameter class, the basal area per hectare by stratum is calculated using the formula:

$$\frac{BAF}{9} \left(\sum_{j=1}^{n_i} d_j\right) / n_i$$

where d_j is the total number of trees in j^{th} cluster with diameter class, d.

2. The basal area per hectare is divided by the basal area at the midpoint of that diameter class (a constant for each diameter class), to give the number of trees per hectare for that class.

3. The stand table then gives the number of trees by species and diameter class.

A stock table will be constructed as follows:

1. Using the previously constructed table of volume : basal area ratios (VBAR's), the volume per hectare for a given diameter class, d, for the i^{th} stratum will be obtained from the formula:

$$\bar{V}_{d_i} = \frac{BAF(VBAR)_d}{9n_i} \sum_{j=1}^{n_i} d_j$$

where $(VBAR)_d$ is the volume : basal area ratio in diameter class, d.

2. The stock table then gives the volume of trees per hectare by species and diameter class.

Since the inventory is stratified by forest types, the stand and stock tables should be set up by forest types. If the stand and stock tables are to be combined for the whole forest, it is necessary to use the w_i factors as weights for the respective strata. It may also be desirable to prepare separate stand and stock tables for damaged and undamaged trees.

For analyzing soil, the soil samples should be taken to a competent soil laboratory (i.e., College of Agriculture at Tehran University). The soil laboratory should determine the texture, bulk density, and organic matter content of the samples.

The main objective of the inventory is to determine the potential productivity of the Western Forest. In order to accomplish this task, data must be collected on the climatic and edaphic factors, ground vegetation, stem-analysis, height-growth of suggested species, and present timber volume (see Figures 15, 16, and 17). Accordingly, in the analysis of this data, it is important to involve a group of foresters specialized in a number of inter-related fields (i.e., biometrics, forest management, silviculture, forest soils, and ecology). Each specialist will analyze and interpret the data in a different manner, focusing upon certain aspects of the data relevant to his specialty. The purpose of an integrated analysis of the inventory information is to fully utilize the data to the fullest extent. Although the data collected in each field would not be sufficient for detailed mapping, it is expected that reconnaissance maps in climatic, ground vegetation types, forest types, soil types, slope classes, and elevation classes could be produced by each of the specialists. These maps should be produced in the form of transparent overlays so that they can be used together over a base map. Using this system will enable the planner or manager to obtain the characteristics of any region for making decisions on the feasibility for plantation establishment, when given the ecological, soil, climatic and other specifications of any species. The maps would also be useful for other management decisions such as determining erosion-prone areas for soil conservation or protection, or areas requiring rehabilitation. Data from the stem-analysis will also serve as the basis for preparing generalized site index curves to be used in conjunction with the maps. As soon as results from the provenance trials on the suggested species are available, the feasibility of introducing these species into new regions could be assessed using these overlays.

Further detailed analysis, possibility including multivariate methods such as principal component analysis, could be carried out by an integrated planning group to determine which factors are most critical for growth of species in the provenance trials. Such detailed studies, however, must await the results of provenance trials.

In the event that aerial photographs become available, further analysis to correlate ground information with photo-interpretation could be carried out. The importance of obtaining periodic airphoto coverage in the future cannot be overemphasized. Airphotos facilitate planning and management as well as inventory operations.

The future of the Western Forest depends on present day efforts and foresight of its planners. It is the responsibility of today's professionals in the natural resources field to ensure that the resources are utilized to their optimum level, with adequate planning for a continued and viable development and growth of these resources. To this end, the planners should utilize modern methods and technology to analyze the information that would be gathered in the proposed inventory.

CHAPTER IX

SUMMARY AND CONCLUSIONS

Iran, the geographically central country in the Middle East, with a population of 29,780,000 persons, has 12,000,000 hectares of forest. Forests constitute the second largest Iranian national resource in terms of dollar value, after oil. In 1971, Iran spent $65,300,000 for importing timber while obtaining only $300,000 from exporting this resource (FAO, 1973). The ratio of imports to exports from 1946 to 1967 constantly increased. The rate of population growth in Iran is one of the highest in the world: the annual growth rate in 1966 was 3.1 percent (Plan Organization, 1968). Not only has the demand for timber been sharply increased due to this high rate of population growth, but also because of the development in educational and housing systems.

The major Iranian forests are the Caspian and the Western Forests. The Caspian Forest, covering 3,400,000 hectares, has several species with excellent qualities and growth, but mainly hardwoods (Kernan, 1959). This forest has been inventoried in 1960 (Rogers, 1960) and has been recently reinventoried (Williams, 1973). The first inventory, by Rogers in 1960 was a triple phase sampling procedure. In the first stage, a large number of photo-points was catagorized as "forest" and "non-forest." In the second, a sample of these points was interpreted on 0.1 hectare photo-plots for crown-density and average total height of the three tallest trees. From the measurements on each plot, the average crown-density and average tree-heights were determined. In the third, a sample of photo-lots was selected for ground plots and the photo estimates of tree-height and crown-density were used to make a regression equation. The estimated average net volume per hectare multiplied by the proportion of forested area provides the mean volume-per-hectare of forested area, and the confidence of this estimate could be calculated.

The Caspian Forest has been reinventoried (Williams, 1973) to update the previous survey. A design included two major sampling techniques. Point sampling was used for selecting sample trees and measuring the diameter while 3P-sampling (Probability Proportional to Prediction) was used for measuring the height to estimate the growth. Point sampling was done with a prism of diopter 3.03. Two questions raised with respect to Williams' design concern selection of BAF and number of points per plot. Since Williams proposed his plan to be a Continuous Forest Inventory (CFI), these matters might bear further investigation. The Caspian Forest has had several management plans such as a saw mill industry plan.

The Western Forest has not been inventoried. Most parts of the forest are in poor condition because of overuse by the native population for charcoal making. The Western Forest was visited by Dr. Tregulov in 1969. He was the former FAO advisor to Iran for establishment of the first College of Forestry in Iran (at Tehran University), and also the expert in silviculture. Dr. Tregubov stated that the Western Forest is capable of producing more profitable conifers because of climatic, edaphic, and existing vegetation. Since Iran has only one domestic paper factory (in Haft Tappeh), and since the need for paper has been sharply increased because of the development in the educational system and standard of living, exploring other alternatives to the importation of paper seems important. Therefore, the objective of this study was to formulate an inventory design which would provide the informational base for potential development of the Western Forest. In this investigation, two plans have been recognized: first, the immediate or short-term plan; and, second, the long-term plan. In the short-term plan of investigation, promising conifer species have been selected, after studying the climatically similar forests in the world. The species are listed in Table 2. Planting seeds of the same species from different locations (i.e., provenance testing) in various easily access parts of the Western Forest and recording their growth is an urgent and immediate task. The results of the provenance will be very helpful in the long-term plan for the development of the area. Therefore, it is strongly recommended.

The execution of a suitable inventory design constitutes the second task. The task includes estimation of the present timber resources and determination of factors influencing the productive capacity of the Western Forest. A pilot survey using concentric point sampling with the most common used BAF's (i.e., 1, 2, and 4 in the metric system) took place in Summer, 1974. For each randomly selected point, the diameter, height, and distance from center of each selected tree for a given BAF was measured and recorded. The results of analyzing the data collected for BAF of 1 indicate that the Western Forest is a balanced uneven-aged stand with a diameter distribution function of $y = e^{5.78 - 0.08x}$ where x is diameter in centimetres, y is the diameter frequency, and e is the base of natural logarithms. Similar values were obtained for other BAF's. A height distribution function of $h = e^{4.58 - 0.19m}$ for BAF of 1 was obtained with similar values for other BAF's, where m is height in half metre, h is the height frequency and e is the base for natural logarithms. The basal area per hectare estimates for all BAF's were similar. However, BAF of 1 has the least variance for basal area estimation and diameter distribution, and BAF of 2 for height distribution. It is noticeable that some of the trees had been chopped off at the top due to some kind of native uses.

A stratified cluster sampling design using variable plots with nine plots per cluster and BAF of 2 is proposed for the Western Forest inventory. The plots are to be 100 metres apart in a square pattern. The samples are to be randomly selected and located on the existing forest type-map. A total of 187 samples are required for a precision of ± 10 percent of the basal area with a probability at the 95 percent level. Soil, slope and other ecological data will also be recorded at each sample point in addition to the data on tree parameters. A 2-way volume table will be constructed using height and dbh data obtained from the stem-analysis. Since both height and dbh will be measured for every selected tree on the plot, an estimate of the volume for the whole forest can thus be made.

It is also proposed that growth measurements be initiated at the time of inventory, using the method of sampling with partial replacement. Therefore, a certain number of samples will be selected as permanent plots and adequately marked for future measurements.
A stem-analysis on one tree in every sample is proposed to estimate the defect and construct the site index and volume table. In the actual implementation of

the inventory, the planning and management of manpower and logistics are crucial to the success of the inventory.

The ultimate objective of the inventory and related studies in the Western Forest of Iran is the planning for development of these forest resources. The data obtained from the inventory will form the basis for such planning. Sufficient information will be available for planning the location and capacities of pulpwood mills and other wood based industries. Steps will also be initiated for growth studies and provenance trials to facilitate the establishment of plantations. The proposals set out are in no way final, but are only the start in the right direction. The inventory results should be continually monitored to ensure the most efficient utilization of funds. Regular inventories of growth every five years by sampling with partial replacement would also provide information on current volume which could be used to update existing plans.

It is hoped that these proposals will in some way contribute to the development of the western region and finally to the welfare and economic well-being of the Iranian people.

APPENDICES

APPENDIX A

A LIST OF PUBLICATIONS BY THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS CONCERNING IRANIAN FORESTRY

FAO Publications

A. In English:

1. Report to the Government of Iran on Wood Technology. FAO, No. 199, November, 1953.

2. Report to the Government of Iran on Forest Range Management. FAO, No. 290, August, 1954.

3. Development of Forestry, Forest Utilization and Forest Industries in Iran, and the Demonstration Forest and Training Centre, Lowe. FAO, No. 1176, 1959.

4. Development of Forest Industries. FAO, No. 1803, 1964.

5. Management Plan for the Central Alborz Protected Region. FAO, No. TA 3046, 1971.

6. Sand Dune Stabilization. FAO, No. TA 2959, 1971.

7. Pulp and Paper Industries Development. FAO, No. 2, 1971.

B. In French:

8. Rapport au Gouvernement de L'Iran sur La Carbonisation. FAO, No. 44, November, 1952.

9. Rapport au Gouvernement de I'Iran sur La politique Et La Legislation En Matiere Forestiere. FAO, No. 140, Juillet, 1953.

10. Rapport au Gouvernement De L'Iran sur Les Etudes Ecologiques Et Systematiques sur La Flore Ligneuse De La Region Caspienne. FAO, No. 520, 1956.

11. Rapport au Gouvernement de I'Iran sur L'etablissement D'un Centre De Recherches Forestieres. FAO, No. 541, 1957.

12. Rapport au Gouvernement De L'Iran sur L'organisation De La Recherche Forestier. FAO, No. 561, 1957.

13. Rapport au Gouvernement De L'Iran sur Le Probleme Du Paturage En Foret. FAO, No. 579, 1957.

14. Rapport au Gouvernement De L'Iran sur Les Directives a Suivre En Matiere De Politiqur Forestiere. FAO, No. 790, 1958.

15. Politique de developpement Forestier. FAO, No. 1297, 1961.

16. Rapport au Govermement de I'Iran sur la Politique Forestiere dt L'organisation de L'administration Forestiere. FAO, No. 436, November, 1955.

APPENDIX B

A SUMMARY OF POINT-SAMPLING

A Summary of Point-Sampling

Forest sampling techniques have been improved substantially during the last five decades either through modification of existing procedures or through introduction of new methods. Of course, this improvement in forest sampling is essentially dependent on the improvement in the area of probability and statistical theory.

The theory of point-sampling is presented by many authors such as Grosenbaugh, 1952; Beers and Miller, 1964; Ckacko, 1965; Kulow, 1965; Avery, 1967; Loetsch, Zohrer and Haller, 1973, and others. However, a summarized presentation of point-sampling theory is described below:

Consider a tract with H hectares (i.e., $A = 10^4$ H square metres) and N trees. Let the tree radii and volumes be: $r_1, r_2, \ldots, r_N$ and $v_1, v_2, \ldots, v_N$, respectively, where the index i denotes a particular tree. Radius is measured in centimetres and volume is measured in cubic metres. Associated with tree i is a plot with radius R_i. The basic concept states that the ratio of any tree radius, r_i, to the distance from the center of the tree to the sampling point, R_i, is sin $(\beta/2)$ when the lines indicating the angle of projection are tangent to the tree cross-section. The angle β is fixed and pre-determined. This may be shown as in Figure B1.

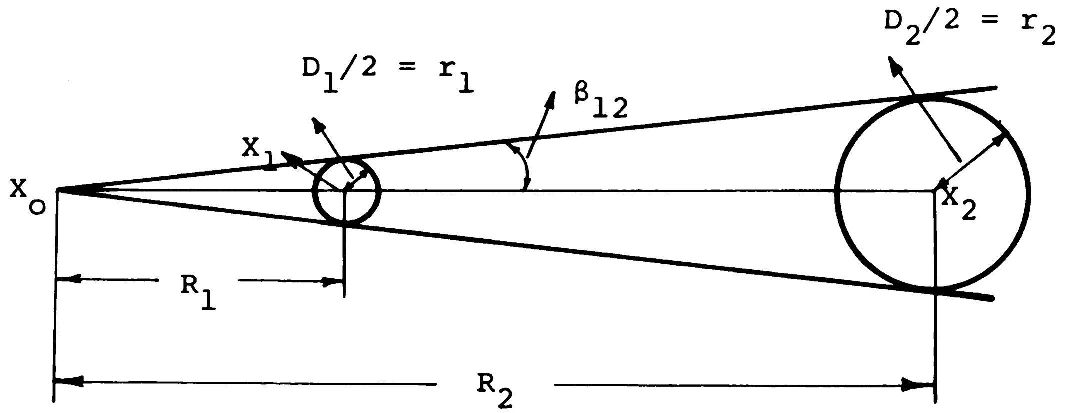


Figure B1: Geometry of Point-Sampling

Then,

(1) $R_i = r_i \ / \ \sin\ (\beta/2)$

and it can be seen that when a single point is selected at random, the probability for tree i is:

(2) $p_i = \pi\ R_i^2 \ / \ A = \pi r_i^2 \ / \ A \ \sin^2\ (\beta/2)$

That means the probability of each tree being selected in the sample is proportional to its Basal Area (BA_i is the cross sectional area at 1.3 metres).

The total number of trees tallied for a single sampling point selected at random is:

(3) $n = \sum_{i=1}^{N} J_i$

where,

$J_i = \begin{cases} 1 & \text{if sample point falls within distance } R_i \text{ of tree i} \\ 0 & \text{otherwise.} \end{cases}$

The expected number of trees tallied for a single sample point is

$$E(n) = \sum_{i=1}^{N} E(J_i) = \sum_{i=1}^{N} p_i$$

$$= \sum_{i=1}^{N} (\pi r_i^2 / A \sin^2 (\beta/2))$$

$$= (1/A \sin^2 (\beta/2)) \sum_{i=1}^{N} \pi r_i^2$$

where $BA_1 = \pi r_i^2$

$$E(n) = (1/10{,}000\ H \sin^2 (\beta/2) \sum_{i=1}^{N} BA_i$$

$$= (1/10{,}000 \sin^2 (\beta/2) ((\sum_{i=1}^{N} BA_i)/H).$$

And $(\sum_{i=1}^{N} BA_i)/H) = \overline{BA}$ which is the basal area per hectare in the tract. Therefore,

(4) $$E(n) = (1/10{,}000 \sin^2 (\beta/2)) \overline{BA}$$

Basal Area Factor (BAF) is defined as basal area in square metres per hectare represented by each tree tallied. In other words, the BAF is the conversion (or expansion factor from number of trees included within the angle at a given sampling point to basal area in square metres per hectare. Therefore,

$$BAF_i = \frac{\pi r_i^2}{10{,}000} \frac{\text{(Area of one hectare in square metres)}}{\text{(Area of a plot in sq. m. of a tree of dia.} D_i)}$$

$$BAF_i = \frac{\pi r_i^2}{10{,}000} \times \frac{10{,}000}{\pi R_i^2}$$

$BAF \; = 10{,}000 \; (r_{i/100R_i})^2$

where r_i is in centimetres and R_i is in metres.

Then,

(5) $BAF = 10{,}000 \sin^2 (\beta/2)$

and it can easily be verified that the product (BAF) n is an unbiased estimator for $\overline{BA}$, the basal area per hectare in the tract. Where n is the number of trees included in the sample when angle guage is β.

If the angle guage is selected, then it is possible to obtain the BAF for that particular angle.

Example: If = 97.22 minutes, β/2 = 48.61, then sin (β/2) = 0.014139

and $\sin^2 (\beta/2) = 0.000199$

BAF = (10,000) (0.000199)

BAF = 2

Selection of β is made in the following manner:

If one wishes to determine β so that the expected number of trees tallied is a pre-determined number, then by using the formula (4) that $E(n) = (1/BAF)\,\overline{BA}$ and substitution of $BAF = 10{,}000 \sin^2 (\beta/2)$ and solving $(\sin^2 (\beta/2) = \overline{BA}/10{,}000\, E(n)$ for β results in:

(6) $= 2\sin^{-1}((1/100)\; \overline{BA}/E(n))$

Thus, if the basal area per hectare in the tract can be pre-estimated and the E(n) can be specified, formula (6) provides the β angle.

It should be noted that the actual number of trees tallied at each sampling point is random, but should on the average be E(n).

Example: If one guesses that basal area per hectare ($\overline{BA}$) tends to be about 100 square metres, and wants E(n) = 10, then:

$$\sin(\beta/2) = (1/100)\ (100/10)$$

$$= 10/100 = 0.0316$$

$$\sin^{-1}(\beta/2) = 1.81215$$

$$\beta = 3.6243$$

<u>Estimation of Volume Per Hectare</u> $\bar{v} = (\sum_{i=1}^{N} v_i)/H$ where H is the total area of the tract in hectare.

It has been seen (i.e., formulas 4 & 5) that (BAF)n is an unbiased estimate of $\overline{BA}$. Note that

(7) $$v' = [(1/H) \sum_{i=1}^{N} J_i\ (v_i/p_i)]$$

$$(1/H) \sum_{i=1}^{N} (v_i/p_i) p_i$$

according to the definition of expectation, therefore:

$$(1/H) \sum_{i=1}^{N} v_i = \bar{v}$$

since by formulas (2) and (5),

$$(v_i/Hp_i) = v_i/(H\pi r_i^2/10{,}000\ H \sin^2(\beta/2))$$

$$= v_i/(\pi\ r_i^2/BAF) = (BAF)\quad (v_i/BA_i)$$

it can be seen that an unbiased estimator for the volume per hectare is

$$v' = BAF \sum_{i=1}^{N} J_i \ (V_i/BA_i)$$

$$\text{or} \quad = BAF \sum_{i=1}^{N} J_i \ (bL_i \ (BA_i)/BA_i)$$

(8) $$v' = (BAF)\ b \sum_{i=1}^{N} J_i L_i$$

where:

b is the cylindrical form factor of the tallied tree, and

L_i is the height of tree i

<u>Number of Required Sample Points</u>: m

With m sample points selected at random and $\bar{v}$ being the estimator for $\bar{V}$,

(9) $$cv(\bar{v}) = \delta_{\bar{v}}/\bar{v} = (\delta/\sqrt{m}\ )/\bar{v}$$

If $cv(\bar{v})$ is specified, say C, then solving for m we obtain:

(10) $$m = (S/\bar{v})^2/C^2$$

One must make a preliminary estimate of $(S/\bar{V})$ where S is standard deviation of v, the estimate based on a single sample point drawn at random. To estimate S, the usual estimator $s = \sqrt{\sum_{i=1}^{N} (v_i - \bar{v})^2/(m-1)}$ can be used.

It is noted that the actual number of trees tallied at each sampling point is random, but should on the average be E(n). In this connection, the two following points are presented:

1. It is known that $n = \sum_{i=1}^{N} J_i$ and $E(n) = \sum_{i=1}^{N} p_i$

where:

$$p_i = (\pi R_i^2/A) = (\pi R_i^2)/(A \sin^2 (\beta/2))$$

$$E\ (nBAF) = \overline{BA} = (\sum_{i=1}^{N} BA_i)/H$$

on the other hand, one knows that

$$var(n) = \sum_{i=1}^{N} p_i\ (1-p_i) + 2 \sum_{i=1}^{i-1} \sum_{i=1}^{N} cov\ (J_j,J_i) \text{ and}$$

$$var(n) \leq \sum_{i=1}^{N} p_i = E(n)$$

for example, if angle β is chosen such that $E(n) = 9$ then $\delta n \leq \sqrt{9} = 3$. Therefore, it can be concluded, from this example, that the expected number of trees tallied at each point should not be too large (i.e., not much larger than 7 according to Beers and Miller, 1964).

2. From formula (8) $v = BAF \sum_{i=1}^{N} J_i\ (V_i/BA_i)$ and

if $R_i = V_i/BA_i$ is relatively constant, say

$V_i = k(BA_i)$, then $v = (BAF)kn$ and

$$\delta_v \leq (BAF)k\ \delta_n \leq (BAF)k\ \sqrt{E(n)}$$

also $E(v') = \bar{v}$ and if $v_i = k(BA_i)$, $\bar{v} = k(\overline{BA})$

so $E(v') = k(\overline{BA}) = kE\ (nBAF) = BAFkE(n)$. Therefore,

$CV(v') = \delta_{v'}/E(v') \leq kBAF\ \sqrt{E(n)}\ /\ kBAF\ E(n) = 1\ /\ \sqrt{E(n)}$

and formula (10) becomes:

(11) $m = 1\ /\ C^2\ E(n)$

A rule of thumb suggested by Beers and Miller, 1964, is that the E(n) should be about 4-10. Therefore, an estimate of the coefficient of variation for the population is sufficient to determine the number of sampling points.

APPENDIX C

A Summary of Data from the Pilot Survey of the Western Iranian Forest Conducted in Summer, 1974

Thirty-three points were examined in the Western Forest; five points (1, 2, 4, 5, and 23) were located in the area which has been overused. Since no measurable trees were available at these points, pictures were taken. The remaining twenty-eight points constitute the raw data. The data collected and the combined frequency of diameter, height and spatial distributions for each BAF are listed in this appendix. The primary species measured was Quercus persica, but a few other species with small diameters were encountered.

Table Cl.--Location of Sample Point and Type of Information Collected in Pilot Survey

Point No.	Location	Date	Parameters Measured: species, dbh, height and distance to the center-point for BAF's 1, 2 and 4
1	Ghasemlo Valley, khan Darrehsie, Rezaiyeh	July, 1974	a photo taken from sample point
2	Cabodan Island, Rezaiyeh	July, 1974	a photo taken from sample point
3	Chako, Naghdeh	July, 1974	parameters were measured
4	Shovakan, Mirabad, Nalain	July, 1974	parameters were measured
5	Almaran, Sardasht	July, 1974	a photo taken from sample point
6	Almaran near to Iraq border	July, 1974	a photo taken from sample point
7	Biloce, Mirabad	July, 1974	parameters were measured
8	Gezileh	July, 1974	parameters were measured
9	Neyaveh	July, 1974	parameters were measured
10	Benaveh, Class	July, 1974	parameters were measured
11	Howrazeh	July, 1974	parameters were measured
12	Howrazeh	July, 1974	parameters were measured
13	Renue Tonel, Ilam	July, 1974	parameters were measured
14	Shishdar, Ilam	July, 1974	parameters were measured

Table C1.--Continued

Point No.	Location	Date	Parameters Measured: species, dbh, height and distance to the center-point for BAF's 1, 2 and 4
15	Shishdar, Ilam	July, 1974	parameters were measured
16	Shisdar, Ilam	July, 1974	parameters were measured
17	Golaza, Kermanshah	July, 1974	parameters were measured
18	Dalab, Ilam	July, 1974	parameters were measured
19	Dalab Tonel, Ilam	July, 1974	parameters were measured
20	Dalab Tonel, Kermanshah	July, 1974	parameters were measured
21	Dalab, Kermanshah	July, 1974	parameters were measured
22	Kavar, Firoozabad, Fars	August, 1974	parameters were measured
23	Najiran, Firoozabad, Fars	August, 1974	a photo taken from the sample point
24	Shoorab, Shiraz, Fars	August, 1974	parameters were measured
25	Shoorab, Shiraz, Fars	August, 1974	parameters were measured
26	Tangetir, Camfirooz, Fars	August, 1974	parameters were measured
27	Tangtir, Camfirooz, Fars	August, 1974	parameters were measured
28	Camfirooz, Fars	August, 1974	parameters were measured

Table Cl.--Continued

Point No.	Location	Date	Parameters Measured: species, dbh, height and distance to the center-point for BAF's 1, 2 and 4
29	Kohmarreh, Nawdan, Fars	August, 1974	parameters were measured
30	Kohmarreh, Nawdan, Fars	August, 1974	parameters were measured
31	Kohmarreh, Nawdan, Fars	August, 1974	parameters were measured
32	Kohmarreh, Nawdan, Fars	August, 1974	parameters were measured
33	Manassanie, Kazeroon, Fars	August, 1974	parameters were measured

Table C2.--Sample Diameter Frequency Distribution for BAF = 1

dbh*	f**	dbh*	f**	dbh*	f**	dbh*	f**	dbh*	f**
10	-	31	16	52	3	73	1	94	-
11	1	32	14	53	2	74	1	95	-
12	3	33	5	54	7	75	-	96	-
13	3	34	12	55	2	76	1	97	-
14	3	35	4	56	5	77	1	98	-
15	1	36	8	57	1	78	1	99	-
16	8	37	2	58	1	79	-	100	-
17	8	38	14	59	-	80	2	101	-
18	7	39	17	60	5	81	1	102	-
19	11	40	7	61	1	82	-	103	-
20	15	41	14	62	5	83	-	104	-
21	4	42	4	63	-	84	-	105	2
22	8	43	8	64	7	85	-	106	-
23	9	44	3	65	3	86	-	107	-
24	11	45	11	66	1	87	1	108	-
25	18	46	6	67	3	88	-	109	-
26	2	47	4	68	2	89	-	110	-
27	15	48	10	69	-	90	-	111	1
28	7	49	4	70	1	91	1		
29	14	50	6	71	1	92	1	143	1
30	5	51	2	72	2	93	1		
							TOTAL	392	

dbh* is measured in centimetres

f** = frequency

Table C3.--Sample Height Frequency Distribution for BAF = 1

Ht.*	f**	Ht.*	f**	Ht.*	f**
2.0	5	9.0	19	16.5	1
2.5	3	9.5	6	17.0	-
3.0	22	10.0	2	17.5	-
3.5	5	11.0	17	18.0	2
4.0	1	11.5	-	18.5	-
4.5	12	12.0	9	19.0	2
5.0	29	12.5	1	19.5	-
5.5	14	13.0	1	20.0	1
6.0	41	13.5	1		
6.5	12	14.0	1		
7.0	4	14.5	2		
7.5	7	15.0	6		
8.0	44	15.5	-		
8.5	6	16.0	5	TOTAL	392

Ht.* = height is measured in half-metres

f** = frequency

Table C4.--Sample Spatial Frequency Distribution for BAF = 1

Dist.*	f**	Dist.*	f**	Dist.*	f**
2.0	5	13.5	1	26.0	9
2.5	3	14.0	14	27.0	5
3.0	10	14.5	2	28.0	3
3.5	3	15.0	12	29.0	1
4.0	16	16.0	21	29.5	1
4.5	4	16.5	2	30.0	9
5.0	16	17.0	11	31.0	1
5.5	4	18.0	11	32.0	2
6.0	15	18.5	1	33.0	1
6.5	1	19.0	4	34.0	3
7.0	16	19.5	1	35.0	2
7.5	2	20.0	18	36.0	2
8.0	25	20.5	2		
8.5	1	21.0	2	39.0	2
9.0	7	22.0	5	40.0	
10.0	19	23.0	15	41.0	1
10.5	2	23.5	1		
11.0	18	24.0	9	43.0	3
12.0	12	24.5	3	44.0	1
12.5	3	25.0	8	45.0	1
13.0	14	25.5	1	50.0	1
				50.5	1
				TOTAL	392

*Distance is measured in half-metres

f** = frequency

Table C5.--Sample Diameter Frequency Distribution for BAF = 2

dbh	f*	dbh	f*	dbh	f*	dbh	f*	dbh	f*
10	-	31	6	52	2	73	1	94	-
11	-	32	7	53	1	74	1	95	-
12	1	33	2	54	5	75	-	96	-
13	2	34	5	55	1	76	1	97	-
14	1	35	-	56	3	77	-	98	-
15	1	36	5	57	1	78	-	99	-
16	3	37	1	58	-	79	-	100	-
17	4	38	5	59	-	80	1	101	-
18	5	39	8	60	4	81	1	102	-
19	5	40	2	61	1	82	-	103	-
20	10	41	5	62	4	83	-	104	-
21	3	42	2	63	-	84	-	105	1
22	5	43	5	64	3	85	-	106	-
23	5	44	2	65	3	86	-	107	-
24	7	45	5	66	1	87	1	108	-
25	10	46	2	67	2	88	-	109	-
26	-	47	4	68	2	89	-	110	-
27	7	48	3	69	-	90	-	111	1
28	4	49	3	70	-	91	-		
29	4	50	3	71	-	92	1		
30	3	51	1	72	1	93		TOTAL	201

dbh is measured in centimetres

f* = frequency

Table C6.--Sample Height Frequency Distribtuion for BAF = 2

Height*	f**	Height*	f**
2.0	4	11.5	-
2.5	3	12.0	55
3.0	15	12.5	-
3.5	1	13.0	8
4.0	15	13.5	-
4.5	3	14.0	5
5.0	14	14.5	-
5.5	9	15.0	3
6.0	20	15.5	-
6.5	4	16.0	4
7.0	20	16.5	1
7.5	3	17.0	-
8.0	30	17.5	-
8.5	3	18.0	-
9.0	10	18.5	-
9.5	4	19.0	1
10.0	1	19.5	-
11.0	10	20.0	1
		TOTAL	201

*Height is measured in half-metres

f** = frequency

Table C7.--Sample Spatial Frequency Distribution for BAF = 2

Dist.*	f**	Dist.	f	Dist.	f	Dist.	f	Dist.	f
2.0	4	12.0	7	22.0	1	32.0	-	42.0	
2.5	2	12.5	-	22.5	-	32.5	-	42.5	
3.0	9	13.0	6	23.0	8	33.0	-	43.0	
3.5	2	13.5	-	23.5	-	33.5	-	43.5	
4.0	15	14.0	5	24.0	3	34.0	1	44.0	
4.5	5	14.5	1	24.5	1	34.5	-	44.5	
5.0	13	15.0	6	25.0	-	35.0	1	45.0	
5.5	4	15.5	-	25.5	-	35.5	-	45.5	
6.0	12	16.0	7	26.0	3	36.0	-	46.0	
6.5	-	16.5	-	26.5	-	36.5		46.5	
7.0	11	17.0	6	27.0	-	37.0		47.0	
7.5	1	17.5	-	27.5	-	37.5		47.5	
8.0	15	18.0	5	28.0	2	38.0		48.0	
8.5	1	18.5	-	28.5	-	38.5		48.5	
9.0	3	19.0	2	29.0	1	39.0		49.0	
9.5	-	19.5	1	29.5	1	39.5		49.5	-
10.0	11	20.0	9	30.0	-	40.0		50.0	-
10.5	2	20.5	-	30.5	-	40.5		50.5	1
11.0	11	21.0	1	31.0	-	41.0		TOTAL	201
11.5	-	21.5	-	31.5	-	41.5			

*Distance is measured in half-metres

f** = frequency

Table C8.--Sample Diameter Frequency Distribution for BAF = 4

dbh*	f**	dbh*	f**	dbh*	f**	dbh*	f**
10	-	32	4	54	3	76	1
11	-	33	1	55	-	77	-
12	-	34	3	56	1	78	-
13	3	35	-	57	-	79	-
14	1	36	2	58	-	80	1
15	-	37	1	59	-	81	1
16	2	38	3	60	3	82	-
17	2	39	3	61	1	83	-
18	3	40	1	62	3	84	-
19	3	41	1	63	-	85	-
20	4	42	1	64	3	86	-
21	3	43	4	65	1	87	1
22	-	44	-	66	1		
23	2	45	2	67	-	110	-
24	3	46	1	68	1	111	1
25	5	47	4	69	-		
26	-	48	-	70	-		
27	2	49	1	71	-		
28	2	50	-	72	-		
29	2	51	1	73	1		
30	2	52	1	74	1		
31	2	53	-	75	-	TOTAL	99

dbh* is measured in centimetres

f** = frequency

Table C9.--Sample Height Frequency Distribution for BAF = 4

Ht.*	f**	Ht.*	f**
2.0	3	11.5	-
2.5	1	12.0	4
3.0	7	12.5	-
3.5	-	13.0	2
4.0	5	13.5	-
4.5	1	14.0	2
5.0	8	14.5	-
5.5	7	15.0	1
6.0	6	15.5	-
6.5	2	16.0	-
7.0	13	16.5	-
7.5	1	17.0	-
8.0	10	17.5	-
8.5	2	18.0	-
9.0	5	18.5	-
9.5	1	19.0	2
10.0	7	19.5	-
10.5	1	20.0	1
11.0	6	TOTAL	99

*Height is measured in half-metres

f** = frequency

Table C10.--Sample Spatial Frequency Distribution for BAF = 4

Dist.*	f**	Dist.*	f**	Dist.*	f**
2.0	4	12.0	4	22.0	
2.5	3	12.5	-	22.5	
3.0	8	13.0	6	23.0	2
3.5	2	13.5	-	23.5	
4.0	131	14.0	1	24.0	1
4.5	4	14.5		24.5	
5.0	6	15.0		25.0	
5.5	2	15.5		25.5	
6.0	7	16.0		26.0	1
6.5	-	16.5		26.5	
7.0	9	17.0	2	27.0	
7.5	1	17.5		27.5	
8.0	9	18.0		28.0	
8.5	1	18.5		28.5	
9.0	2	19.0		29.0	
9.5	-	19.5		29.5	
10.0	2	20.0	2	30.0	
10.5	-	20.5		30.5	
11.0	5	21.0		31.0	
11.5	-	21.5		31.5	
				TOTAL	99

*Distance is measured in half-metres

f** = frequency

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