MONITORING OF SEASONAL CHANGES OF VEGETATION BY NOAA/AVHRR DATA

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Cover photo

30 August 2000
N50° 22′ 52″ E107° 2′ 52″
Near Lake Baikal, Russia

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DEDICATED TO THE SACRED TREE OF THE JAPANESE

The authors have dedicated this monograph to Sakura, the sacred tree of the Japanese.

"Since the cherry flowers bloom very briefly and then scatter, they have also become a convenient symbol of the Japanese esthetic sense, an ephemeral beauty."

-Matsuda Osamu

"If someone wishes to know the essence of the Japanese spirit, it is the fragrant cherry blossom in the early morning."

-Motoori Norinaga

"In the old days the way the blossoms die with good grace was metaphorically compared to the samurai chivalry."

-Masao Minato

As known, Sakura tree (*Prunus spp.* from *Rosaceae* family) grows wild in mountains of Japan; and it is also cultivated throughout the country. The variety of this species in agriculture includes about 300 sub–species. But this species is known not because of its economic value, but rather as an esthetic symbol of the Japanese. During the Heian period (794 – 1185), the popular symbol of cherry blossoms was such that the word "hana" (flower) was simply taken as a symbol for "Sakura" (Matsuda Osamu, 1983).

A phenological map of Sakura – cherry blossom front is shown by the map given in **Figure 1** (Masao Minato, 1977). The lines that links the days when the first cherry blossoms are observed is called "sakura – zensen", the cherry blossom front. Full bloom is usually observed 5 – 10 days after the flowering day. During the period from March to April this front moves gradually from southern areas of Japan to north indicating the coming of spring.

Among the people of Japan, cherry blossom viewing, known as "hanami", is very popular. People participates in excursions and picnics; and in some places flower – viewing parties are held on traditionally estimated dates according to the lunar calendar. This customs was probably derived from the ancient agricultural practice on the beginning of spring farm activity. In April, usually radio and television stations hourly report on the blossoming local cherry trees.

But the enjoyment of cherry trees in full bloom is short–lived. Sometimes cherry blossoms are blown away by strong winds, so often occurred in spring. Daisetsu Suzuki (1988) said about that artistically :

The plum blossoms fall in the garden;
Are they really snow-flakes
Floating from the sky ?..

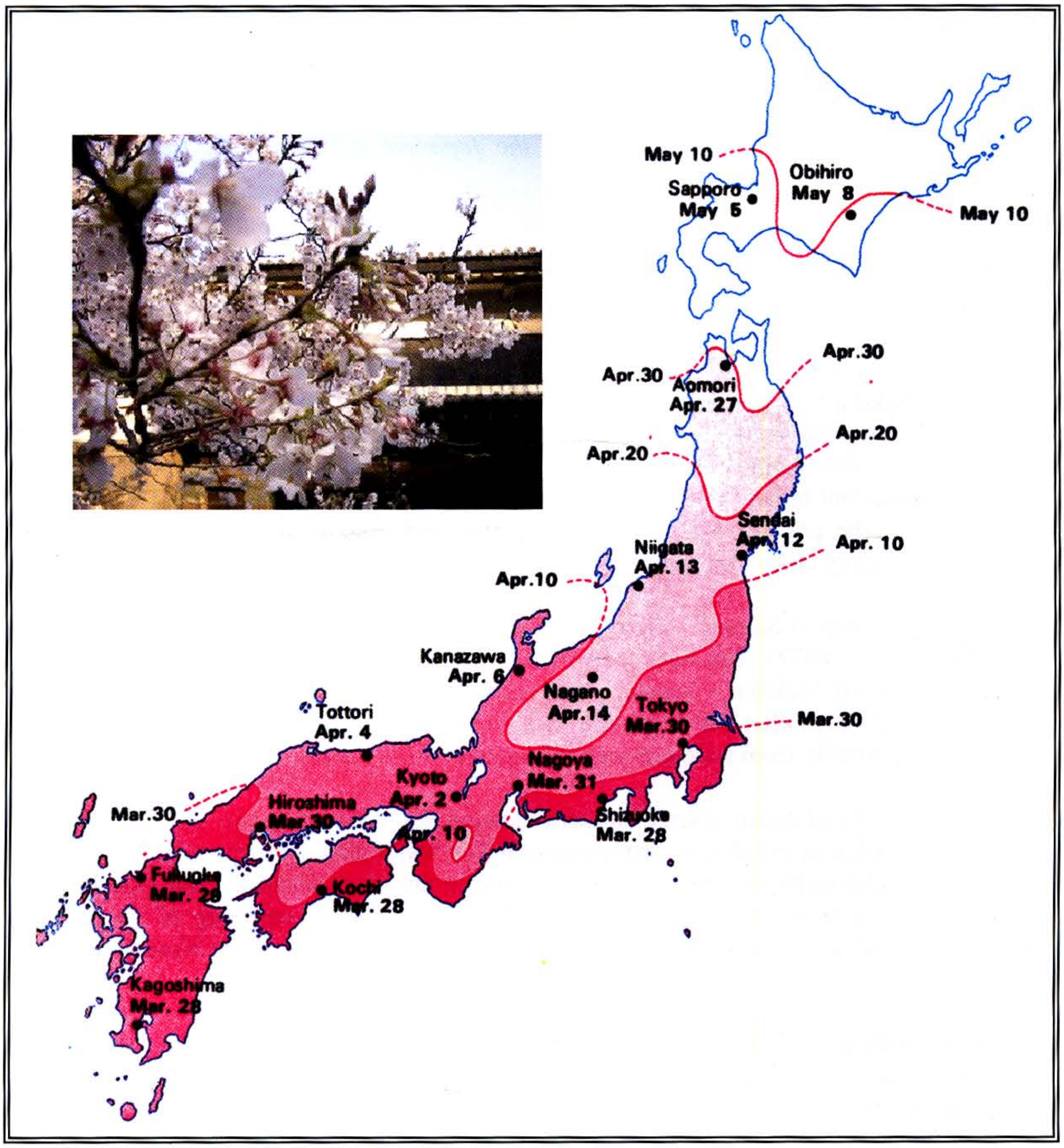


Figure 1 Cherry-blossom front marches north. Line indicate the same flowering days of cherry blossoms. Full bloom is usually 5-10 days after the flowering day

ACKNOWLEDGEMENTS

The authors must thank two graduate students of Chiba University, Mr. Mitsuhiko Ebata for his contribution of phenological analysis and data processing, and Mr. Jose Edgardo Aban for his editing and layout work.

PREFACE

Seasonal aspect is the physiognomy of vegetation. From the beginning of time, any kind of human activities was correlated with seasonal changes of vegetation. Seasonal indicators of hunting, fishing, collecting wild fruits, etc. were well known to human beings at the beginning of civilization.

From 250,000 – 300,000 plant species, known in the world, combinations of them form a variety of seasonal aspects in each landscape. Reduction of the number of species under the impact of man has led to changes of seasonal aspects. Instead of multicoloured seasonal aspects, so pleasant to human eyes, new monotonous aspects of nature arise. These new aspects characterize more simple structure of plant communities.

At present time, cycles of the seasonal development of nature play an important role in many branches of the national economy in all countries of the world. Phenology is not only science, but also practice in agriculture and forestry. The time of sowing and harvesting agricultural crops depends upon the knowledge of the seasonal cycles of nature. All measures on protection and exploitation of forests are also correlated with a phenological status of tree species. Creation of big population agglomerations and construction of new industrial plants lead as a rule to the change of the seasonal cycles of nature because of the change of microclimate and environmental pollution.

Cutting the forests and disturbing the desert vegetation are the reasons in changes of seasonal aspects in vast geographical regions. These changes can be used as indicators by the assessment of land degradation by remote sensing.

Starting in the early 1990s, composite vegetation index, known as Normalized Difference Vegetation Index (NDVI) is used to register seasonal variations in plant vigor. Complex global NDVI coverage is possible every day. NDVI data have lower volume and low cost to be compared with other technical systems of Earth observations; so these data can be used to study large areas of the world.

We consider this book as the further development of our previous activities on assessment and mapping desertification. We met one problem – seasonality because a seasonal effect can have a significant impact on imagery. In spite of small ground resolution, NDVI imagery, even in the desert zone, is closely correlated with phenological status of ecosystems. So, we have done the next step in interpretation of the imagery – assessment of seasonal aspect of vegetation by NDVI imagery

Converted to 10 days or monthly data sets, NDVI can be used as a criterion for description of seasonal aspects of vegetation. Contrary to phenological spectra, characterizing the seasonal development of single plant species, NDVI spectra can describe the periods of seasonal development of nature within one pixel, for example: winter aspect, leaf growth, summer aspect, golden autumn, etc. It is a new type of phenological information which can be used for thematic mapping and assessment of human-induced changes in natural ecosystems.

The second problem discussed in the book concerns the ground truth collection. As known, this problem always gives much trouble to land managers dealing with compilation of thematic maps by remote sensing data. We have compiled a database on ground truth on desertification in the countries of Asia.

CONTENTS

Chapter 1

FIELD PHENOLOGICAL OBSERVATIONS AND PHENOLOGICAL MAPPING

1.1. Introduction

What is *phenology*? Many branches of human activities are closely correlated with the seasonal rhythms of plants. In ancient days, seasonal events in nature were used as a timepieces to mark the passage of time. Ancient hunters and shepherds were the first people who invented this clock. Seasonal indicators of agricultural works are still being practiced actually to now. A. S. Ermolov (1905) gathered many phenological signs which became proverbial in Russia, for example: *"Perch bites when Sweet Brier blossoms"*, *"Sow oats when the Bird Cherry begins to blossom"*, *"If the leaf coloration takes place early in autumn, the grass will appear early next year"*, etc.

Modern agriculture, forestry and many other aspects contributing to national economies, directly or indirectly depend upon the seasonal changes in nature, and need objective criteria as well as indicators which determine in most cases the final results of human activities. *Ocular phenological observation* being a classical method for studying seasonal rhythms of plants, does not satisfy, in many cases the needs of these branches. Among the shortcomings and errors of the ocular method should be mentioned here :

1. One of the common errors of phenologists was the fact that they didn't distinguish "absolute points" and "relative points" by conducting phenological observations. "Absolute points" register the number of plants coming into phase, and "relative points" register the percentage of plants coming into phase. For example, flowering Bird Cherry *(Padus sp.)* in many regions of European Russia is the indicator of a suitable time for planting potatoes (V. A. Batmanov, 1961). But this indicator is true only by mass flowering of this plant, when 50% and more plants come into phase. Single flowers appearing in the beginning of the phase do not indicate the proper time for planting potatoes.

2. Ocular estimation of phenological phases does not give objective results because observers often have different ideas about such categories like phenological phase, mass phenological event etc. So, the results of phenological observations conducted in different geographical regions are not always comparable.

3. One of the false concepts of ocular observation includes the following point. If an observer did not register the timing of a phenological event in day a and registered it in day b, did it mean that this phenological event really occurred in day b? One had no right to assume this. But in practice, this situation could be accepted, and b could be considered as the real time of registration of a phenological event. But in fact, the most probable time of such an event x may be estimated as :

$$x = \frac{a + b}{2}$$

Two conclusions can be drawn from this formula, namely : **a)** The accuracy of observations can be improved if the time interval between two observations will be reduced, **b)** In the tables of phenological observations, two dates should be given : one date when a phenological event was not registered and the second date, when an observer registered the date.

Introduction of this proposal can improve the accuracy of phenological information. Russian phenologist V. A. Batmanov (1961, 1970) had developed new proposals for improving the accuracy of phenological information. The approach is known as **mathematical phenology**. Application of the mathematical methods in phenological observations needs a special clarification of terms given below.

1.2. Terminology

Phenological Time (PHT) is the most ancient system of time registration, not based on a standard calender. **PHT** is a local phenomenon. By phenological investigation Ancient Time (**AT**) can be expressed in the days of phenological model (cumulative graph, explained below), it is a number of conventional days between two relative phenological points, for example between 25 – 50% of phenological boundary.

Observation unit (OU) is a unit of observation and counting. Different **OU** can be selected depending upon a purpose, scale and specific requirements of a project. **OU** can include the plant as a whole, parts of single plants (one leaf, one flower, one branch), group of plants (for example square, 1x1 m in size by studying grasses). In phenological mapping, **OU** can include plant association, landscape units or square of different size, depending on the scale of phenological survey.

Phenological phase (PP) is a stage of ontogenetic development in plants distinguished through morphological features (bud bursting, flowering, leafing out , autumnal leaf coloration, leaf fall, etc.). All such phenological phases can be clearly identified and can be done by observers of middle-level educational attainment. This is very important by implementing phenological nets. **PP** should be identified together with phenological boundaries which are explained below.

Phenological boundary (PB) is a new term proposed by the mathematical phenology. It is a predetermined status within a phenological phase. Two examples given below can explain this term.

<u>*Example 1.*</u> Three observers have conducted phenological observations in one day in three separate points – 1, 2, 3 (**Figure 1.2.1**). The beginning of the phase ***a*** and the end of the phase ***b*** occurred in different days. But by ocular estimation the same phase was registered in three points : in point 1 it was the beginning of the phase, in point 2 it was the height of the phase and in point 3 it was the end of the phase. The results of these observations were false because the **PB** was not identified (V. A. Batmanov, 1971).

<u>*Example 2.*</u> On 2 November 1977, N. G. Kharin et al. (1981) conducted phenological observations on leaf coloration of *Acer turcomanicum* in the vicinity of Ashkhabad, Turkmenistan. Observations were conducted in three experimental plots, each 0.5 ha

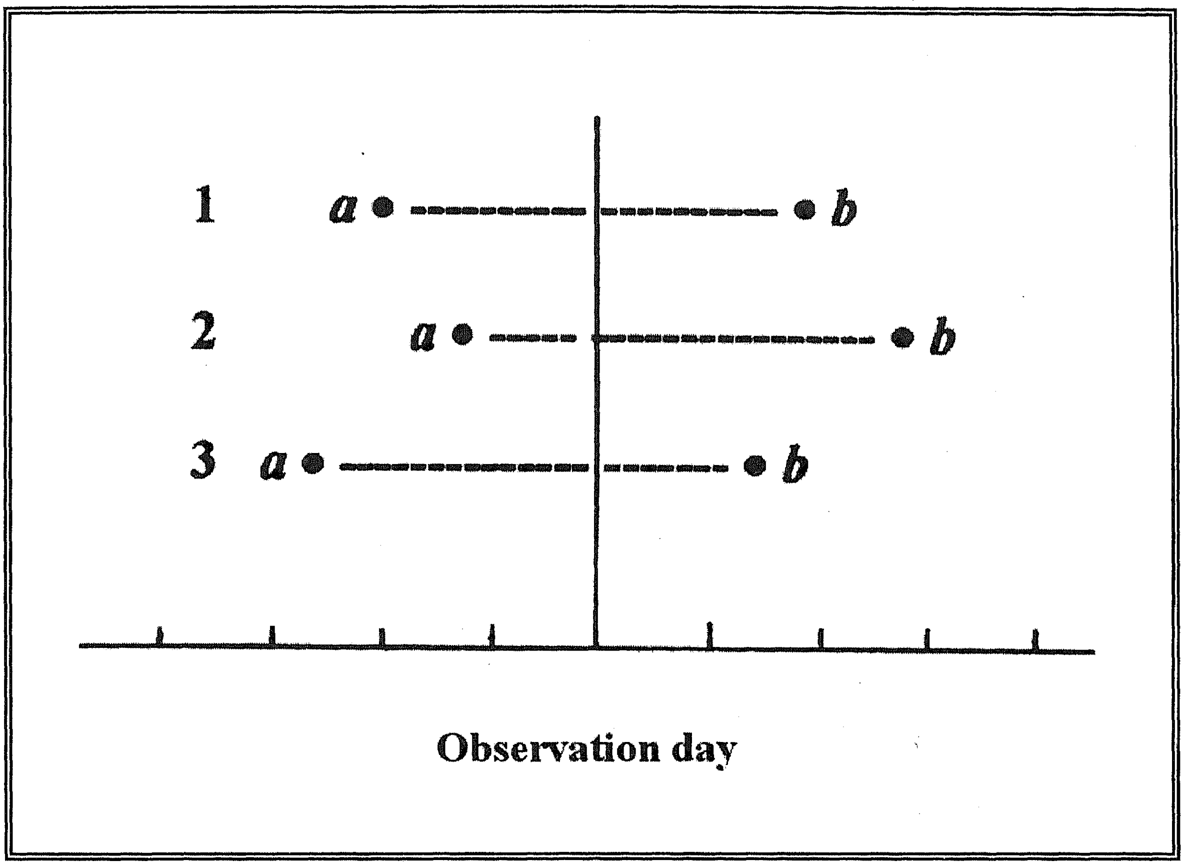


Figure 1.2.1. Hypothetical observations conducted by three observers during one day (V. A. Batmanov, 1971)

in size. The results of these observations are given in **Table 1.2.1**. If we predetermine different **PB,** the number of trees with leaf coloration will be different. So, if **PB** < 25% only 11 trees on the sample plot were considered as to have changed their leaf coloration. But if **PB** >25%, 42 trees were considered as coming into phase (20 + 17 + 5 = 42), etc.

Table 1.2.1

The results of observations on leaf coloration of *Acer turcomanicum*, 2 November 1977 (N. G. Kharin et al., 1981)

PB (percentage of leaf coloration)	Number of trees crossed over the **PB**		
	Sample plot 1	*Sample plot 2*	*Sample plot 3*
< 25	11	8	5
25 – 50	20	9	11
50 – 75	17	18	28
75 – 100	5	20	30
Total	53	55	74

PP and **PB** should be identified together. An example is given in **Table 1.2.2** when both criteria were estimated for one tree species by conducting phenological observations in the Firyuza experimental area, Turkmenistan in 1977. One tree was identified as an **OU**.

Table 1.2.2

PB and **PP** of *Cercis griffithi* (N. G. Kharin et al., 1981)

Phenological phases	**PB**
Vegetative	
Swelling the buds	Increase of bud size by 25%
Opening leaf buds	Appearance of the leaf tip
Leafing	First fully formed green leaf
Leaf coloration	Change of leaf color on 50% of leaves
Leaf fall	50% leaf fall of a single tree
Generative	
Swelling flower buds	Increase of flower buds in size by 25%
Flowering	Appearance of the first fully opened flower
Formation of ovary	Appearance of the first fully formed green fruit
Fruit ripening	Uniform brown color of the whole pod

Phenological frequency distribution graphs show the distribution of those **OU**s which have crossed over a **PB.** Normal distribution is most often used as a model by processing phenological information. This type of statistical distribution is not a universal law in nature (G. I.Yule and M. G. Kendall, 1950), but the Gaussian graph characterizes as a rule, a normal phenological process especially if we study a great number of **OU**s (V.A. Batmanov, 1961, N. G. Kharin, 1976). If a process was disturbed by environmental factors, the phenological frequency graph can have an abnormal form, as shown in **Figure 1.2.2.**

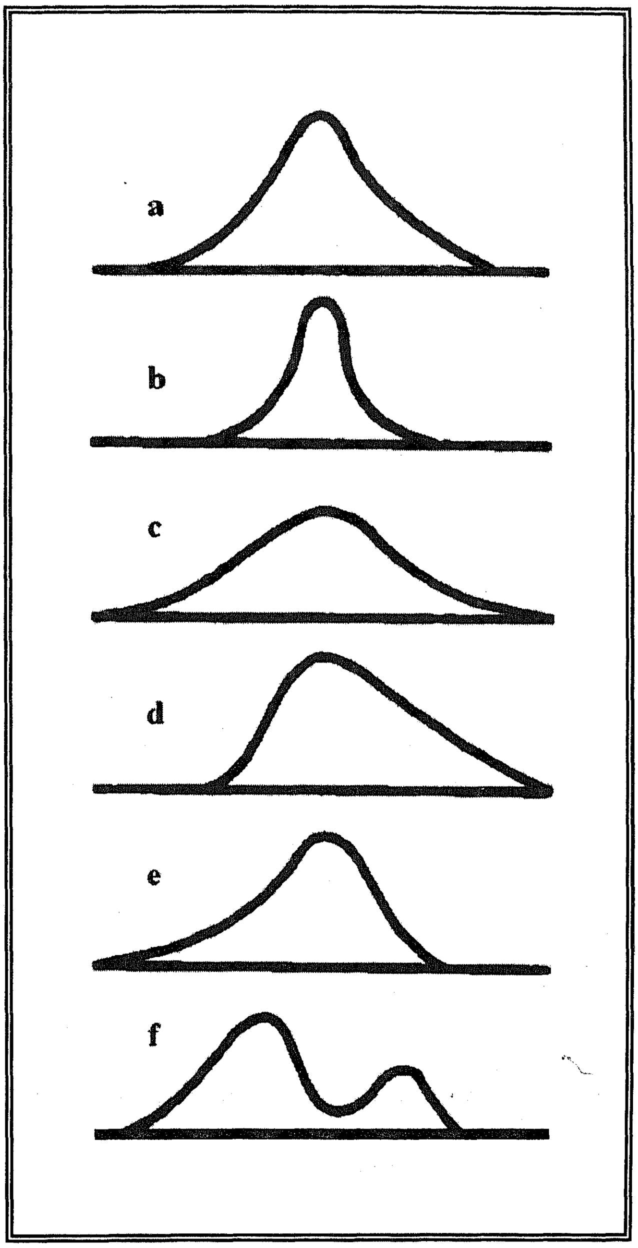


Figure 1.2.2. The most common forms of phenological frequency graphs : a–normal process, b–accelerated process, c–low process, d– process accelerated in the beginning of the phase, e–process accelerated in the end of phase, f–reversed phenological process (N. G. Kharin et al., 1993).

Phenoanomaly represents the fluctuation of annual phenological dates from a mean annual or from other relative situation.

Ecoanomaly is the difference between the timing of a phenological phase in a given ecological site and a relative "zero point".

Phenological model is a model of phenological phase dynamics, given in tabular or graphical form. A phenological model is calculated on the basis of long term phenological observations.

The first empirical graph is the ogive (cumulative frequency distribution graph) from many years of phenological observations. It is calculated by intervals of 5 – 10%.

The second empirical graph is the ogive of one year's observations. It is calculated for one phenological phase. An example of this graph is given in **Figure 1.2.3**. Observations were conducted on the flowering phase of *Colutes buhsei* in the Central Kopetdag Mountains, Turkmenistan in 1977 (N. G. Kharin et al., 1981). The main elements of this graph are shown. Median is the index of mass timing **OUs** into a phase. In case of normal distribution, the median and the mean have the same values. But the median can be estimated graphically, which makes it more useful in phenological investigations. Median can be calculated in the field without computer.

Phenological map is a map in which *isophenes* show the differences in the timing of the phenological events on the territory to be mapped.

Minimal area is a minimal mapping unit which shows the differences in timing of the phenological events between the parts of the territory to be mapped.

Phenological interval refers to the number of days between two isophens in a phenological map.

Map of ecoanomalies is a map in which isolines show the differences in the timing of the ecological events with respect to a base model of many years duration, or from any other relative "zero point".

Phenological variability refers to variations in the timing of the phenological events, between the individuals of a plant population or between communities, under the influence of biological or ecological factors. The main types of phenological variability are shown in **Figure 1.2.4** (M.K. Kupriyanova, 1974).

Phenological gradient is a coefficient which shows the variation of the timing of phenological events according to latitude, longitude and elevation above sea level. N. G. Kharin (1966) calculated phenological gradients of the beginning of growth of Saxaul *(Haloxylon persicum)* in the deserts of Central Asia (**Table 1.2.3**).

Table 1.2.3 demonstrates the influence of environmental factors on the growth of Saxaul. By the movement from south to north, this phenological phase is observed to occur 2.0 – 3.0 days later per degree of the latitude. By increase of the altitude per 100 meters, the phase is also observed to occur 2.0 – 2.4 days later. The influence of the longitude can be negative or positive (– 0.4 or + 0.4 day).

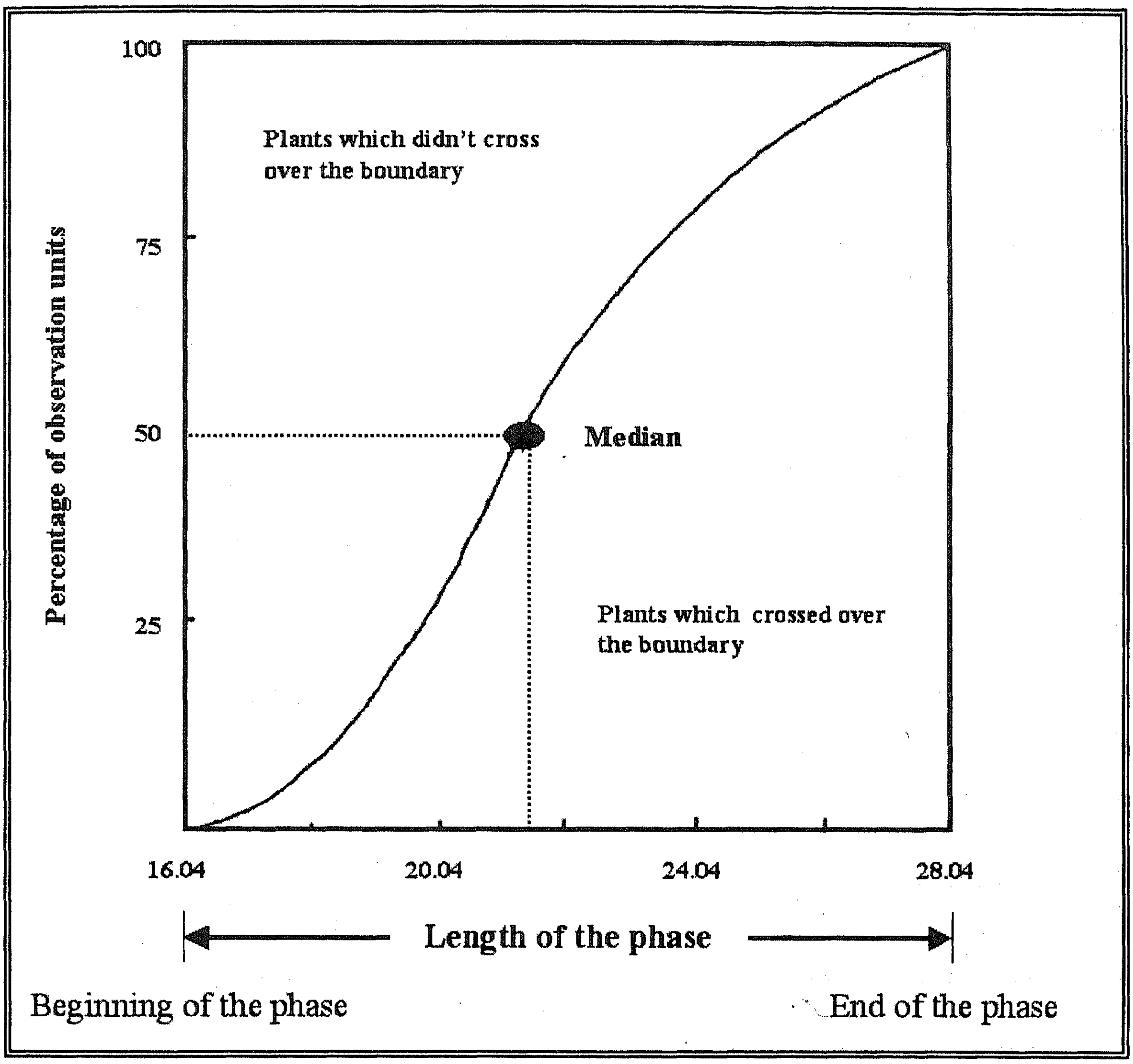


Figure 1.2.3. The second empirical graph of flowering *Colutes buhsei* in Central Kopetdag, Turkmenistan (N. G. Kharin et al., 1981).

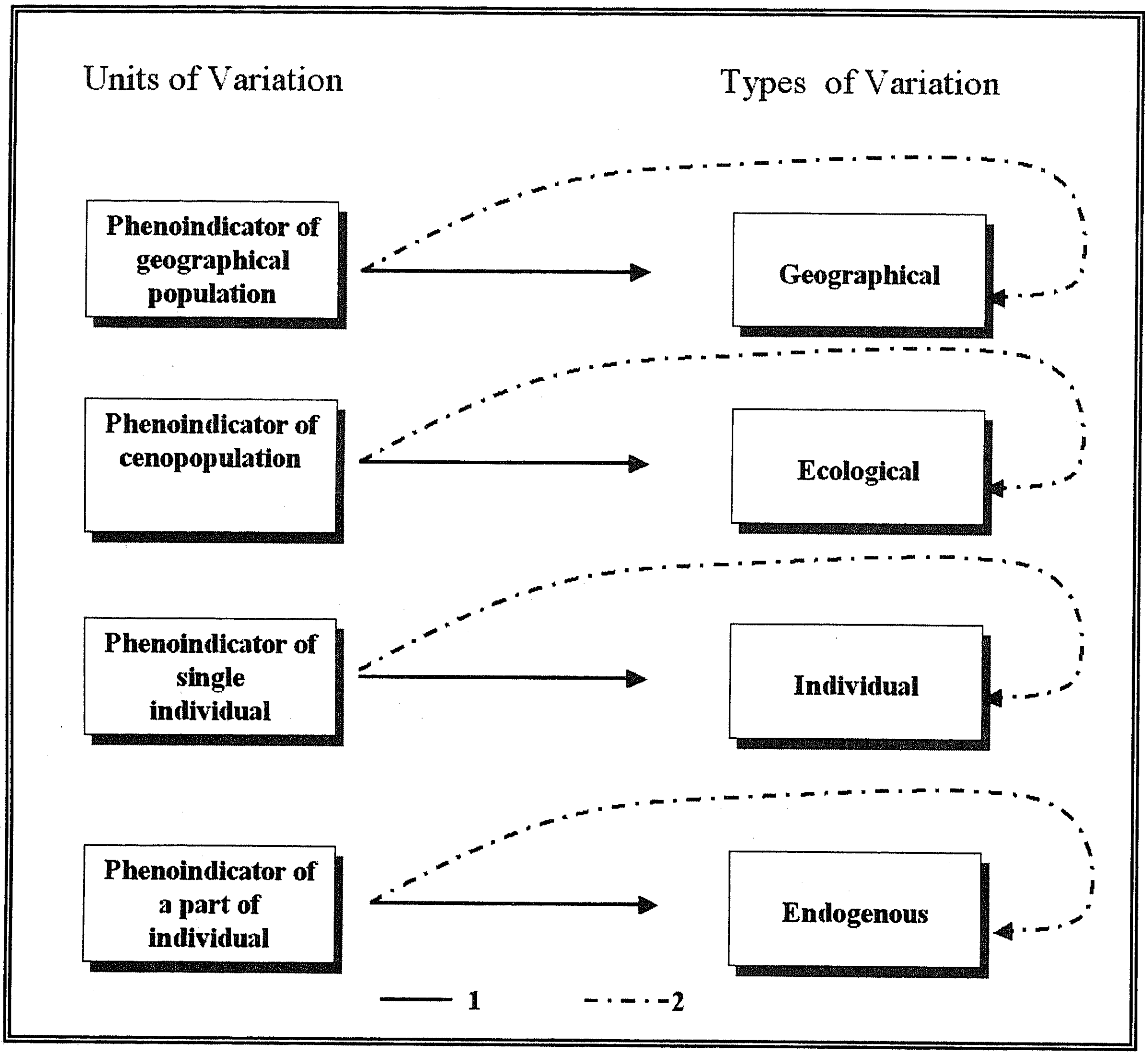


Figure 1.2.4. The types of inner phenological variability of plants. 1– variation of phenological indicators during the same time, 2– variation of phenological indicators in the same space (M. K. Kupriyanova, 1974)

Table 1.2.3
Phenological gradients of the beginning of growth of *Haloxylon persicum* in the deserts of Central Asia (N. G. Kharin, 1966)

Regions	Latitudinal, number of days per 1°	Longitudinal, number of days per 1°	Elevational, number of days per 100 m
Muyunkum	+ 2.5	+ 0.4	+ 2.4
Balkhash Lake Region	+ 2.0	+ 0.4	+ 2.4
Southeast Karakum	+ 3.0	- 0.4	+ 2.0
Kyzylkum	+ 2.5	+ 0.4	+ 2.0

1.3. Classification of the methods of phenological observations

Classification of the main methods of phenological observation is given in **Table 1.3.1**. All methods are divided into four groups, and each group is divided into two classes : ***primary*** and ***integral***. Primary methods are traditional ocular methods of phenological observations, while integral methods have been developed through the application of mathematical phenology. The role of elementary phenological observations is indicated in **Figure 1.3.1** (V.A. Batmanov, 1970).

Table 1.3.1
Classification of the methods of phenological observations (V. A. Batmanov, 1967)

Group of methods	Elements to be registered	Classes of methods: Primary	Classes of methods: Integral
1. Registration of dates	Elements of time	Primary method of registration of dates	Integral method of registration of dates (Integral second)
2. Descriptive	Phenological status in a given time	Primary descriptive method	Integral descriptive method (Integral first)
3. Indicator of productivity	Material indices of phenological status	Primary indicative method	Integral indicative method (Integral third)
4. Ecometric	Elements of locality	Primary ecometric method	Integral ecometric method

Method of registration of dates

In this method, the elements of locality and **PP** are predetermined and an observer registers the elements of time. This method of phenological observation (as primary method of date registration) is widely used in plant ecology.

As a rule, the element of time is estimated on the level of "one day" (24 hours). If an observer wants to study the quantitative changes of phenological events within one day (for example, the opening of the flower buds of some plants) he must register the hours.

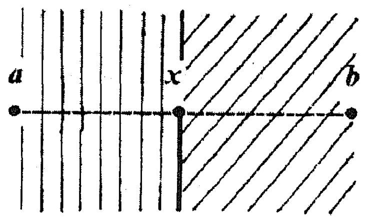
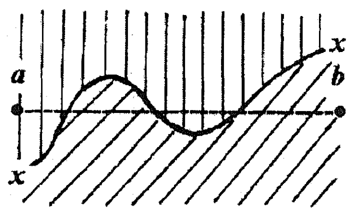
GROUP OF METHODS	ELEMENTARY OBSERVATION	INTERRELATION BETWEEN *x, a, b*
1. Registration of date	*a* *x* *b* 14.05 20.05	*a* < *b*
2. Descriptive	*a* *x* *b* *Boundary one* *Boundary two*	*a* < *b*
3. Indicator of productivity	*a* *x* *b* *10 kg* *20 kg*	*a* < *b*
4. Ecometric	 *Boundary between zones a and b*	 *Location of the x line on the terrain*

Figure 1.3.1. The role and place of an elementary phenological observation in studying the seasonal changes in nature (V.A. Batmanov, 1970).

The methods of this group have two positive features which make it easier in conducting phenological observations :

1) *Standard units of time* (days or hours) are used by registration of phenological phases. By further processing, any recalculation of time or application of models are not necessary, because the observation itself gives the final result.
2) An observer can predetermine a proper *phenological status*, selecting the most striking seasonal events.

Two dates should be registered by this method : ***a*** - the date when a phenological event has not arrived; and ***b*** - the date of its arrival. The most probable date of timing a phenological phase is between these two dates. If only the date of ***b*** is registered, the accuracy of observations is unknown. Obviously, the passage of time is an irreversible process. As to phenological events, most of them are likewise irreversible. But seasonal events in the inorganic word can be reversible, for example, snow can fall, then melt during a thaw and fall again. In this case, several ***x*** can be registered between points ***a*** and ***b***.

By conducting phenological observations, it must be understood that each method has specific errors by predetermination of three elements : time, locality and phenological phase. Each of these elements may not be precise during the observation. But the method under consideration has a specific error. This error depends upon the interval between ***a*** and ***b***. If this interval is increased the error is also increased.

Integral second method can be recommended for phenological observations of higher accuracy. By calculation of mean dates, the results can be given in portions of days, for example, 12.6 May. The results of observations conducted by the integral second method differ from that conducted by the integral first method. In the first case, they are expressed in units of time and their processing is simple. In the second case, we need a phenological model (see below).

But the integral second method has its shortcomings. It can not be used to study the dynamics of phenological processes. Only the integral first method can be used for such a study. Neither can it be used when mass timing phenological events is observed in all **OU**s, or in cases when the number of them is small.

The main point of the integral second method consists of estimating for each of ***n*** **OU**s the dates ***a*** and ***b***. For example: on May 25 an observer registered on a sample plot 23% of **OU**s which had crossed over the **PB**, and by repeated observations on May 29 he registered 49%. It could be concluded that 26% (49 – 23) crossed over the **PB** between 25 and 29 May. For all **OU**s, the dates ***a*** and ***b*** were the dates of observations and point ***x*** was in the interval between observation days.

Application of the integral second method to study leaf fall

Quantitative assessment of leaf fall phase is very difficult. If the trees are high it is practically impossible to climb them and to count the leaves. Only when trees or shrubs are of low height can direct counting be possible. The current methodology relates to the first case. This methodology is based on counting leaves that have fallen on the ground.

The case study was conducted in the Firyuza National Park, located in the Kopetdag Mountains, Turkmenistan (N. G. Kharin et al., 1981). Series of sample plots, 1 m^2 in size were located in forest stands where 13 tree species were registered. The plots were located in such a way that all tree species were represented, the plots being distributed in dense patches as well as between them. Reliable results can be obtained if the number of sample plots is 15 – 20. In special cases (for example, in plant selection) the number of plots can be greater, but an observer should take into consideration the labor-intensive character of this work. Before the first tallying, all plots were cleaned from leaves. Periodically, with an interval of 5 days the leaves on each sample plots were counted, then each plot was cleaned from leaves. In several cases, the leaves of one tree species was registered on two or three plots. The form of leaves registration is given in **Table 1.3.2.** Observations were conducted during 21 September – 30 November 1977. The number of leaves of one tree species varied from 185 to 16,000.

Further processing included recalculation of the number of leaves to and their percentages for all species of the stand. A theoretical distribution graph was also calculated for all species of the stand (**Figure 1.3.2**). It can be seen that in 1977, mass leaf fall passed ahead the theoretical median by 12.6 days ($M1$ - $M2$). According to the previous investigations (A. V. Batmanov, 1961, N. G. Kharin, 1975), long term phenological processes can be characterized by the normal Gaussian curve. So it may be concluded that leaf fall in 1977 in the study area occurred 12.6 days earlier to be compared with the mean long term process.

Table 1.3.2

The form of registration of fallen leaves in Firyuza on sample plots in 1977 (Kharin et al., 1981)

Tree species	Plots	September		October						etc.
		21	26	1	6	11	16	21	26	
Acer turcomanica	8	12	14	8	7	6	18	31	32	
Ailant altissima	7	none	none	2	8	21	31	25	11	
Platanus orientalis	10	5	6	7	9	10	9	8	7	
Populus nigra	9	none	4	6	7	10	11	9	10	
etc.										

Descriptive method

The method of date registration described above gives information in calendar scale (i.e. in days), but the *descriptive method* estimates phenological information in units of **AT** (i.e. in percentages). In the descriptive method, the following ranks of phenological status are studied : the **PP** (an interval of seasonal development), the **PB** (a point of development) and the portion of the **PB.** By the descriptive method, an observer should identify a phenological status and estimate the differences between two status. It is difficult task because several phenological processes can occur simultaneously in the same object of observations. Direct process is that in which each next event occurs later than previous (e.g., flower bud – flower – fruit). The accuracy of observations increases if an observer will use quantitative (integral) method. for estimation of the portion of **PB** – the percentage (for example, 45% of apple trees begin blossoming). So, the percentage is a unit of measure of **AT**.

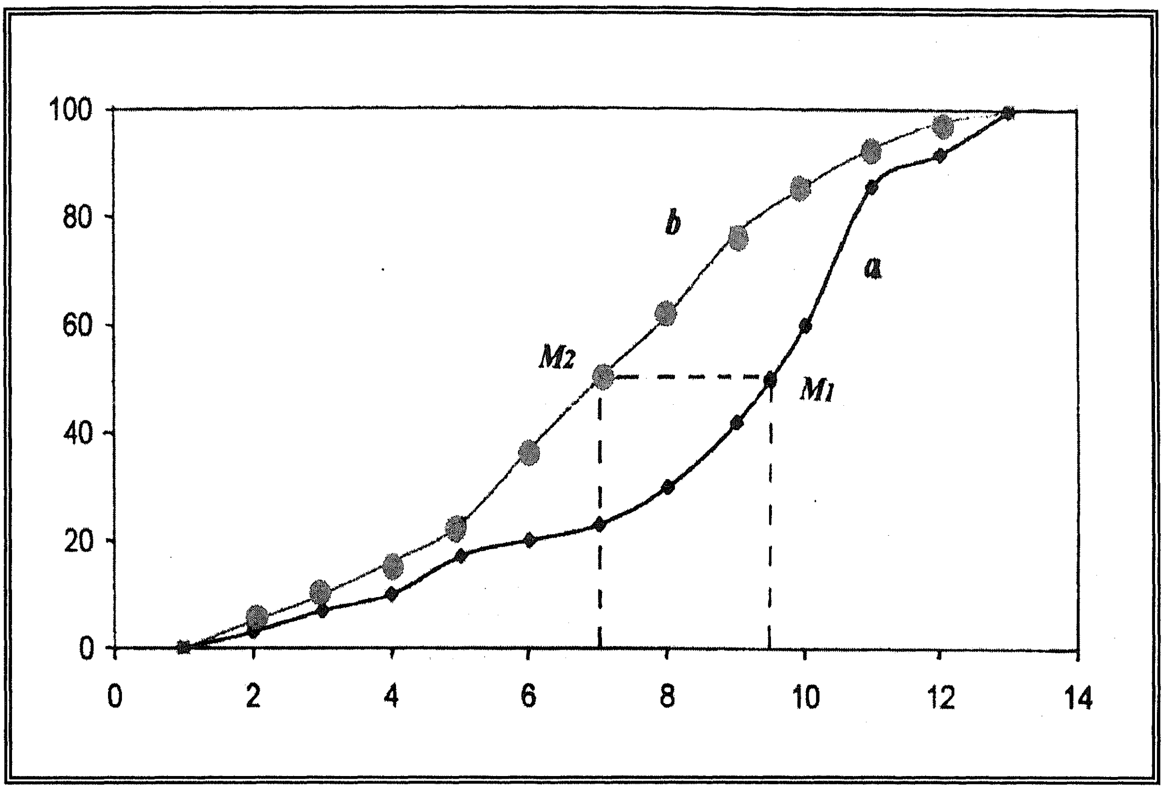


Figure 1.3.2. The second empirical graph of leaf fall for 13 tree species in Firyuza experimental area, Turkmenistan, in percentage values and days : *a* – the empirical graph of phenological observations conducted on sample plots, *b* – a theoretical graph, calculated as a Gaussian graph of normal distribution, *M1* – the empirical median, *M2* – the median of the theoretical frequency distribution graph (N. G. Kharin et al., 1981)

But this approach has its difficulties. An observer must conduct several measurements (observations) in sequence. We may say that, if ***a*** was registered earlier than ***b*** and was registered earlier than ***c*** , hence we may suppose that ***a*** arrived earlier than ***c***. But it cannot be surmised which interval is greater , – ***ab*** or ***bc***.

The most significant shortcoming of the descriptive integral method is the unit of observations. The formal unit of the integral method is changed by recalculation to the calendar time. This shortcoming can be removed by developing a scale for transition from **AT** to calendar time. By preparation of phenological models, the unit of **AT** are units of measurements. But these units are equal to the calendar time only if two processes which are compared develop under the same conditions. Under different conditions, model days and calendar days can be different. So, considering a model and several phenological observations, these observations can be compared via this model. For example, a one year model can be compared with phenological processes within one year.

Indicator of productivity

The term "*productivity*" is used here in the wide meaning of the world, characterizing the material indices of phenological processes. This method includes all types of assessment of material indices of objects to be studied. An observer should answer the question: "*What are the material index of the object in the predetermined place at the predetermined time*?" The method includes estimation of indices that are *continuous* in their development (i.e. height, weight, volume), or *discrete indices* (i.e. the number of fruits, quality of yield, etc.).

In studying material indices, it must be understand that a variety of factors can define the final result of seasonal development (e.g. the yield of agricultural crops). If a great number of independent factors defines the material indices of the object, it can be surmised that their action can be different. Some of them can stimulate the accumulation of yield, while others can hinder this process.

The unity of material indices is observed to be rarer than the unity of temporal indices. But, as has been shown in previous studies, the unity of temporal indices is the basis of indicative phenology. Registration of material indices should always be conducted together with analysis of several environmental factors and human interference, for example, application of chemicals in agriculture.

An example on Central Asia is given below. Agrometeorologists of this region studied the correlation between productivity of forage plants on desert rangeland and meteorological data. In **Table 1.3.3**, correlation is given between productivity of rangeland and precipitation in Uzbekistan (P. A. An, N. S. Konovalova, 1981). This correlation was used for forecasting the productivity of desert rangeland.

Application of integral method can improve the final results of observation because an observer can take several of *OU*s. But the integral third method is developed in less extent than other methods of phenological observations because the material indices are often beyond the interests of phenologists.

Table 1.3.3
Correlation between precipitations and productivity of rangeland in Uzbekistan
(P. A. An, N. S. Konovalova, 1980)

Stations	**Equations**	***R***	***S***
Akbaital	$y = 0.019\,z + 1.2$	0.81	3.5
Buzaubai	$y = 0.026\,z + 0.92$	0.94	1.9
Mashikuduk	$y = 0.029\,z + 1.48$	0.79	4.8
Kulkuduk	$y = 0.035\,z + 0.15$	0.67	4.5
Dzhangel'dy	$y = 0.15\,z + 0.15$	0.67	4.5
Mubarek	$y = \dot{0}013\,z + 1.87$	0.76	3.4
Zhaslyk	$y = 0.030\,z + 1.50$	0.86	2.4

Note : y – annual forage, MC per hectare (MC – Metric Centner, 100 kg),
z - the sum of precipitations, (mm), registered 30 days before and 30 days after the air temperature crossed the zero threshold,
R - correlation coefficient
S - mean annual forage, MC per hectare

Ecometric method

The purpose of this method is the division of the territory into different zones which are characterized by differences in phenological status. An observer should find those elements of locality (points x) which have predetermined elements of time and phenological status. All methods of phenological mapping are at the bottom of the ecometric methods.

By application of the ecometric method the results of observations in n points are different from that received by other methods mentioned above. By application of other methods, the results of observations included mean values (mean date, mean percent, mean productivity) or the indices of productivity. Mathematical probability of central points x is simple depending upon a question, put before the observations. By application of the ecometric method only location of points x in three-dimensional space can give the final result. The other specific features of this method are the following:

- During the same time, changes in the situation between two elements of locality can occur in three directions because the space is three-dimensional. So this fact should be taken into consideration by development of the methodology;
- Phenological survey can be conducted by indices of time or by material indices. For example, a map can be compiled timing the yield or a map showing the amount of yield. In both cases, the maps give the space distribution of these indices;
- The ecometric method can be named in a certain way as "the secondary method" because it is based on criteria of other methods. For example, the accuracy of phenological maps depend upon the accuracy of base maps. An observer should always adapt phenological survey to the scale and other characteristics of topographic maps. In the process of phenological observations, it is impossible to change these parameters;
- By the ecometric integral method an observer should also describe by quantitative indices, the environmental situation (e.g. the coordinates of observation points), because the final phenological map contains not only specific (phenological) information, but also general cartographic information. So, the availability of topographic maps is a pre-condition of application of this method.

By application of thematic maps for phenological survey, the mapping units of thematic maps (e.g. plant associations) can be taken as minimal areas. In this case, the isophenes in the phenological map should coincide with the contents of thematic maps. Aerial and space photos can also be used in phenological mapping. In specific cases, the status of plant communities can be assessed directly by photographic imagery (N. G. Kharin, 1980, N. G. Kharin et al., 1993).

By application of the ecometric method **synchronized timing** should be taken into consideration. As had been shown, changes in phenological status can be three-dimensional or temporal. The ecometric method is used to study three-dimensional changes. The influence of temporal factors should be excluded from assessment. This can be achieved by conducting phenological survey during a synchronous time, for example during one day. In this case one day is the synchronous time of phenological survey. But the situation is changed if we compile a phenological map consisting of 10 years phenological observations, in numerous points. The mean annual dates registered in each point are not the results of simultaneous observations, but they have one common period of observations – 10 years. So, in this case 10 year observation period is a synchronous time. In compiling phenological maps, the same synchronous time should be observed.

1.4. Large scale phenological mapping

Classification of phenological maps

Published phenological maps can be divided into two groups : maps compiled on the basis of ocular phenological observations and maps based on application of statistical methods. As was mentioned earlier, ocular estimation of phenological phases does not give the objective results because observers can have different ideas about the same seasonal events. Classification of phenological maps is given in **Table 1.4.1** (N. G. Kharin, 1977).

Visual phenological survey

Visual phenological observations is a method which is widely used for studying seasonal rhythms of plants. This "classical" or traditional method is based on the visual registration of phenological phases of plants, and is the most simple method of phenological mapping. It can be conducted by practical training of students, by school children under the guidance of teacher, in tourist excursions and in several other cases when people want to study local phenological phenomena. An instructor must have a large scale topographic map.

Survey line (or survey lines) should cross the main elements of topography or other environmental features. They can also be confined to roads (that will help to avoid additional difficulties in implementation of survey). The most striking phenological events should be selected for mapping, for example plant flowering. A predetermined phenological phase can be described by qualitative or quantitative criteria. The first can include the alternative PB (for example, plants are flowering or not flowering) or the quantitative PB (for example, 50% of plants have flowers).

The main task of survey is the estimation of boundaries between zones ***A*** and ***B***. If these zones have clear differences in phenological status and the transition strip is narrow, one

Table 1.4.1

Classification of phenological maps (N. G. Kharin, 1977, modified)

Types of maps	**The main characteristics of phenological maps**			
	Minimal mapping Unit	**Scale**	**Interval between the isophenes**	**Scale of the topographic base map**
Macrophenological	1° latitude per 1° longitude	1 : 1,000,000 and smaller	10 days	1 : 1,000,000 – 1 : 2,500,000
Regional	30′ latitude per 30′ longitude	1 : 500,000 – 1 : 250,000	5 – 10 days	1 : 1,000,000 – 1 : 500,000
Large scale	Plant associations or other terrestrial units	1 : 100,000 – 1 : 25,000	3 – 5 days	1 :100,000 – 1 : 25,000
Microphenological	Plant associations or landscape units	1 : 10,000 and larger	2 –3 days	Large scale topographic maps or aerial photos

can draw the line x by visual estimation. Using the pairs of points a and b, one can estimate the probable location of the line x in the middle of the strip ab.

It is very important to produce a phenological map in the field and enhance the map using color pencils. This can illustrate in the best way, the idea of phenological mapping.

Visual phenological observations conducted without application of statistical methods, have a low accuracy. First of all, a proper selection of an object of phenological observations should be done. The object of survey should include some "middle" ecological sites which are characteristic of the area under consideration. In this case, the phenological variability will less likely influence the results of observations, and, on the contrary, if an observer wants to study the correlation between seasonal development of vegetation and ecological conditions, he should select observation plots in "middle" and extreme ecological sites.

V. A. Batmanov (1967) indicated the following consideration about the selection of objects for phenological observations:

1. The greater is the rate of a seasonal process, the better is the accuracy of observations;
2. Observations on common plants are more accurate than observations on grasses;
3. Observations on common plants are more accurate than observations on rare species;
4. Observations on well known plant species are more accurate than observations on species identified with difficulties;
5. The quality of observations is better by study of phenological phases which can be identified by an observer of middle-level educational attainment.

The problem with the accuracy of ocular phenological observations is very important. According to special investigations conducted by A. A. Kiril'tseva (1975), the final accuracy of phenological observations is characterized by a standard deviation ± 3.46 days. This error includes the following components : frequency of observations, error of proper selection of the object of observations, and error of the proper registration of phenological phase.

Large scale phenological mapping on the basis of aerial photos

The experiment on compilation of large scale phenological map was conducted in 1973 in the territory of Badkhyz Reserve, Turkmenistan. Aerial photos, scale 1 : 25,000 were used for compilation of the type maps of Pistachio woodland *(Pistacia vera)* and for compilation of the leafing out phenolological map. Pistachio woodland had low crown density (20 %– 30%), the age of trees was between 80 – 100 years, while the tree height reached 1.5 – 3.0 m (N. G. Kharin, 1975).

First of all, the map of forest types of Pistachio tree stands was compiled (**Figure 1.4.1**). Six main stand types were identified :

1. Pistachio stands confined to narrow ravines;
2. Pistachio stands on steep slopes with sandstone talus;
3. Pistachio stands on steep north west slopes;
4. Pistachio stands on gentle southern slopes;
5. Pistachio stands on east slopes;
6. Pistachio stands on upper sites of foothills.

The methodology of field survey included the following works. Two ogives (the second empirical graph) were calculated for different Pistachio stands (**Figure 1.4.2**). They characterized the specific conditions of leafing out Pistachio tree in different ecological sites. Phenological survey included the counting of the number of Pistachio leaves that crossed over the boudary. It should be mentioned here that Pistachio is a *dioecious* plant. This means that male and female trees grow separately. Special investigation showed that differences in leafing out pistachio trees between male and female trees were statistically not significant. So, counting this characteristic of trees was not taken into consideration. The results of field surveys are given in **Table 1.4.2.**

Table 1.4.1 needs the following explanation :

- In column 1 the number of stands (**Figure 1.4.1**) is indicated;
- In column 3 the number of standard cumulative graph (**Figure 1.4.2**) is indicated;
- In column 3, 4 and 5 the results of field survey are given (the total number of counted trees, the number of trees having crossed over the boundary and their percentages);
- In the next column (refer to stand 2a) the sum $m + x$ indicates the number of days between 47% of trees and 50% of trees which have crossed over the boundary (refer to the cumulative graph in **Figure 1.4.2**); this interval is 0.3 day;
- The last column contains the calculation of a hypothetical date of Pistachio tree leafing out. For stand 2a, in the formula:

Figure 1.4.1. The map of Pistachio woodland types, compile by aerial photo, scale 1 : 25,000, Badkhyz experimental area, Turkmenistan. The legend : 1– Pistachio stands confined to narrow ravines, 2 – Pistachio stands on steep slopes with sandstone talus, 3 – Pistachio stands on steep north west slopes, 4 – Pistachio stands on gentle southern slopes, 5 – Pistachio stands on east slopes, 6 – Pistachio stands on upper sites of foothills (N. G. Kharin, 1975).

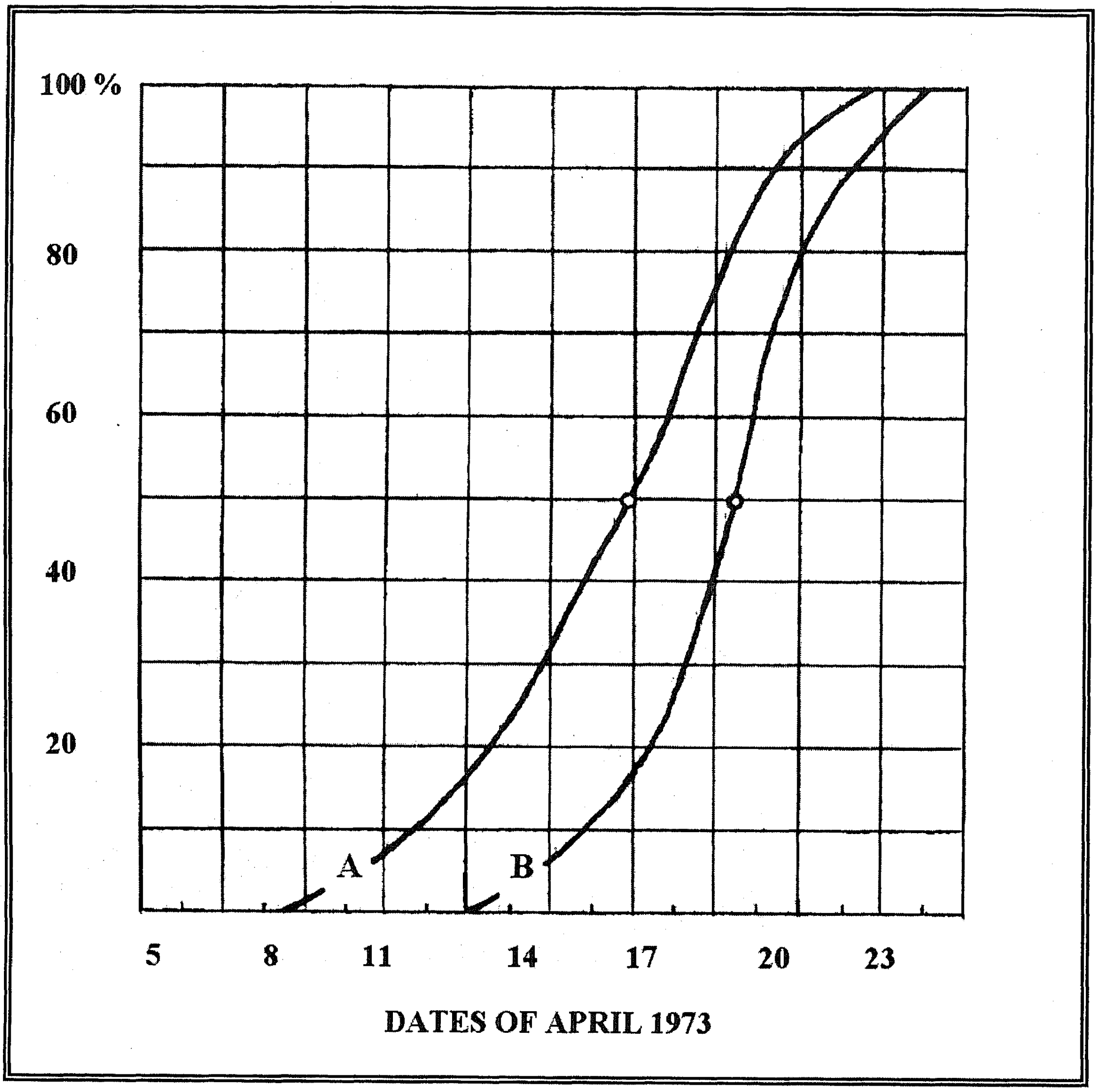


Figure 1.4.2. The second empirical graphs of leafing out Pistachio trees on the experimental area of Badkhyz, Turkmenistan. A – for Pistachio types 2,4, B – for Pistachio types 1,3,5,6 (N. G. Kharin, 1975).

15 + 0. 3 = 15.3.04

- the first component (value15) means the mean date of leafing out Pistachio trees according to the standard cumulative graph; value 0.3 means the number of days between this date (15.0 April) and the date of field survey calculated by the standard cumulative graph; and the final component 15.3.04 is the supposed date of leafing out of Pistachio trees in stand 2a, 15.3 April.

Table 1.4.2
The results of field phenological survey (leafing out pistachio trees) in 1973
(N. G. Kharin, 1975)

Stands	Ogive	Date of survey (day, month)	Number of counting trees		% of trees crossed over boundary	*m* +*x*	Calculated date
			Total	Crossed over boundary			
2a	1	15.04	30	14	47	+0.3	15 + 0,3 = 15.3.04
2b	1	15.04	29	9	30	+2.0	15 + 2.0 = 17.0.04
3a	2	20.04	31	23	74	+1.0	20 + 1.0 = 21.0.04
3b	2	20.04	26	20	80	+1.6	20 + 1.6 = 21.6.04
4a	1	20.04	27	22	81	-2.6	20 – 2.6 = 17.4.04
4b	1	20.04	36	23	64	-1.2	20 – 1.2 = 18.8.04
4c	1	20.04	38	21	55	-0.5	20 – 0.5 = 19.5.04
5b	2	20.04	35	27	77	+1.3	20 + 1.3 = 21.3.04
6a	2	20.04	37	31	84	+1.9	20 + 1.9 = 21.9.04
6b	2	20.04	32	27	84	+1.9	20 + 1.9 = 21.9.04

As a result of implementation of this survey, a large scale phenological map was compiled (**Figure 1.4.3**). As can be seen, 3 days interval was selected between the isophenes for this area. The isophenes coincide with the boundaries of the typological map of Pistachio stands. In several cases, the isophenes were corrected in the field on the basis of aerial photos.

1.5. Compilation of macrophenological maps

Phenological mapping is one of the most difficult tasks in agriculture and forestry because many factors should be taken into consideration by drawing isophenes (i.e. small number

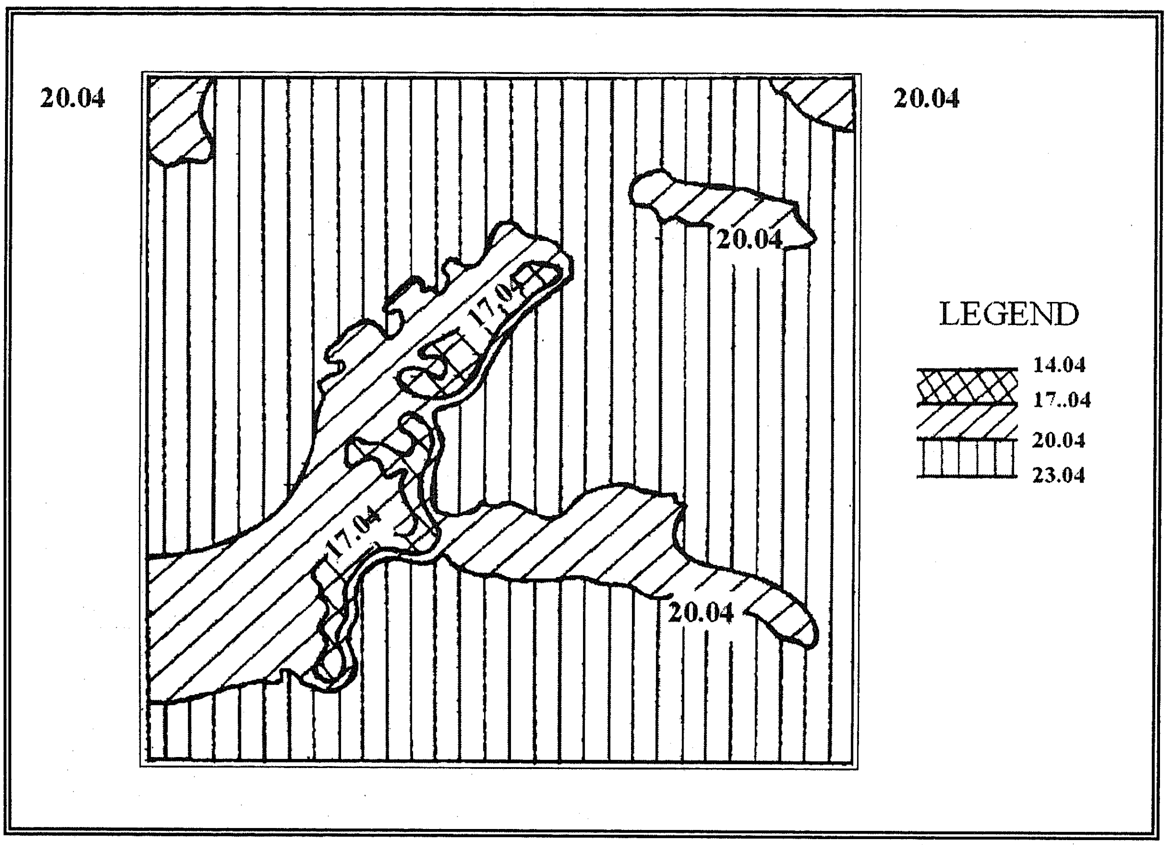


Figure 1.4.3. A fragment of the phenological map of Pistachio trees in Badkhyz experimental area, scale 1 : 25,000 (N.G. Kharin, 1971).

of observation points, annual fluctuations in timing of seasonal events, absence of quantitative phenological criteria etc.). The following principal methods of compilation of small scale phenological maps are shown:

Ocular phenological mapping. The method includes ocular drawing of isophenes on a small scale base map (topographic map or any kind of thematic map). This is the simplest method of phenological analysis without the need for statistical processing of the initial observations. Several phenological maps compiled using this method were published in "*The Atlas of the USSR Forests*" (1973). These maps included : blossoming of oak, ripening of oak fruits (*Quercus sp*), pollination of alder (*Alnus sp.)*, pollination of hazelnut (*Corillus avelana*), to name a few.

Modelling of phenological events. Many scientists have published several models for calculating hypothetical dates. One of these models had been published by A. D. Hopkins (1938). This model is given in **Figure 2.5.1**. The map contains *isophenological parallels* 30°, 40°, 50°, 60° and 70°. These parallels do not coincide with topographic parallels; and the map can not be used for practical purposes.

The second example concerns a global model of seasonal development of vegetation developed by B. E. Datier et al. (1975). The authors of this project have prepared the following phenological maps covering the whole territory of the world :

1. The map of timing "green wave" which includes the beginning of growth of all vegetation types (from agricultural crops to forests);

2. The map of timing " brown wave" (the end of vegetation growth, leaf coloration and ripening of all types of corn).

Method of macrophenological mapping. The method was proposed by V.A. Batmanov (1961) and further developed by N. G. Kharin (1966) who published several phenological maps of birch. These maps were based on numerous observation points *in situ,* conducted by many authors within the territory to be mapped. Methodology included the following steps:

1. Preliminary analysis of collected information
2. Reduction of all dates to one period of observation years
3. Division of the territory into physical regions
4. Calculation of phenological gradients (latitudinal, longitudinal, altitudinal)
5. Drawing isophenes by topographic map.

Analysis of these maps is done in **Section 2.5** of the monograph.. It can be seen that isolines of the green wave do not coincide with the isophenes of birch. The greatest differences are confined to the mountain regions of Siberia and the Far East. The isolines of the green wave cut the topographic features (counter lines), which contradicts the existing regularities in timing of seasonal events in mountain regions.

Phenological mapping by direct assessment of photographic image produced by remote sensors. All the methods mentioned above are based on single observation points which cover the territory to be mapped in different way. This is a common shortcoming of these methods. Direct assessment of a photographic image, however, strong correlation with phenological status of plant communities can be established. This methodology is discussed in **Chapter 2** of the monograph.

Chapter 2

APPLICATION OF NOAA/AVHRR DATA FOR ASSESSMENT OF SEASONAL ASPECTS OF FORESTS

2.1. Study of seasonal aspects of forests *in situ*

What is a seasonal aspect?

According to the definition given by I. A. Dudka (1984), *"Aspect is a general view of plant community which is changed during the seasons of the year according to the alteration of the phenological phases of plants"*. The definition given by M. M. Kohtman (1974) is less clear: *"Aspect is visual impression of vegetation at a particular time or as seen from a specific point"*. The theory of seasonal aspects of plant communities was developed by Russian scientists (G. E. Shults, 1981 and I. N. Elagin, 1983). They believed that the change of seasonal aspect is a regular phenomenon, which reflects the process of development of plant communities, and their interrelations with environment. By this concept, a general view of plant community is not a subjective feeling, existing only in the human mind, but rather, it is a reality that indicates the status of plant community.

G. E. Shults (1981) distinguished two types of seasonal aspects : *general* and *specific*. He indicated several general aspects : *winter "snow up aspect", aspect of "black spring" after the snow melting, summer "green aspect", aspect of "golden autumn", etc.* In his opinion, specific aspects can be distinguished: flowering of plant communities, flowering of fruit gardens, ripening of cereals in the cultivated fields, ripening of cotton balls on plantations of cotton in the arid zone, aspect of reaped fields, among others. Specific seasonal aspects can be created by changes occurring in inorganic nature (e.g. spring floods, aspects created by dust storms, etc.).

I. N. Elagin (1983) described seasonal aspects of forests in several regions of Russia. The names of the aspects can be very simple, e.g., winter aspect, summer aspect, autumnal aspect, or the author gives long sophisticated names, like "monotonous dark green coloration of mixed coniferous – deciduous forests". But the most interesting thing in the theory of aspects is that aspects indicate several seasonal events which have occurred under the forest canopy or in the soil. These events can not be registered by remote sensors, but they can be predicted by the analysis of seasonal aspects distinguished by aerial or space imagery.

Inter-annual fluctuations as well as the timing of the periodic phenomena are well known. Russian proverb says: "*Weather of any two years is not identical*". These fluctuations "cause headache" to agro–meteorologists who try to forecast the yield of agricultural crops or pasture productivity for the next year. Inter–annual fluctuations of seasonal phenomena can be explained by cyclic variations of climate or by the influence of local phenomena. According to G. E. Shults (1981), at least 25 years of observations are necessary to study and explain these variations. But this information is mainly based on visual registrations of phenological phases of plants of low accuracy. As such, special analysis may be necessary to exclude methodological errors.

Identification and description of seasonal aspects

A standard methodology for description of seasonal aspects is absent. Even the names of aspects, as was shown above, can be different. So, we give some examples of description of seasonal aspects in forests of Russia.

Example 1. Seasonal aspects of forests in Moscow region.

A. Strizhov (1981) has identified the following seasonal aspects of forests in Moscow region:

- *Spring animation.* It begins by the appearance of the first thawed patches in the forest. Flowering of Alder (*Alnus sp.*) is the indicator of the end of this period. The following characteristic seasonal events are observed during this time: flowering of Colt's foot (*Tussilago farfara*), leafing out of Birch tree (*Betula sp.*), pollen formation of Elm tree (*Ulmus sp.*).

- *Spring at its height.* Mean annual length of this period is 22 days. Leafing out of Birch tree is an indicator of this season. Flowering of Service tree (*Sorbus sp.*) and flowering of Liliac (*Siringa sp.*) are the indicators of the end of this season. The following sums of the effective temperatures were registered for different periodic events :Σ 70° for leafing out of Birch tree, Σ 125° for flowering of Bird Cherry, Σ 184° for flowering Apple tree.

- *Beginning of summer.* Flowering of Sweetbrier and Raspberry are the indicators of the beginning of this season. Ripening of Strawberry indicates the end of this season.

- *Full summer* is indicated by waxy ripening of Rye.

- *Abatement of summer* is indicated by ripening of Cowberry.

- *Beginning of autumn* is indicated by coloration of Birch tree, Elm tree and Mountain Ash, the mean annual date being 18 September.

- *Golden autumn* is indicated by leaf coloration of Birch, Elm and Aspen.

- *Full autumn* is usually registered 10–14 October when the leaves of all deciduous trees have fallen. Transmigration of cranes to south is usually observed in the end of September.

The process of leaf fall occurs in the region under consideration in different way by different tree species. The following trees lose their leaves in the beginning of September : Linden, Elm, Hawthorn, Maple. Some trees lose their leaves 10 days later; Bird Cherry tree, Aspen, Ash tree and Red Elder. Linden and Poplar lose their leaves first from the upper parts of crowns, Elm and Hazelnut from the top. Some tree species, like Ash tree, Maple and Poplar lose their leaves after the first autumnal frost. As proverb says, *"Apple-tree does not hasten to lose its leaves after the first autumnal frost"*.

Inter–annual fluctuations of seasonal events in the region have several specific features. In Moscow region, for example, the following years were especially warm: 1924, 1934, 1935, 1944 and 1947. Phenological anomalies were observed in nature during this years:

1. Frogs croak in May,
2. Cherry tree and Red Bilberry blossom two times,
3. Raspberry and Wild Strawberry produced the secondary yield of berries,
4. Wood lark and starling piped at the second time in 1934.

Example 2. Seasonal aspects of nature in the Ural region.

V. A. Batmanov (1949) published a calendar of periodic phenomena in the vicinity of Sverdlovsk (now Ekaterinburg). This information is given in **Table 2.1.1** in which the dates and the month numbers are indicated. The length of observations varied from 15 to 47 years. Standard deviation (δ) is also given, having the value of 4–10 days.

Table 2.1.1

Calendar of seasonal events in nature in the vicinity of Ekaterinburg (V. A. Batmanov, 1949)

Seasonal events	Number of observation years	Dates			δ days
		Mean	The earliest	The latest	
Spring					
Arrival of rooks	46	24.03	10.03	10.04	7
Sap rising in birch tree	18	18.04	6.04	3.05	7
Opening of leaf buds of birch	16	3.05	8.04	18.05	10
Flowering of bird-cherry tree	56	21.05	23.04	20.05	7
Flowering of Siberian pea (*Caragana arborescens*)	47	28.05	12.05	17.06	8
Summer					
Flowering of fire weed (*Epilobium angustifolium*)	24	25.06	10.06	5.07	7
Ripening of raspberry	24	17.07	2.07	11.08	9
Feathering of wagtail nestlings	20	18.07	10.06	25.06	5
Waxen ripening of winter rye	?	27.07	?	?	?
Autumn					
First colored trees of birch	15	10.09	2.09	22.09	5
Full coloration of birch	17	30.09	25.09	6.10	4
Full leaf fall of poplar tree	15	12.10	5.10	18.10	4

Seasonal aspects of forests in Siberia

Phenological observations in Siberia were conducted by several scientists, but many of them registered local phenomena. As such, the results of these observations can not be used for identification of seasonal aspects in vast areas. It is for this reason that, in this section, examples of studies of seasonal aspects of forests are only given. **Table 2.1.2** provides phenological observations in 14 stations located in the Krasnoyarsk territory. The observation stations were located along the meridian of 90° E. This

Table 2.1.2

Duration of the birch leaves growth in the Krasnoyarsk territory

Observation points	Coordinates		Phenological phases				Duration of phenological periods		
	Latitude	Longitude	Beginning of leaf growth, D1	Beginning of leaf coloration, D2	Full leaf coloration, D3	End of leaf fall, D4	T1 (D2 – D1) days	T2 (D3 –D1), days	T3 (D4 –D1), days
Essei	68° 40'	102° 30'	19.6.06	20.4.08	1.0.09	18.9.09	61.8	73.4	91.3
Igarka	67° 30'	86° 10'	21.8.06	21.6.08	10.2.09	22.0.09	61.0	80.4	92.2
Sovetskaya Rechka	66° 20'	83° 55'	21.5.06	27.0.08	8.1.09	21.5.09	67.5	79.5	93.0
Verechagino	64° 20'	88°40'	15.8.06	25.8.08	4.3.09	27.0.09	71.0	80.5	103.2
Verkhne – -Imbatskoe	63° 25'	88° 18'	5.6.06	21.5.08	7.5.09	22.7.09	76.9	93.3	109.1
Podkamennaya Tunguska	61° 40'	90° 18'	6.0.06	24.5.08	9.0.09	26.5.09	79.5	95.0	112.5
Chindet	56° 25'	89° 23'	9.0.06	?	10.0.09	1.0.10	?	94.0	115.0
Mikhailovka	57° 55'	91° 55'	13.7.05	23.8.08	13.3.09	10.8.10	106.5	122.6	150.1
Sukhobuzimskoe	57° 25'	93° 21'	22.0.05	26.0.08	17.0.09	6.0.10	96.0	128.0	137.0
Rybnoe	57° 42'	94° 06'	13.0.05	7.5.09	1.0.10	20.0.10	117.5	141.0	161.0
Verkhny Kuzembar	53° 21'	93° 40'	10.9.05	14.8.08	28.3.09	24.0.10	109.5	140.4	166.1
Boguchany	58° 20'	97° 30'	15.8.05	22.2.08	17.2.09	29.9.10	105.4	124.4	137.1
Balyksa	53° 18'	98° 19'	8.9.05	21.8.08	20.1.09	28.6.09	105.4	134.3	148.2
Velmo	61° 25'	93° 42'	26.6.05	26.6.08	12.1.09	29.4.09	93.0	108.5	126.8

information is based on a special processing of the initial data developed by N. G. Kharin (1972). The observations were transformed to the common period of observations; and they can be considered as long-term data. Birch tree was selected as an indicator of seasonal aspects. By rough estimation, the timing of leaf growth came later at 3 days by its apparent movement towards north, progressing by 1° of latitude. I. N. Elagin (1983) published very interesting information on seasonal aspects of the south taiga region of Siberia (**Table 2.1.3**). NDVI values were calculated for the same locality, and are shown in **Table 2.1.4**.

Table 2.1.3

Phenological indicators of seasonal aspects in Siberia (I. N. Elagin, 1983)

Regions	**Coordinates**	**Dates of timing seasonal aspects**				
		Black spring	**Intensive growth of leaves**	**Full leaf aspect**	**Autumnal aspect**	**Leaf fall**
North taiga	61°00' N – 90°13' E	15.06 – 20.06	25.06-5.07	10.07-18.08	18.08-28.08	25.09-5.10
Middle taiga	59°30' N-91°00' E	9.05-15.05	1.06-10.06	22.06-10.08	2.09-15.09	No information
South taiga	57°44' N-93°10' E	10.05-20.05	25.05-15.06	15.06-15.08	1.09-10.09	No information
North forest steppe	56°20' N-92°50' E	20.04-30.04	20.05-5.06	5.06-1.09	8.10-15.10	No information

G. E. Shults (1981) had calculated the mean annual dates of seasonal development of Larch tree in the north-east part of Siberia. This information is given in **Table 2.1.5.** Similarly, a very interesting study of seasonal aspects (phenological seasons) was conducted by T. N. Butorina (1979) in the Krasnoyarsk territory, within the limits of 52°-68° N. She identified three seasons of the year (except of winter): spring, summer, autumn. The author also recommended the following seasonal (periodic) events as indicators of seasonal changes of aspects: beginning of mass melting of snow, beginning of sap circulation in Birch tree, beginning of flowering Sweetbrier (*Rose sp.*), beginning of leaf coloration of Birch tree, beginning of needle coloration of Larch tree (*Larix sibirica*), snow cover. She said that two indicators of the growing season can be named for the region under consideration: birch sap circulation in spring and the beginning of larch coloration in autumn. The length of this season is 2.5 months in the north, and 4.5 months in south parts of the region.

Table 2.1.4

Characteristics of seasonal aspects of the south Taiga (coordinates : 57°44′ N - 93°10′ E)

Aspects	**Length of aspects (I.N.Elagin, 1983)**	**NDVI (1992)**	**Length of aspects by NDVI**	**Seasonal indicators (I. N. Elagin, 1983)**
Melting snow, except edges of fo- rest (Black spring)	10.05 – 20.05	< 0.05	5B – 5M	The soil is saturated by water; Needles of Pine becomes bright-green, swelling of Pine buds, dispersion of Pine seeds; Swelling leaf buds of Birch and Larch; Seedlings of some grasses have appeared; Blossoming of *Caltha palustris.*
Slightly green colo- ration of Birch leaves (Intensive growth of leaves)	25.05 – 15.06	0.1 – 0.425	5M – 6B	Mean daily air temperature has reached +10°; Intensive growth of leaves of Larch, Bird Cherry tree, Mountain Ash, *Salix sp.*, Sweetbrier, Currants, and Spirea; Opening buds of Aspen. Swelling buds of Pine and Cedar; Flowering of Norway spruce, Birch, Bird Cherry tree; Arrival of swallows; Nesting of many migratory birds as well as settled birds; Beginning activity of mosquito; End of sowing field crops : pea, corn, oats and maize.
Monotonous coloration of coniferous and deciduous forests (Summer aspect)	15.06 – 15.08	0.425 – 0.45	6B – 8B	In the beginning of the period, leaves of Birch and needles of Larch take on summer coloration; Homogenous coloration of coniferous and deciduous trees are the indicators of the high activity of gad-fly and mosquito.
Orange yellow forest stands among green and dark green forests	1.09 – 10.09	0.348 – 0.33	9B – 9M	In the beginning of the period the first autumnal frosts take place. Change of leaf color of Birch (25 – 50%), first leaf fall of Birch; Larch has green coloration; Edible mushrooms have appeared; Many migratory birds have left the area heading for the south (cuckoos, martlets, swallows); Intensive harvesting of cornfields; Selective

Table 2.1.4 (continued)

(Early autumnal aspect)				digging of potato; End of activity of mosquito.
Forest canopy consists of two aspects : orange-red and dark green (Full autumn)	8.09 – 20.09	0.31 – 0.271	9M	Bright coloration of Birch and Aspen leaves; Yellow coloration of Larch needles. Dark green coloration of coniferous trees. End of growth of the main part of plants. Dissemination of seeds of fir. End of digging potato.
Orange-yellow patches against gray background of leafless birch and aspen and dark background of coniferous trees (End of autumn)	20.09 – 5.10	0.211 – 0.182	9E – 10B	All evergreen plants (including coniferous trees) have entered the dormancy stage. Full leaf fall of Birch, Aspen and Larch. Dissemination of seeds of Larch. Water fowls have migrated to the south. End of season of laying-in mushrooms. The best period for collection of Pine and Fir cones.

Note : The numbers indicate the months (5, 6, etc.)
B – beginning of month (the first ten days period)
M – middle of month (the second ten days period)
E – end of month (the third ten days period)

Table 2.1.5

Mean annual dates of seasonal development in the Northeast Siberia (G. E. Shults, 1981)

Seasonal events	**Observation points**				
	Magadan 59°45′N - 150°06′E	**Palatka 60°03′N - 150°13′E**	**Seimchan 62°01′N - 150°40′E**	**Zyryanka 64°40′N - 150°12′E**	**Srednekolymsk 67°40′N - 151°48′E**
Destruction of snow cover	13.05	18.05	16.05	19.05	-
Leafing out Larch	1.06	-	22.05	25.05	28.05
Beginning of Wild Rosemary flowering	17.06	16.06	12.06	-	15.06
Needle coloration of Larch	10.09	10.09	-	21.08	-
Full coloration of Larch	26.09	16.09	-	-	-
End of needle fall of Larch	7.10	2.10	22.09	22.09	-

2.2. Study of seasonal aspects of forests from aircraft and by aerial photos

Visual observations from aircraft

Phenological observations from aircraft were conducted by G. G. Samoilovich (1958) in the forests of Russia and described the first methodology of these observations. N. G. Kharin (1958) used helicopter for similar observations. The techniques required periodical flights above forest tracts to register the phenological status of forests. During the summer of the year of observation, periodical flights were repeated consisting each of 10-day duration. During the autumnal season, however, the periodicity of observations was shorter (5–7 days). By phenological observations, an observer could distinguish the following features :

- Land cover types (forest, burnt forest, forest cutting, swamp, hay land, agricultural lands, etc.);
- Composition of forest stands, by dominant and sub-dominant forest species,
- Crown closure, in dozens of percentage;
- Age of forest stands by groups (young, middle aged, pre-mature, mature and over-mature forests);
- Pests of forest stands, in some cases – the agents of pests by indirect criteria;
- Phenological stages of forest (leafing out, full leaf, beginning of leaf coloration, leaf fall, etc.).

In some specific cases, an observer could estimate the status of undergrowth or register the intensity of fructification of forest trees.

The results of phenological observations were given in descriptive form or a phenological spectrum was prepared. By these observations, it was very difficult to use quantitative criteria of seasonal development of forest. That was the main shortcoming of this methodology.

Study of seasonal aspects of forests by application of aerial photos

For several decades, ground survey in forestry and compilation of forest maps were based on the use of black-and-white, panchromatic, aerial photos of different scales. The Laboratory of Aerial Methods, Academy of Sciences of the USSR conducted from 1958–1959 experimental works on the application of the Soviet *false colour film SN – 2* for inventory of Russian forests. The experiments were conducted in Lisino Forest District, Leningrad region, in Onega Forest District, Arkhangel'sk region and in some other regions of Russia. These experiments demonstrated very good correlation between image quality of aerial photos and phenological status of forests.

Initial use of the technique by enthusiasts proved to be overwhelming in that its application needed strict selection of conditions of aerial photography (i.e. proper phenological status of forests, higher sun elevation, better weather conditions etc.). In publications of S. V. Belov (1959) and E. S. Artzybashev (1959), the recommendations were given about selection of a proper season of photography. Applications of false colour photographs were possible during the summer period when forest trees were in the stage of full leaf. The beginning of leaf coloration in autumn, was an indicator of the proper phenological stage for application of false colour film. But panchromatic and color films could be used during this season (**Figures 2.2.1** and **2.2.2**).

Application of this new false color film gave an impetus to further development of photo interpretation of forests and for compilation of forest stand maps. Two groups of forest trees: coniferous (Pine, Cedar, Spruce) and deciduous (Birch, Aspen and a coniferous species Larch), were clearly distinguished in photos by their different colours. The new film also improved the interpretation of forest damages, water, swamps, agricultural lands.

At present time, the following film types are being used in the photography of forests in Russia (E. P. Danyulis et al., 1989):

- *Panchromatic films T – 22*, *T – 27, T – 28* and *T – 29*, sensitive to visible spectrum;
- *Oprochrom film AS – 2*;
- *Infra film*, sensitive to near infrared spectrum (maximum 900 nm);
- Two layer false colour film *SN – 6* with two sensibility regions : 680 – 800 nm and 570– 670 nm;
- Three layer false colour film *SN – 23* with three sensitive regions : 500 – 600 nm, 580 –680 nm and 650 – 800 nm;
- Colour film with natural colour reproduction, with three sensitive layers (590 – 730 nm, 500 – 600 nm and maximum 510 nm).

The same authors described the following categories of scale used for forest inventory and mapping in Russia :

- Photos with ground resolution 1 km (scale 1 : 8,000,000),
- Photos with ground resolution 250 m (scale 1 : 2,500,000),
- Photos with ground resolution 100 m (approximate scale 1 : 1,000,000),
- Photos with ground resolution 25 m (approximate scale 1 : 500,000),
- Photos with ground resolution 10 m (approximate scale 1 : 200,000),
- Photos with ground resolution 3 m and greater (scale 1 : 50,000 and larger).

For proper application of these photos, strict observance of seasons of photography and weather conditions may be necessary.

2.3. Use of NOAA/AVHRR data for retrospective monitoring of forests

NDVI and phenological profiles

NOAA/AVHRR data were found to be useful for the analysis of seasonal aspects of forests. Normalized Difference Vegetation Index (NDVI) was calculated by the formula:

Figure 2.2.1. Golden autumn. Oblique aerial photo from the personal archives of N. G. Kharin.

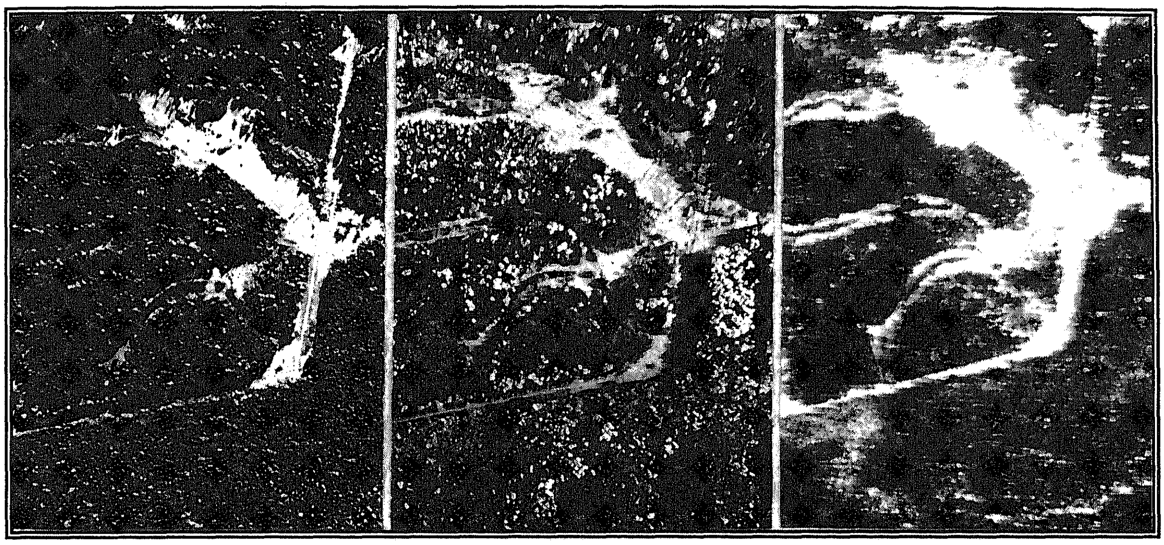


Figure 2.2.2. Seasonal images of taiga forests on panchromatic photos, Leningrad region, Russia. Left photo – summer, central photo – autumn, right photo – winter. Photos from the personal archives of N. G. Kharin.

NDVI = (NIR – RED)/(NIR + RED)

where : **NIR** – reflectance in near infrared spectral band (channel 2 of AVHRR)
RED – reflectance in red spectral band (channel 1 of AVHRR)

In the current study two types of NOAA/AVHRR data were used:

- *Original data (1982–1999), 8-km resolution data.* These data were geometrically registered to a 4 arc-minute grid. One hundred thirty (130) sample plots were selected for description of seasonal aspects of forests for the whole territory of Russia;

- *April 1992–March 1993 data, 30 arc–second resolution NDVI data.* The original data in the Global Land 1–km AVHRR data set produced by the United States Geological Survey (USGS) which consists of 10–days composites, nominally 1-km resolution data.

For each sample plot, the ***Mean NDVI*** (4 arc-minute imagery) was calculated from 5 contiguous pixels :

	North	
West	**Central**	**East**
	South	

Thematic maps and various publications were used as a source of ground truth information which consisted of descriptions of seasonal aspects of forests.

Investigations have shown that NDVI value is an objective characteristic of phenological stages of forests, mainly their seasonal aspects because NDVI is an integrated, 10-day composite image of a particular landscape. The dynamics of seasonal aspects can be seen from a phenological profile on sample *plot 135* (**Figure 2.3.1**). This profile shows the main stages of seasonal development of forests. The following seasonal aspects can be identified from this profile:

Winter aspect with NDVI ≤ 0;

1. Black spring aspect with NDVI values 0 - 0.2 (from melting snow till the beginning of leaf growth);

2. Leaf growth aspect, when leaves (needles of coniferous trees) develop intensively;

3. Summer aspect, when leaves form the dense cover and NDVI values reach 80% of maximum; and

4. Autumnal aspect, when NDVI values loss 20% from the summer value.

During some years, phenologists identify two autumnal aspects : "*golden autumn*" and "*black autumn*". The last aspect is a period when the leaves have fallen, but winter does not come, and the soil under the forest canopy is not covered with snow. But this aspect is not clearly identified on the basis of 10 days periods, and not much studies have been made on this.

In the northern taiga areas, some seasonal aspects can not be clearly identified during the years of specific weather conditions. For example, the aspect of black spring may not be observed every year in these areas because the spring can be very cold. In such cases, after

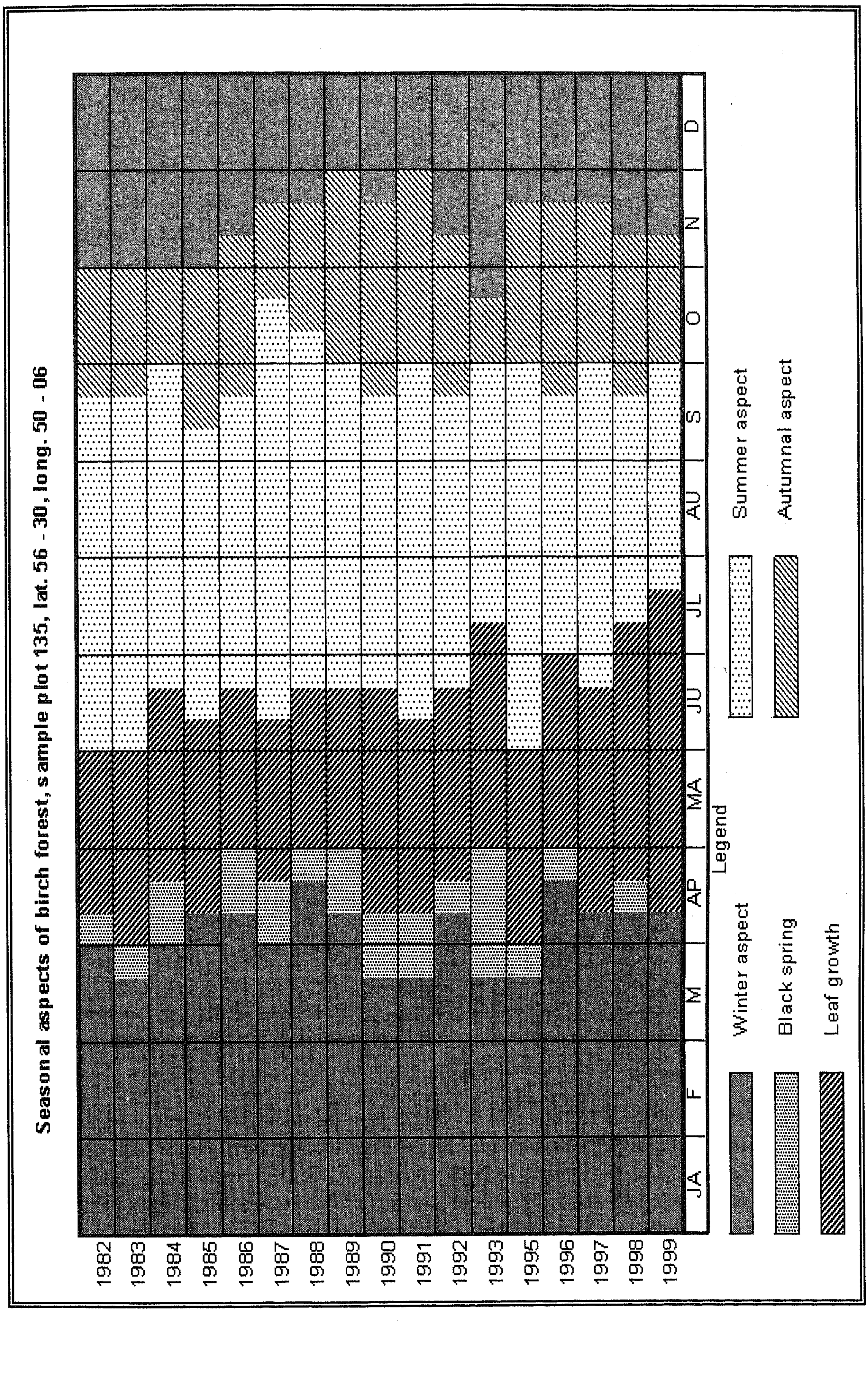


Figure 2.3.1. Seasonal aspects of birch forests, sample plot 135.

the winter aspect, the period of leaf growth comes. Also, autumnal aspects are not always observed during the years of early winter. Examples of these fluctuations are given in the next section of this chapter.

Two types of variations of phenological profiles can be distinguished :

1. Variations in absolute values of NDVI within the same season of the year. These can be explained by the different intensities of photosynthesis during the growing season;

2. Variations of the timing of seasonal aspects, when the profile is replaced along the time scale. These can be explained by different weather conditions in different years.

"*Abnormal*" (not expected) fluctuations of NDVI curve from "normal" phenological profile can be explained by different causes, among which are due to: influence of cloud cover during the imagery registration (especially in spring), by sensor noise and by other errors of processing. But in several cases, these fluctuations look like one produced by pathological agents (e.g. fires, insects, fungi, etc). An example is given in **Figure 2.3.2.** Phenological profiles of Larch forests in 1985, 1986, 1987 and in 1988 have the following specific features:

1. In 1985, Larch started its coloration in August, probably under the impact of pathological factors,

2. In 1986, the profile was abnormal because the NDVI values fell during the summer, and coloration began in August,

3. In 1987, the green wave came later, but the status of Larch forest became normal by the end of the summer,

4. In 1988, the NDVI values began to fall in July; which proved the fact that photosynthesis was reduced during the summer.

As had been mentioned earlier in the text, "*Weather of any two years is not identical*". Retrospective monitoring of phenological stages of forests and cultural vegetation is of great theoretical and practical interest. NOAA/AVHRR is a huge source of remotely sensed data that have been continuously archived since 1982. Seasonal aspects of plants can be studied within the whole period of these observations. The scale of this monitoring has two parameters: *parameter of time* (10 days) and *parameter of minimal area* (8kmX8 km). The changes occurred within 10 days and within a minimal area can be not registered by this method. So, low resolution imagery can be used for monitoring changes which have occurred at the level of plant formations.

As had earlier been indicated, 130 sample plots were selected, corresponding to 1 pixel in size, and with the dominance of Birch and some other tree species, Birch being the main tree species. Phenology of Birch was studied better in previous investigations, and this tree species was used as an indicator of seasonal periods for aerial photography in the forests of Russia (N. G. Kharin, 1972). Furthermore, Birch is the most common tree species in mixed forests of Russia, and a nominal name "Birch forest" mainly relates to mixed forest with a considerable part of crown cover belonging to Birch. The *Atlas of the USSR Forests* (1973) was used as a source of ground truth information.

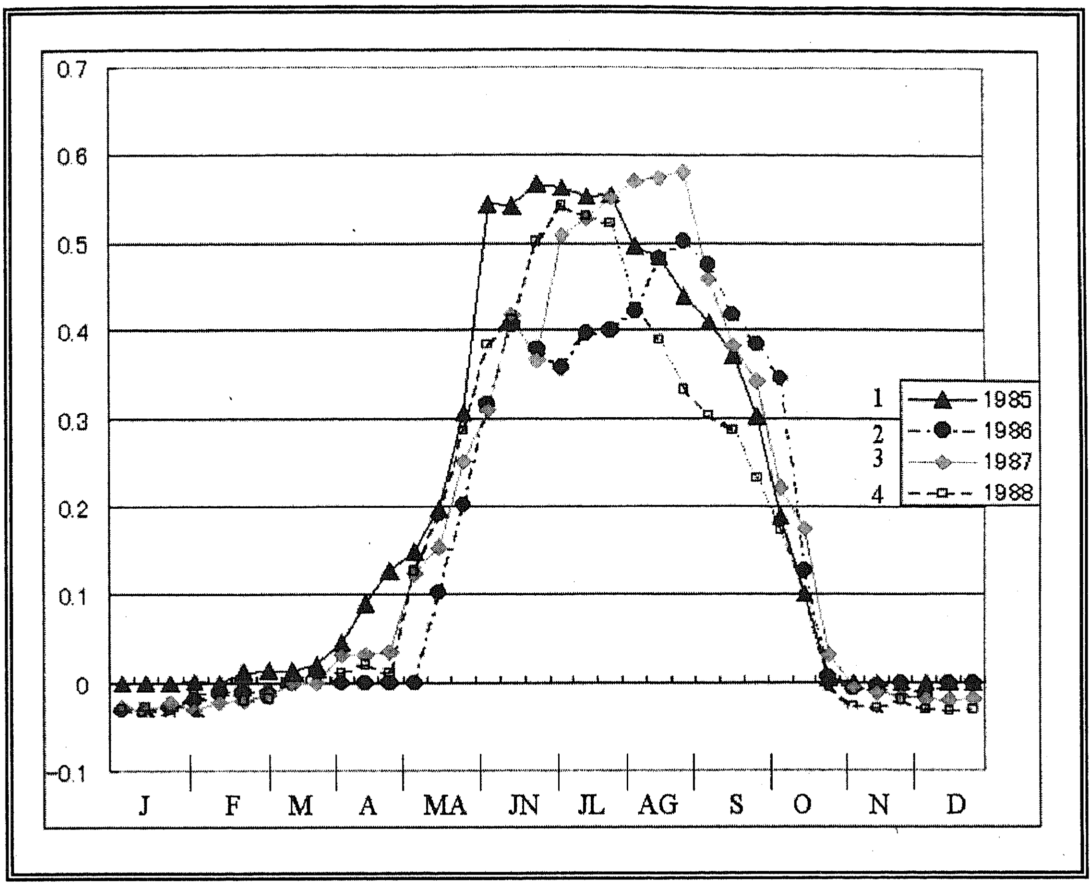


Figure 2.3.2. Abnormal variations of NDVI during 1985 – 1988 in larch forests. 1 – 1985, 2 – 1986, 3 – 1987, 4 - 1988

Variations of NDVI within the same seasonal aspects

These variations were studied in 10 sample plots located in the Krasnoyarsk administrative territory (See **Table 2.1.2** from the previous section). The maximum value of NDVI for each aspects are given in **Table 2.3.1.** *Black spring* is a period with unstable characteristics of NDVI, because it is a transition period between winter and the beginning of leaf growth. Annual variations in phenological status and unstable weather conditions are the sources of great variations in the absolute values of NDVI. This means, in several cases, variations of NDVI can be attributable to technical errors. In general, the absolute values of NDVI can be seen to increase by transition from north to south, with values from 0.075 till 0.293. The trend of reduction in variations is clearly identified, in the northern part of the region where the value reaches ± 70 – 100%, while in the southern part ± 20 – 40% can be seen.

Leaf growth indicates the beginning of the growing season. The trend of increase of the absolute values of NDVI from north to south, logically, comes from climatic indices, but is not clearly expressed. This uncertainty may be probably due to tree stand composition and other local phenomena. Variations in NDVI are from ± 6 – 8% in the north and ± 10 – 15% in the south of the study region.

The maximum growth of vegetation is observed during the summer aspect. The absolute values of NDVI can be seen to increase from 0.525 in Essei to 0.765 in Verkhny Kuzhembar. However, two of the most southern points, Balyksa and Boguchany are exclusions from this rule. In general, this increase is 0.012 for a transition of one degree of latitude. This can be explained by more intensive photosynthesis in the southern areas, and by denser cover of vegetation. Variations of NDVI percentage do not show a clear trend. Variations are ± 12% in Igarka and Sovetskaya Rechka, ± 1 – 2% in Verkhny Kuzhembar and Boguchany.

The autumnal aspect is not stable in duration and the values of NDVI variations are ± 92% in Essei, ± 71% in Verechagino and ± 37% in Verkhny Kuzhembar. Unstable weather conditions during this period of year, including rain and even snow may have been the main reasons of this variability. Seasonal aspects for the same observation points are given in **Figure 2.3.3.**

The fluctuations of timing of spring and summer aspects for selected sample plots (**Table 2.3.2**) are given in **Table 2.3.3**. The length of the growing season and variations in timing of seasonal aspects depend upon a geographical location of sample plots, mainly in their latitudes. Birch forests of the north taiga (sample plot 132) have comparatively stable period of black spring, as compared with other regions. Probably, weather conditions during the beginning of spring are rather stable. Variations in the beginning of the leaf growth season for the same plot are also comparatively small.

The length of the growing season in Larch woodland (sample plot 54) lasts for 3 months and one ten days period. The autumnal aspect is short (2 – 3 ten days period), and the inter–annual fluctuations are minimal.

Very specific phenological spectrum can be seen in larch woodland (sample plot 47), located in the region with eternal frost. The soil melts here for a short period during the summer months. The growing season lasts three and half months, and the period of black spring is not registered on ten days level each year. For several years, needle growth of Larch starts after the winter aspects.

Table 2.3.1

Variation of NDVI within seasonal aspects in the forests of the Krasnoyarsk territory

Observation points	Black spring		Leaf growth		Summer aspect		Autumnal aspect	
	t	*δ*	*t*	*δ*	*t*	*δ*	*t*	*δ*
Essei	0.075	0.115	0.516	0.040	0.525	0.037	0.177	0.162
Igarka	0.090	0.134	0.651	0.037	0.550	0.068	0.210	0.155
Sovetskaya Rechka	0.081	0.085	0.669	0.53	0.573	0.069	0.149	0.140
Verechagino	0.097	0.069	0.583	0.097	0.683	0.054	0.161	0.115
Verkhne Imbatskoe	0.172	0.050	0.390	0.050	0.659	0.055	0.377	0.142
Podkamennaya Tunguska	0.328	0.102	0.711	0.042	0.695	0.050	0.418	0.154
Chindet	0.223	0.018	0.728	0.038	0.653	0.041	0.290	0.140
Mikhailovka	0.224	0.105	0.677	0.058	0.717	0.041	0.334	0.114
Sukhobuzimskoe	0.239	0.010	0.581	0.116	0.760	0.036	0.284	0.148
Rybnoe	0.387	0.064	0.634	0.084	0.745	0.026	0.517	0.125
Verkhny Kuzhembar	0.221	0.044	0.725	0.041	0.765	0.170	0.477	0.178
Boguchany	0.393	0.086	0.748	0.041	0.704	0.061	0.461	0.083
Balyksa	0.152	0.072	0.465	0.076	0.518	0.058	0.390	0.058
Velmo	0.293	0.069	0.640	0.050	0.588	0.077	0.403	0.140

Note : ***t*** - mean value
δ - standard deviation

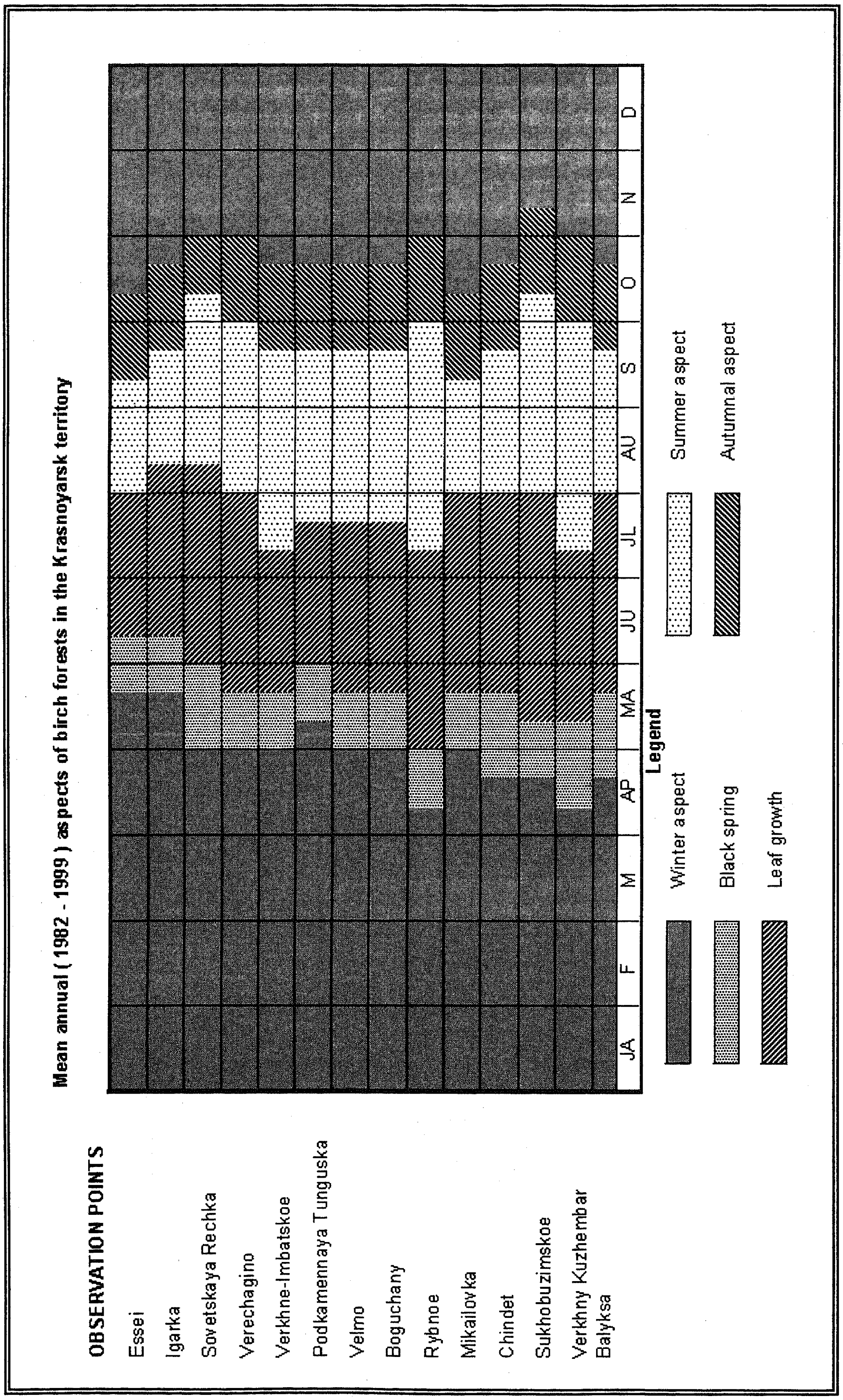


Figure 2.3.3. Seasonal aspects of forests in observation points of the Krasnoyarsk territory.

Table 2.3.2

Selected sample plots used to study the seasonal aspects of forests in Russia

Tree species	Plot number	Coordinates		Forest regions
		Latitude	Longitude	
Birch	132	65°40' N	54°00' E	North taiga of Fennoscandia and East European Plain
Birch	135	56°30' N	50°06' E	South taiga and mixed forests of East European Plain
Birch	150	60°00' N	58°00' E	Taiga forests of the Ural
Pine	130	63°44' N	83°44' E	North woodland of West Siberian Plain
Birch	2	56°42' N	77°08' E	Middle and south taiga of West Siberian Plain
Larch	47	66°00' N	106°00' E	Larch woodland of Middle Siberian Plain
Birch	105	52°15' N	90°13' E	Taiga forests of the Sayan - Altai Mountains
Larch	54	68°00' N	150°00' e	Larch woodland and tundra of the North – East Siberia
Birch	85	50°00' N	131°10' e	Taiga and broad leaved forests of the Far East
Dwarf birch	73	55°30' N	161°30' E	Woodland of dwarf birch and dwarf cedar of Kamchatka

Table 2.3.3

Inter–annual fluctuations in timing of spring and summer aspects in forests of Russia

Dominant tree	Plot number	Beginning of black spring			Beginning of leaf growth			Beginning of summer		
		Tm	***Te***	***Tl***	***Tm***	***Te***	***Tl***	***Tm***	***Te***	***Tl***
Birch	132	4B	4B	5B	5B	5B	6B	7B	6B	7B
Birch	135	3E	3E	4E	4B	4B	4E	7E	6B	7M
Birch	150	4B	3E	4E	5B	4E	5M	6E	6M	7B
Pine	130	4M	4B	5E	4E	4M	5E	6M	6B	8B
Birch	2	3E	3E	5E	4E	4M	5M	6M	6M	7B
Larch	47	4B	4M	6B	5E	5M	6M	6M	6B	8B
Birch	105	4M	4E	5E	5B	4E	5E	6E	6B	8B
Larch	54	4E	4M	5E	5B	4E	5E	6E	6B	8B
Birch	85	3E	3M	4M	4E	4B	5E	7B	6B	7M
Dwarf Birch	73	5M	5M	6E	6B	6B	6E	8B	7B	8M

Note : ***Tm*** - mean annual ten days period
Te - the earliest ten days period
Tl - the latest ten days period
8 - month number
B, M, E – beginning, middle, end of month, by ten days period

Information about the timing of autumnal aspects for the same plots is given in **Table 2.3.4**.

Table 2.3.4

Inter-annual fluctuations in timing of the autumnal aspects in forests of Russia

Dominant tree	Plot number	Beginning of leaf coloration			End pf leaf fall		
		Tm	*Te*	*Tl*	*Tm*	*Te*	*Tl*
Birch	132	9B	8E	10E	10E	10M	10E
Birch	135	9B	8M	9E	10M	10E	11E
Birch	150	9B	8E	10M	10M	10M	11B
Pine	130	9B	8M	9M	10B	9M	9E
Birch	2	9B	8E	10M	10E	10B	10E
Larch	47	8M	8B	9B	9M	9B	9E
Birch	105	9B	9B	9E	9E	10B	10E
Larch	54	9B	8E	9B	9E	9M	9E
Birch	85	9B	9B	10M	10M	10B	11B
Dwarf Birch	73	9M	9M	10M	11B	10M	11B

Forests of the middle and south taiga of the west Siberian plain (sample plot 2) have longer growing season (4 – 5 months). Here, the inter–annual variations in the length of seasonal aspects are greater than in the northern regions of Russia.

Summarizing the study of seasonal aspects of forests in Russia, it can be concluded that:

1. The duration of the growing season in the sample plots which were studied, mainly depends upon the latitude of these plots;

2. The aspect of the black spring is not stable in its duration, because of the large variability in the absolute values of NDVI. Furthermore, variations in weather conditions during this season and technical errors attributable to the sensor, are the additional sources of variations;

3. Variations in timing the leaf growth and the summer aspect depend upon the geographical location and probably upon the local conditions which the study did not take into account, due to the lack of ground truth information;

4. Autumnal aspects are not stable because of large inter–annual variations in weather conditions, especially in the end of the study period;

5. In general, a phenological profile drawn from NDVI is an objective characteristic of forest status, especially during a particular growing season. It can be said that all phenological changes in the forests can be registered through phenological profiles, at the level of plant formation;

6. Retrospective study of forests by phenological profiles, based on 8-km imagery, is a new method of environmental monitoring which allows for the study of seasonal aspects of vegetation on a regional level.

2.4. Use of NDVI imagery for forest inventory in Siberia

The experiment was conducted in "Baikal" experimental area within the coordinates: 51° 00' - 51° 40' N, 103°00' - 104° 50' E. It was located to the northwest of Lake Baikal (**Figure 2.4.1**). The forest tract included 34 river basins of the third order, which were used as forest inventory units. The structure and composition of mountain forests were studied.

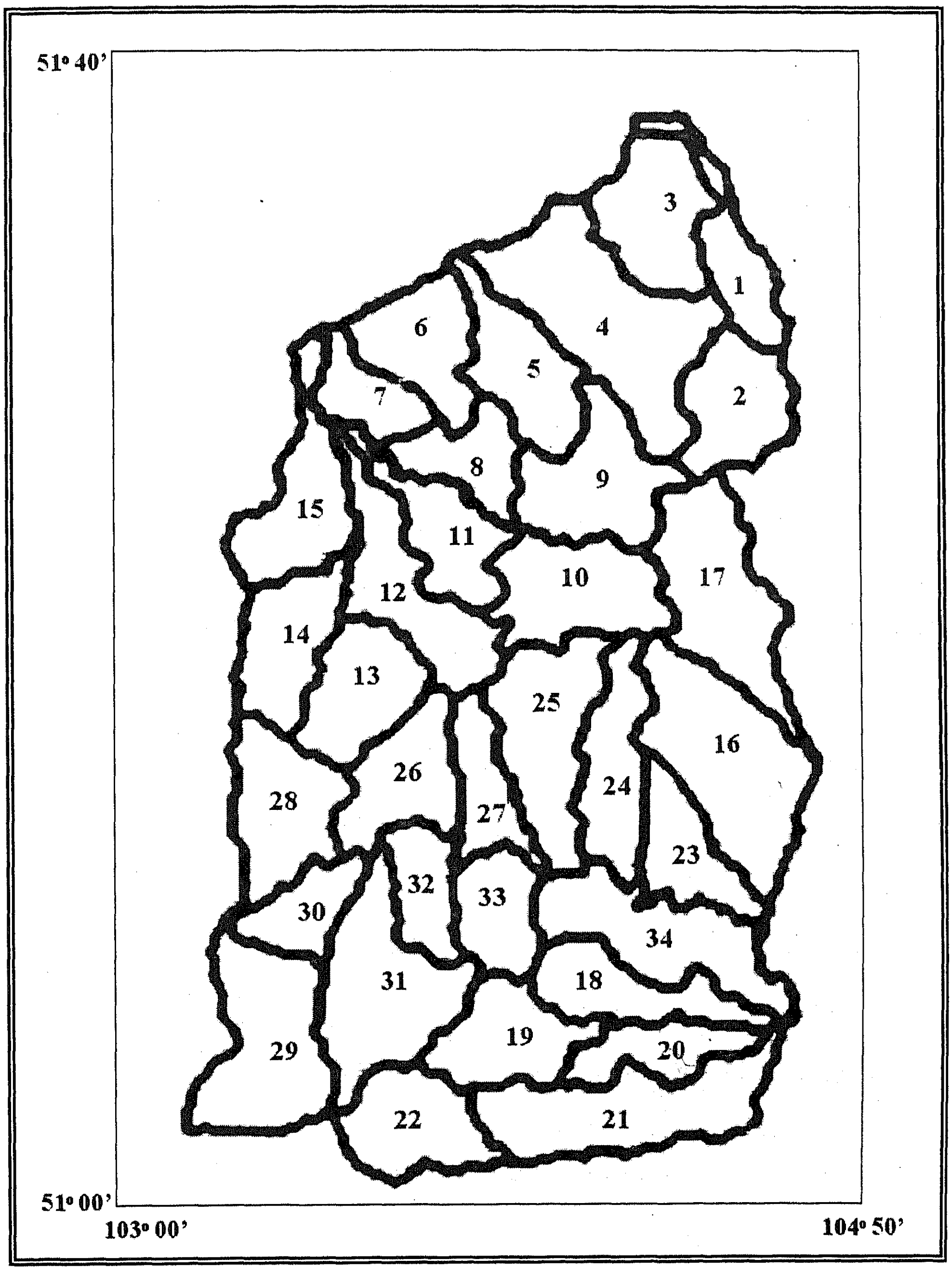


Figure 2.4.1. Location of the experimental area "Baikal "

The forest inventory map derived from photographs taken from space, and which had a scale of 1 : 200, 000, was used as a source ground truth data. According to published information, these photos can provide the most reliable information on the composition of boreal forests (M. J. Coulombe, 1995). Likewise, NDVI imagery with 1-km resolution, was used, which consisted of mean monthly values (from 10-day composite data) of April, May, June, July, August, October of 1992 and January of 1993 . The mean number of pixels for one river basin was 120.

Characteristics of the forest cover of the experimental area

In the experimental area "Baikal", the following characteristics of the forest cover were estimated using the above-cited photographs, with a scale 1:200 000:

- *Percentage of the forested land* (***L***) which was estimated by the formula : $S : L = Sc / S$ where : ***Sc*** – the size of the forested area and ***S*** - the total area of basins,

- *Integrity of forests* (***C***), which is the relationship of the forested area (***Sc***) to all potentially forest land (***Sl***) or : $Sl : C = Sc / Sl$,

- *Share of coniferous forests* (***N***), which is the relationship of the area covered with coniferous forests (*Sn*) to the area of the forested land : $N = Sn / Sc$,

- *Share of mature coniferous forests* (*Nm*), estimated as the relationship of the area of mature coniferous forests (*Sm*) to the area of the forested land : $Nm = Sm / Sc$; Also, this criterion relates to communities of climax coniferous forests,

- *Share of the most productive forests* (***P***) which the relationship of the area of the forest land to the total area of potentially forest land, or $P = (Sc - Sr) / Sl$.

- *Share of woodland* (**R**), estimated as the relationship of the area of woodland (**Sr**) to the area of forested land **Sc** : $R = Sr / Sc$, (woodland is forest stand with low stock density),

- *Disturbance of forests* (***D***) which is the relationship of the area of the secondary forests to the area of potentially forest land. As secondary forests, the following categories were considered : coniferous, deciduous, and mixed forests (young, middle-aged and premature), as well as burnt forest, woodland and clear cuts , or $D = 1 - (Sc - Sm) / Sl$.

Ground truth characteristics of the test area "Baikal" are given in **Table 2.4.1**. In general, the forests are characterized by high degree of forested area with the dominance of coniferous tree species. Composition of forests is rather uniform. The share of mature coniferous forests and woodland is low.

The results of forest inventory and discussion

For the experimental area, correlation was studied between NDVI and the main characteristics of the forest cover. Mean number of pixels for one river basin was 120. The results of processing are given in **Table 2.4.2** (Significant correlation with probability $p >$ 5.0000% in bold fonts).

In general, correlation between mean NDVI and the characteristics of the forest cover is low, except the share of coniferous forests.

Table 2.4.1

Ground truth characteristics of the test area "Baikal"

Basin number	*L*, %	*C*, %	*N*, %	*Nm*, %	*P*, %	*R*, %	*D*, %
1	90	93	89	37	89	4	42
2	96	98	87	35	94	4	36
3	96	97	72	43	96	1	45
4	91	97	69	35	93	4	37
5	94	97	91	42	94	3	44
6	95	97	91	39	96	1	41
7	99	99	82	35	93	6	36
8	97	100	85	41	98	2	41
9	93	98	83	30	89	9	31
10	81	85	84	28	76	11	39
11	90	95	92	29	88	7	33
12	94	99	83	17	86	13	18
13	95	95	72	18	84	12	22
14	83	100	63	7	86	14	7
15	87	98	75	8	92	6	10
16	87	95	90	19	88	7	23
17	88	92	93	26	85	7	32
18	82	95	87	19	79	17	23
19	75	84	92	40	70	17	49
20	82	98	92	21	86	12	23
21	47	96	86	22	82	15	25
22	65	78	92	31	70	11	46
23	79	90	90	19	78	13	27
24	89	95	90	19	88	7	23
25	89	96	92	21	90	6	24
26	93	98	90	17	92	6	19
27	94	98	92	31	93	5	32
28	84	99	61	16	91	8	17
29	90	97	91	38	85	12	40
30	93	98	97	52	95	3	53
31	87	93	87	38	85	8	43
32	93	97	95	30	93	4	32
33	92	96	94	15	93	3	19
34	82	95	90	31	86	10	34

During April and May, deciduous trees are leafless and the NDVI component of coniferous species is clearly distinguished.

But as **Table 2.4.3** shows, there is correlation between the share of coniferous trees and NDVI values during the other seasons of the year. In connection with that we have calculated quasi Newton piecewise linear regression which demonstrates the correlation between NDVI values (May + June + September) and the share of coniferous species (**Table 2.4.3**). Correlation coefficient of this model was 0.934 and standard deviation totalled 4.25 %. This accuracy is rather high, so the estimation of the share of coniferous trees has a practical importance.

Table 2.4.2

Correlation matrix of the forest cover characteristics and NDVI; 1-km resolution in the "Baikal" experimental area

Forest cover characteristics	**By NDVI, 1992**					
	April	**May**	**June**	**August**	**September**	**October**
Percentage of the forest land ***(L)***	0.02	-0.22	0.30	0.16	-0.08	0.24
Integrity ***(C)***	-0.12	-0.20	-0.15	-0.17	-0.16	0.10
Share of coniferous forests ***(N)***	**0.71**	**0.59**	**0.51**	0.20	**0.40**	0.02
Share of mature coniferous forests ***(Nm)***	0.25	0.18	0.25	**0.71**	**0.37**	0.24
Share of the most productive forests ***(P)***	-0.05	-0.21	0.03	0.04	0.03	0.30
Share of wood land ***(R)***	-0.06	0.14	-0.21	-0.21	-0.20	**-0.40**
Disturbance of forests ***(D)***	0.27	0.23	0.28	**0.71**	**0.39**	0.21

We have studied the NDVI values for different physical regions of Siberia. In general, these integral characteristics registered by low resolution sensor are closely correlated with physical conditions and structure of plant communities. Correlation established for Siberia in our study can be used for estimation of phytomass, because productivity of forests depends upon the quantity of heat. Such experiments were conducted in other regions of Siberia by V. M. Zhirin and N. V. Yastrebova (1997). They studied correlation between NDVI, geomorphology, slopes and productivity of forest lands in Yakutia.

We also can mention very interesting study of taiga forests by joint team of Russian and Japanese scientists (Masayuki Tamura et al., 1998). The experiment was conducted in the Ob basin on application of NDVI imagery for identification of different land cover types in wetland area. The results were verified by ground truth data and high resolution space imagery. The following land cover types were identified : wetland, grass, lake, birch forests, coniferous forests.

Seasonal values of NDVI contain very important characteristics on phenological development of forests. Correlation between the NDVI values in spring months and in summer months (June, July and August) can be used for forecasting the optimal season of space and aerial photography and for planning the measures for forest regeneration. Combinations of three months values (April + July + October) gives the best results for identification of several forest cover types. American scientists (Zhilliang Zhu and D. L. Evans, 1992) also used seasonal combinations of NDVI to study the percentage of the forest cover and mapping the forest lands. They used the following three combinations: two weeks in spring, one week in summer and two weeks in autumn.

In conclusion we want to emphasize the importance of application of low resolution imagery for monitoring the taiga forests. Vast areas of the forests in the region under consideration are drastically changed under the impact of forest fires, cutting and other planned and non-planned activities of people. For example, E. S. Artsybashev (1998) has developed a new methodology for monitoring forest fires in Siberia. This methodology is based on application of NOAA imagery. Low cost of this imagery and the possibility of studying the same objects after a short period if time are useful for monitoring the forest cover. In our opinion, the further investigations should include the development of a methodology of multiple application of NOAA/AVHRR data, in particular:

Table 2.4.3

The share of coniferous trees estimated by NDVI values and that calculated by the model in the "Baikal" experimental area

Basin numbers	Share of coniferous trees, %	
	Estimated by NDVI	Calculated by model
1	89	88.66
2	87	88.19
3	72	78.35
4	69	73.44
5	91	90.86
6	91	91.03
7	82	80.05
8	85	78.50
9	83	83.79
10	84	80.96
11	92	90.26
12	83	83.52
13	72	72.61
14	63	61.52
15	75	67.52
16	90	87.93
17	93	91.56
18	87	89.98
19	92	92.14
20	92	90.76
21	86	90.90
22	92	92.87
23	90	90.16
24	90	92.11
25	92	90.32
26	90	90.12
27	92	91.27
28	61	68.66
29	91	91.66
30	97	92.09
31	87	90.75
32	95	92.64
33	94	91.06
34	90	90.57

- Registration of the current changes in taiga forests, first of all forest fires, insect damages and other disasters,
- Monitoring the slow developing processes, like regeneration of clear-cuts and burnt areas, rehabilitation of the areas affected by insects etc.,
- Study of phenology of forests, that is important for planning remote sensing missions, forecasting the yield of seeds of forest trees and for planning the measures of forest regeneration.

2.5. Phenological indicators of aerial photographic missions of the forests in Russia

Published phenological maps

Phenological mapping is very difficult tasks because many factors should be taken into consideration. So, several scientists published models for calculation of hypothetical dates. One of these models was published by A. D. Hopkins (1938). This model is given in **Figure 2.5.1**. The map contains isophenological parallels of 30°, 40°, 50°, 60° and 70°. These parallels do not coincide with topographic parallels and the map can not be used for practical purposes.

The second example concerns a global model of seasonal development of vegetation proposed by B. E. Datier et al. (1975). The authors of this project prepared the following phenological maps covering the territory of the world :

1. The map of "green wave" which includes the beginning of growth of all vegetation types (from agricultural crops to forests),
2. The map of "brown wave" (the end of vegetation growth, leaf coloration and ripening of all types of corn).

N. G. Kharin (1966) published phenological maps of birch. These maps were based on numerous observation points conducted *in situ* by many observers. Let's compare these maps (**Figures 2.5.2.** and **2.5.3**). We can see that isolines of green wave do not coincide with isophenes of birch. The greatest differences are observed in mountain regions of Siberia and in the Far East probably because the green wave ignored the influence of topography on phenological phases. The green wave in the European part of Russia runs at 3° of the latitude to be compared with isophenes of birch. We can see the same differences by comparing the green wave with isophenes of leaf coloration of birch. In the desert zone of the former USSR, the green wave does not coincide with the isophenes of the growth of white Saxaul (N. G. Kharin, 1972).

Phenological indicators of aerial photographic missions

The proper selection of the seasons of aerial or space photography for forest inventory is an actual problem till present days. By proper identification of other parameters (scale, film, filter etc.), but not a suitable season of aerial photography, photos are not suitable for forest survey of high quality. According to published data (N. G. Kharin et al., 1993), in many regions of the former USSR aerial photos used in forestry did not satisfy the demands of seasonality. The percentage of aerial photos of improper seasons totaled 10-20, and some regions 40–50. In several cases, forest survey expeditions wanted "to save money" using aerial photos of bad quality. But in this case, the accuracy of ground survey was low.

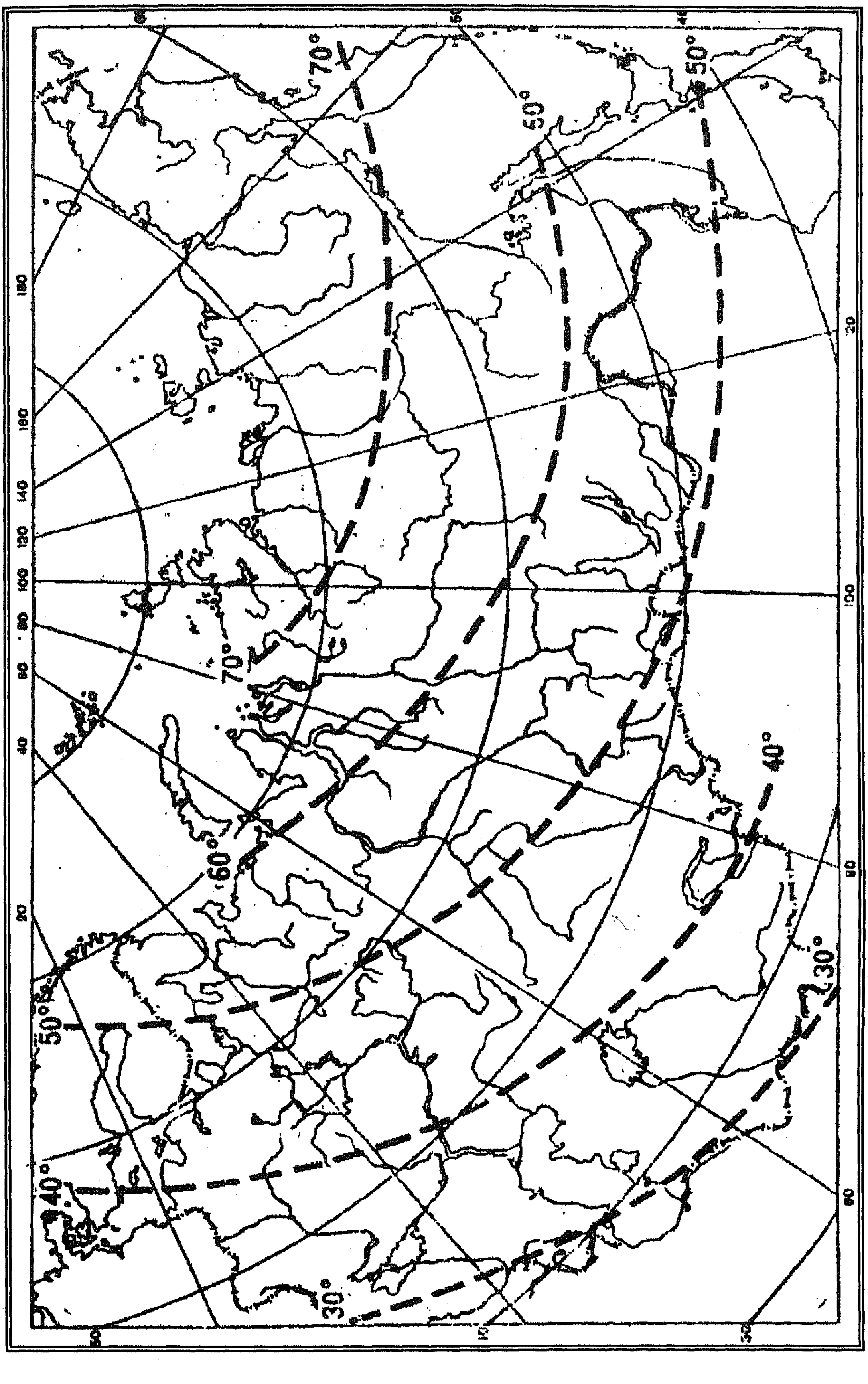


Figure 2.5.1. Phenological parallels on the isophenological map of A. D. Hopkins (1938). 30°, 40°, 50°, 60° and 70°, shown by dotted lines, are the phenological parallels.

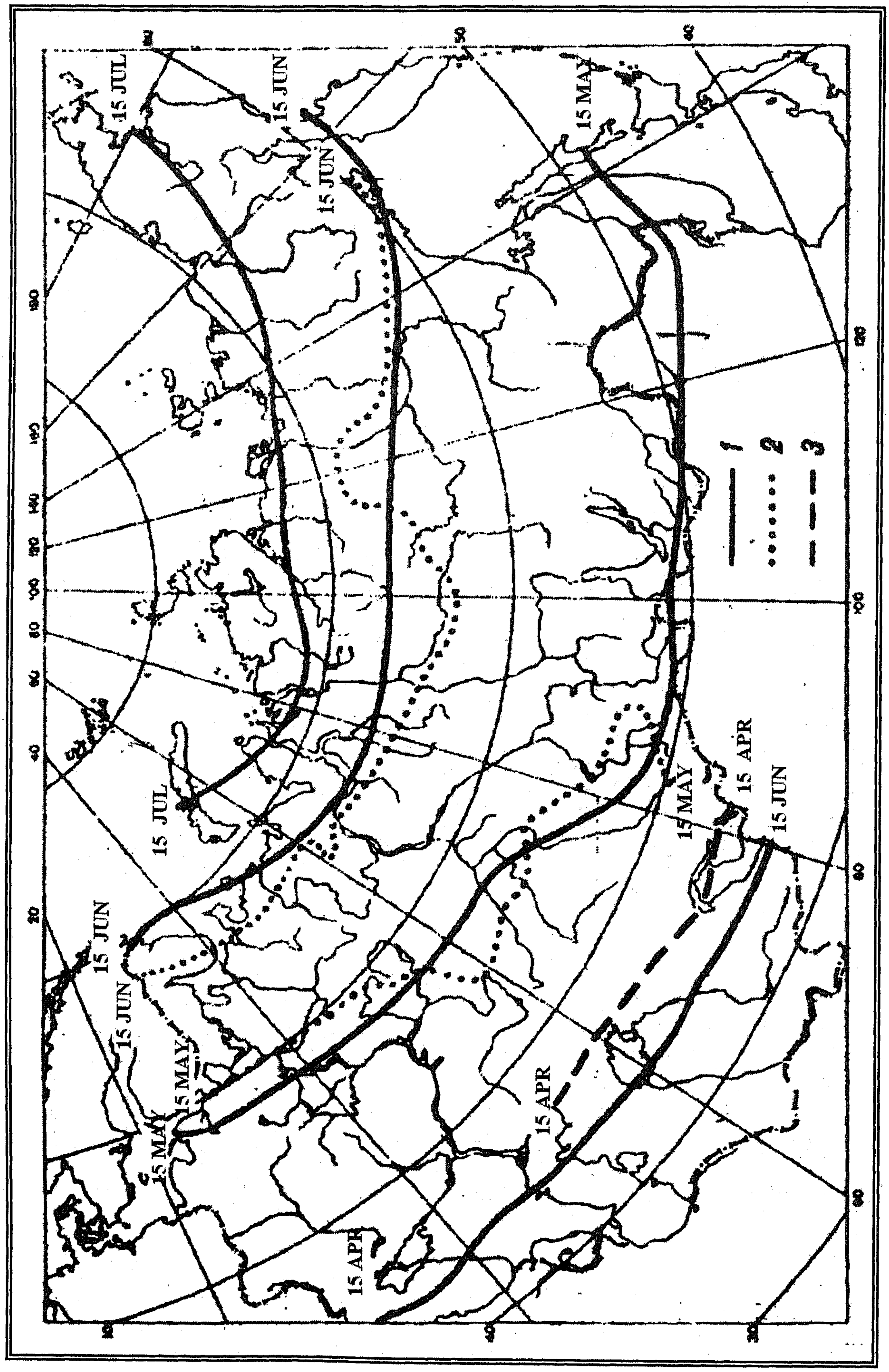


Figure 2.5.2. Comparison of the global "green wave" (B. E. Datier et al., 1975) with isophenes (N. G. Kharin, 1966). 1 – "green wave", 2 – leafing out of birch, 3 – beginning of growth of white saxaul.

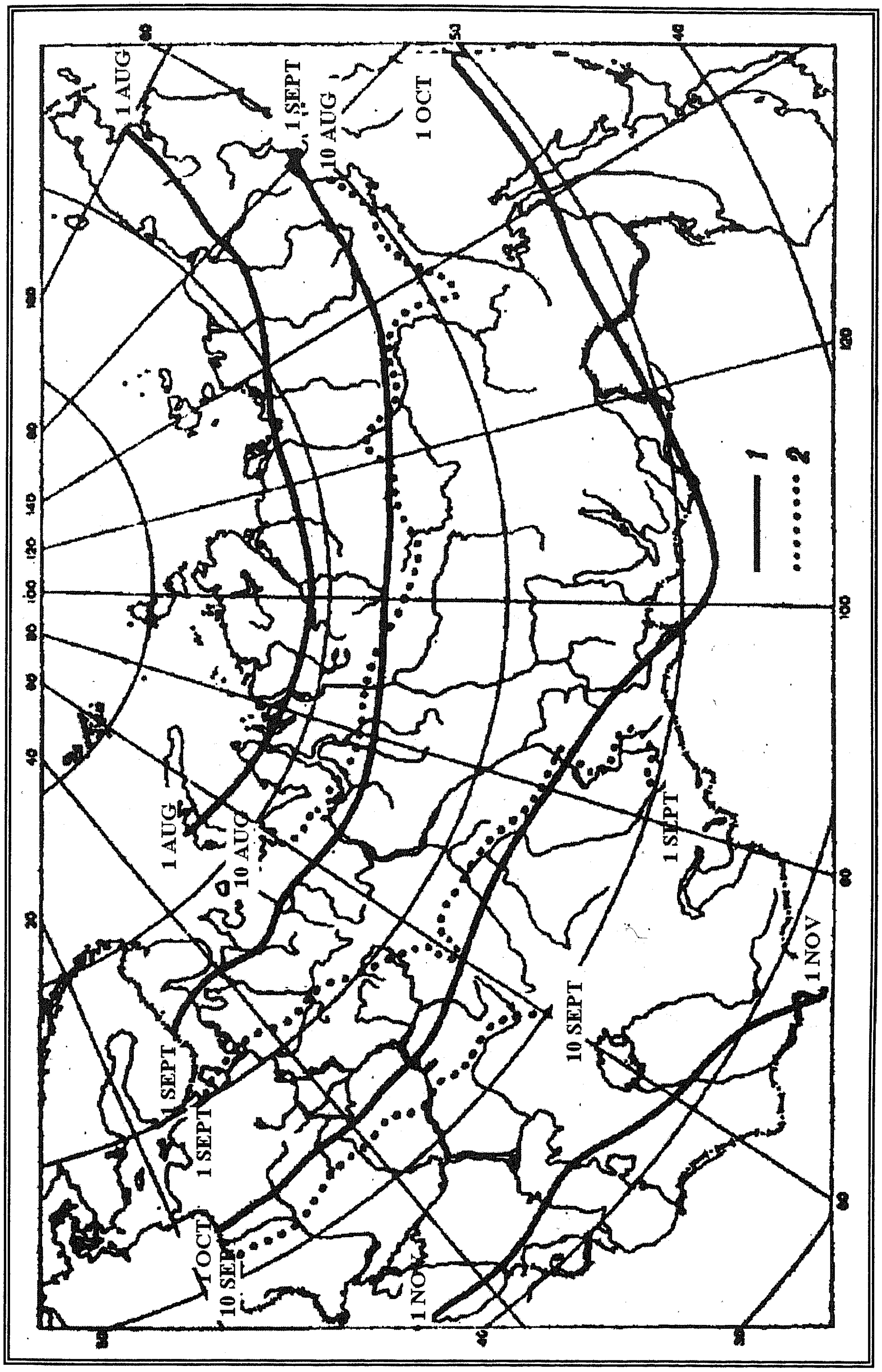


Figure 2.5.3. Comparison of “brown wave” (B. E. Datier et al., 1975) with isophenes (N. G. Kharin, 1966).
1 – “brown wave”, 2 – leaf coloration of birch

Special phenological observations for identification of seasonal indicators of remote sensing missions were conducted in Russia by S. V. Belov (1959) E. S. Artsybashev (1959) and N. G. Kharin (1977).

An example of field observations on leaf growth conducted by N. G. Kharin in 1963 is given in **Figure 2.5.4**. Large scale aerial photo covering the experimental area is given in **Figure 2.5.5**. The experiment was conducted in Bekin forest district of the Far East. The main part of tree species of this area had an intensive growth of leaves during one month – from May 10 till June 10. Only three plant species (*Quercus mongolica, Phellodendron amurense, Fraxinus manshurica*) continued their growth during a long period of time: and they reached the maximum size of leaves only in the middle of July. So, in the area under consideration, the spring period of aerial photography lasted from June 1 till June 10.

Phenological indicators of aerial photography during all seasons of the year are given in **Table 2.5.1**. They are based on phenological information summarized by N. G. Kharin et al. (1993).

Table 2.5.1
Phenological indicators of aerial photography in taiga forests
(N. G. Kharin et al., 1993)

Seasons of year	Phenological indicators	Photographic films	Notes
Spring	Full leaf of birch, beginning of leafing out aspen, opening leaf buds of fir and spruce	Panchrom	
Summer	Full leaf of fir and spruce	Panchrom, Infra, False color	
Autumn	Beginning of leaf coloration of birch	Panchrom, Color	Full leaf coloration of birch is the indicator of the end of this period
Winter	End of leaf fall of birch and larch	-	The season is not suitable for aerial photography of forests

2.6. Phenological indicators of aerial photographic missions of forests in Central Asia

Optimal seasons of aerial photography of forests in central Asia (on the territory of the former Soviet Republics), are different from that developed for the territory of Russia. The forests of Central Asia can be divided into three main categories : desert forests, tugai forests and mountain forests.

Forests of the desert zone

During the Soviet period, shrub thickets of the desert zone of Central Asia were considered as forests and stayed under the control of Forest Departments of the former Soviet Republics. Woodland and thickets of Saxaul (*Haloxylion persicum, H. aphyllyum), Calligonum sp.* and some other desert shrubs belonged to this category of forests. This land cover type played an important protective role for stabilization of moving sand dunes

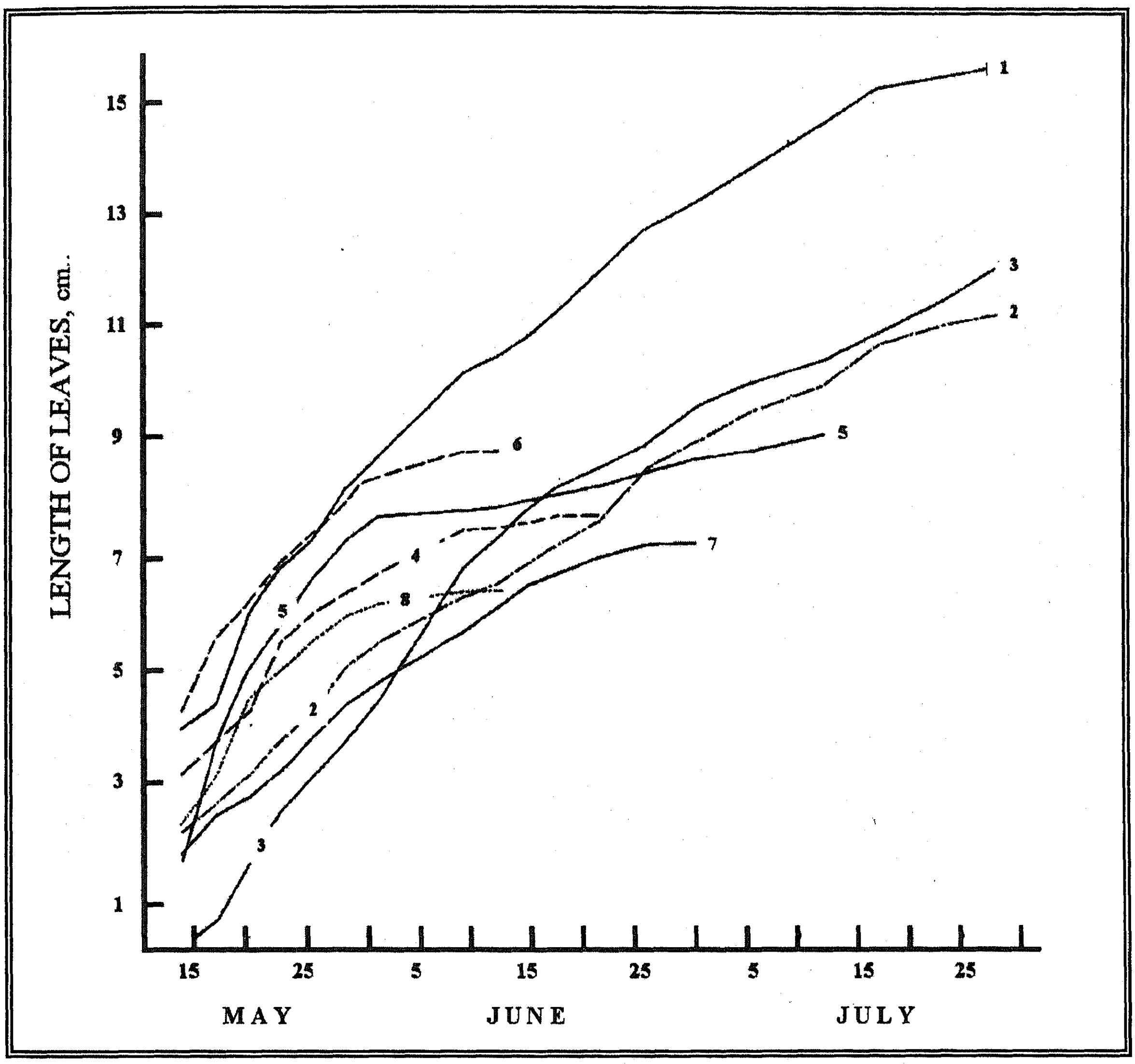


Figure 2.5.4. The dynamics of leaf growth in Bekin forest district, Khabarovsk administrative region, Russia. Observations were fulfilled by N. G. Kharin in 1963. Tree names of tree species : 1– *Quercus mongolica,* 2 - *Phellodendron amurense*, 3 - *Fraxinus manshurica*, 4 - *Tilia amurense*, 5 – *Acer mono*, 6 – *Populus tremula*, 7 - *Ulmus japonica*, 8 – *Betula platyphylla.*

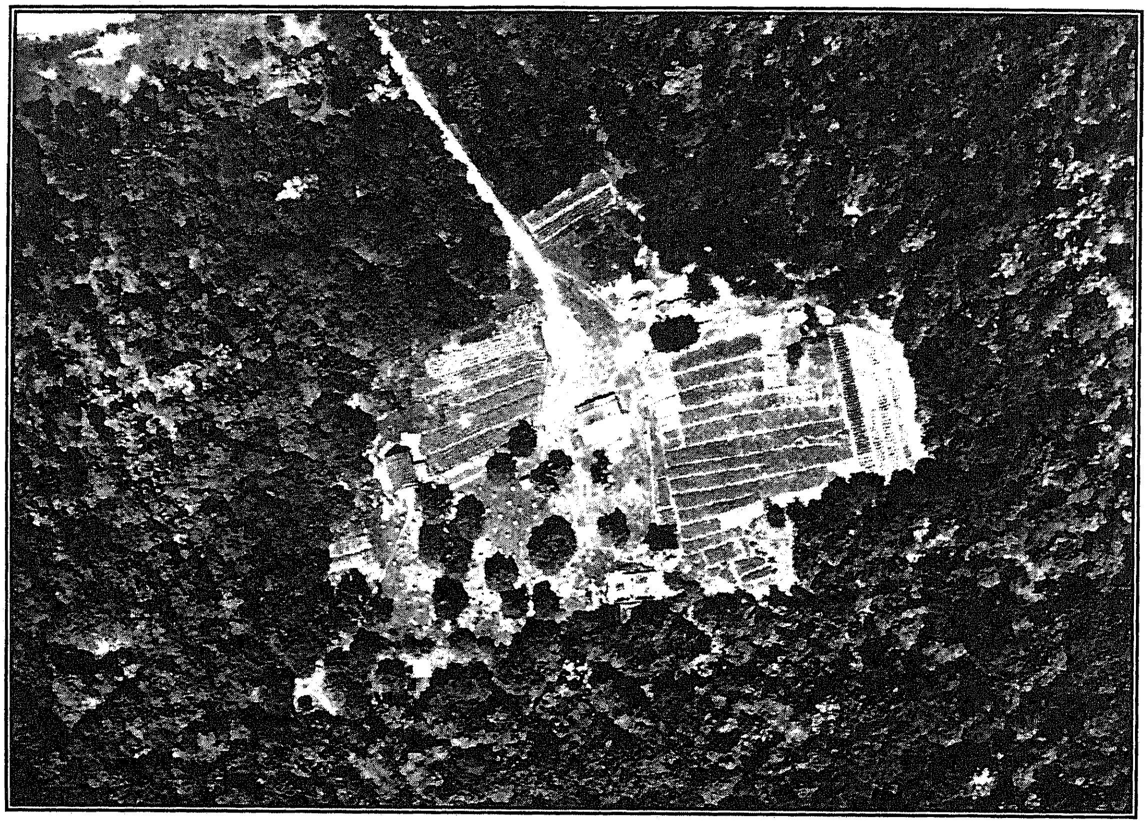


Figure 2.5.5. Large scale (1 : 3,000) photo covering the experimental area in Bekin. Bee garden is located in the central part of the photo. From the personal archives of N. G. Kharin

and was the source of fuel for local population. Protective role of desert forests is increased at present time because of the progress in desertification.

N. G. Kharin (1980) developed a special recommendation on selection of the optimal season for aerial photography of desert forests. Panchrom film is the most suitable film for mapping of desert forests. Application of color and false color films did not give better results because of low spectral reflectance of desert shrubs. Spring is the most suitable season of aerial photography. The following indicators were selected for identification of the proper season of aerial photography:

1. For the beginning of the period, beginning of growth of white saxaul (*Haloxylon persicum*), 10 days later after appearance of the first vegetative shoots,

2. For the end of the period, drying up of ephemeroid *Carex physodes*.

The dates of the optimal season of aerial photography are given in **Table 2.6.1**. These dates are corrected for the annual fluctuations, and **Table 2.6.3** can be used in any year.

Table 2.6.1
Optimal season of aerial photography of desert forests in Central Asia
(N. G. Kharin 1980)

Geographical regions	**Optimal seasons of aerial photography**		
	Beginning	**End**	**Length, days**
South East Karakum	20.03	20.04	32
Central and Unguz Karakum	1.04	25.04	25
Kyzylkum	5.04	25.04	21
Deserts of North Kazakhstan	20.04	5.05	16

Mountain forests

Study of phenology of broad leaved mountain forests and measurements of spectral reflectance (N. G. Kharin et al., 1981) were used by A. G. Rozhkeev (1979) for identification of proper seasons of aerial photography. Experimental works were conducted in Firyuza experimental area, located in Central Kopetdag mountains, Turkmenistan. In **Table 2.6.2** these recommendations are given. One can see that full spring period is the most suitable for aerial photography, and panchrom film can give the best results of photo interpretation. Application of false color film did not give good results because of very low mixture of coniferous trees (*Uniperus turkestanica*).

Tugai forests

Tugai vegetation occupies river valleys and deltas of many rivers in Central Asia. Vegetation consists of the thickets of *Populus diversifolia, Salix sp.* and many other shrubs and grasses, parcels of agricultural land and waste land. The areas of tugai vegetation are reduced in Central Asia from year to year. Photographic images of tugai have specific mosaic because of combination of different land cover types. Only application of large scale photos can provide a proper mapping of these land cover types. A. G. Rozhkeev (1976) studied phenology and spectral reflectance of tugai vegetation in the Tedzhen oasis of Turkmenistan. The results of these investigations are given in **Table 2.6.3.**

Table 2.6.2
Seasons of aerial photography of broad leaved forests of the Kopetdag mountains, Turkmenistan (after A. G. Rozhkeev, 1979, modified)

Aspects	**Phenological indicators**		**Contrast spectral bands, nm**	**Specific conditions of aerial photography**
	Beginning	**End**		
Early spring	Beginning of growth of ephemeral vegetation (the first ten day period of March)	Mass flowering of *Amygdalus tucomanica* (the second ten day period of April)	550 – 650	The period is suitable to study water erosion by application of panchrom and infra films
Full spring	Mass flowering of *Amygdalus tucomanica* (the second ten day period of April)	Drying up ephemeral vegetation, end of intensive growth of tree and shrub leaves (the second ten day period of May)	500 –700	The period is suitable for application of panchrom film
Summer	Drying up ephemeral vegetation, end of intensive growth of tree and shrub leaves (the second ten day period of May)	Mass coloration of leaves of *Amygdalus turcomanica* (the third ten day period of September)	550 – 750	The period is characterized by low contrast between *Juniperus turkestanica* and deciduous trees
Early autumn	Mass coloration of leaves of *Amygdalus turcomanica* (the third ten day period of September)	Mass leaf coloration of *Cercis griffithii* (the third ten day period of October)	500 – 650	Several tree species are not pictured on aerial photos because they are leafless. Panchrom and color films can be used to study phenology
Later autumn	Mass leaf coloration of *Cercis griffithii* (the third ten day period of October)	Full leaf fall of *Cercis griffithii* (the third ten days period of November)	580 – 700	The main part of tree species is not pictured, except *Juniperus turcomanica* and some other trees of later leaf coloration
Winter	Full leaf fall of *Cercis griffithii* (the third ten days period of November)	Beginning of growth of ephemeral vegetation (the first ten day period of March)	None	Low contrast between different ground objects. The period is not suitable for aerial photography

Table 2.6.3
Seasons of aerial photography of tugai forests of Turkmenistan
(after A. G. Rozhkeev, 1976, modified)

Aspects	**Phenological indicators**		**Contrast spectral bands, nm**	**Specific conditions of aerial photography**
	Beginning	**End**		
Early spring	Growth of shrubs (the second ten day period of March)	Leafing out of *Populus diversifolia* (the third ten day period of April)	500 – 700	Panchrom film is the most suitable, but the period is characterized by not stable spectral reflectance of plants
Spring	Leafing out of *Populus diversifolia* (the third ten day period of April)	Drying up *Carex physodes* (the second ten day period of May)	500 – 625 700 – 840	Panchrom and false color films can be used. The best contrast between different ground objects
Summer	Drying up *Carex physodes* (the second ten day period of May)	Leaf coloration of all trees and shrubs (the second ten day period of October)	625 – 650	High contrast between river valley vegetation, desert vegetation and agricultural land. Application of false color film is recommended
Autumn	Leaf coloration of all trees and shrubs (the second ten day period of October)	Full leaf fall of all trees and shrubs (the second ten day period of December)	550 – 625 750 – 840	Unstable spectral reflectance characteristics of desert vegetation and agricultural land. Aerial photography can be used only for specific tasks, e.g. for melioration study of tugai

2.7. Methodology of compilation of the maps of seasonal aspects on the basis of NDVI imagery

NDVI data and its preprocessing

The source NDVI data is Pathfinder global 10 day composite 8 km AVHRR NDVI data which is available from:

http://daac.gsfc.nasa.gov/data/dataset/AVHRR/01_Data_Products/04_FTP_Products/ index.html

More information about the data can be obtained from:

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/LAND_BIO/Pathfinder_Data_Desc.html

The following steps of preprocessing were applied to these NDVI data:

(a) *Transformation of map projection*

The original map projection is Interrupted Goode Homolosine projection. It was transformed to Plate Carree projection (latitude/longitude coordinate system) for easier usage of the data.

(b) *Temporal Window Operation(TWO) Method*

10-day composite NDVI data still include some clouds which prevent to extract land surface information from NDVI data. In order to remove the effect by clouds, the TWO method was applied to the time series NDVI data. By the TWO method, smooth seasonal change pattern of NDVI data can be obtained.

(c) *Transformation from NDVI to RG*

The Relative Greeness(RG) calculated by the following formula was used for the subsequent procesing of the detection of seasonal aspects. The use of RG is simply to normalize the variation of NDVI values in one year. This transformation was applied for easier detection of phenoligical phases described below.

$$RG(t) = \frac{(NDVI_{(t)} - \min_{NDVI})}{(\max_{NDVI} - \min_{NDVI})} \times 100$$

where NDVI (t) ··· NDVI at the time 't'
$\max_{NDVI}$ ··· maximum NDVI in a year
$\min_{NDVI}$ ··· minimum NDVI in a year

Detection of phenological phases

Figure 2.7.1 is a schematic graph showing five phenological phases (phenologically characteristic times) in a RG curve of one growing cycle. Five characteristic times are:

- starting period of growing season (GS)
- starting period of full leaf season (FL)
- peak period (PP)
- starting period of leaf coloration (LC)
- end of leaf fall (LF)

Figure 2.7.2 and **Figure 2.7.3** show how to detect starting period of growing season (GS) and end of leaf fall (LF) respectively. The GS is defined as the middle time of three consecutive 10-day Relative Greeness(RG)s, with RG values of RG_{i-1}, RG_i, and RG_{i+1} in the order of time, which has the maximum value of (RG_{i+1} - RG_{i-1}) among all sets of three consecutive RG. Similarly, the LF is defined as the middle time of three consecutive 10-day Relative Greeness(RG)s, with RG values of RG_{i-1}, RG_i, and RG_{i+1} in the order of time, which has the miminum value of (RG_{i+1} - RG_{i-1}) among all sets of three consecutive RGs.

Figure 2.7.4 shows how to detect peak period (PP). The PP is defined as the middle time of three consecutive 10-day Relative Greeness(RG)s, with RG values of RG_{i-1}, RG_i, and

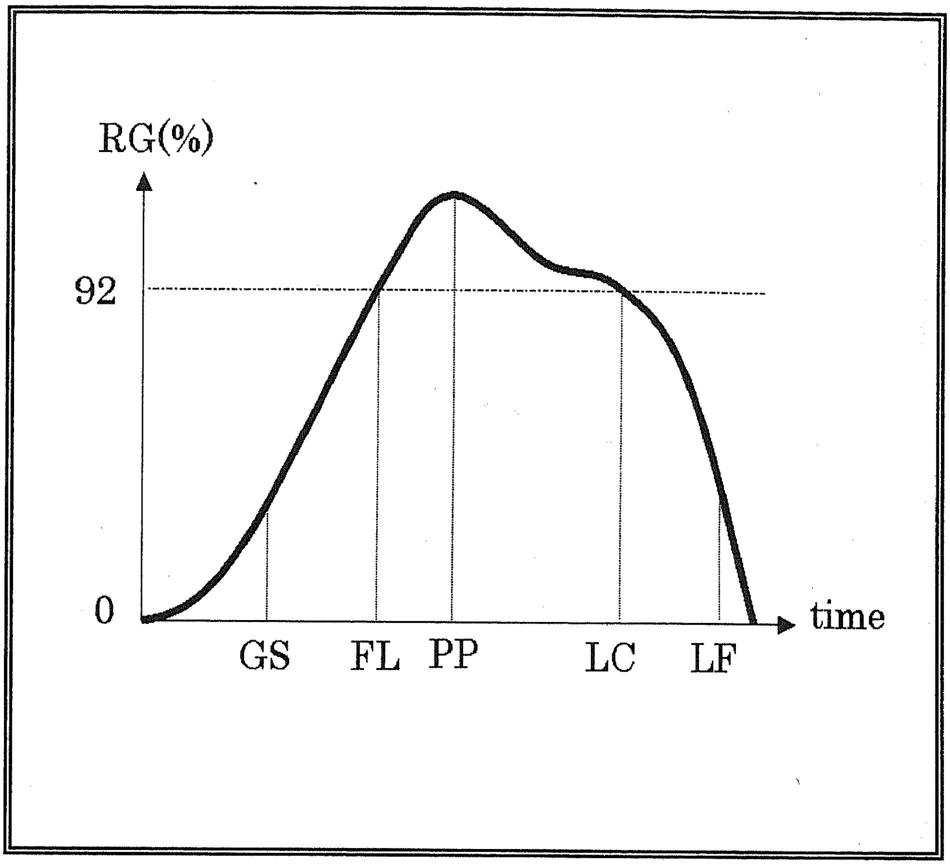


Figure 2.7.1 Detection of starting period of growing season (GS)

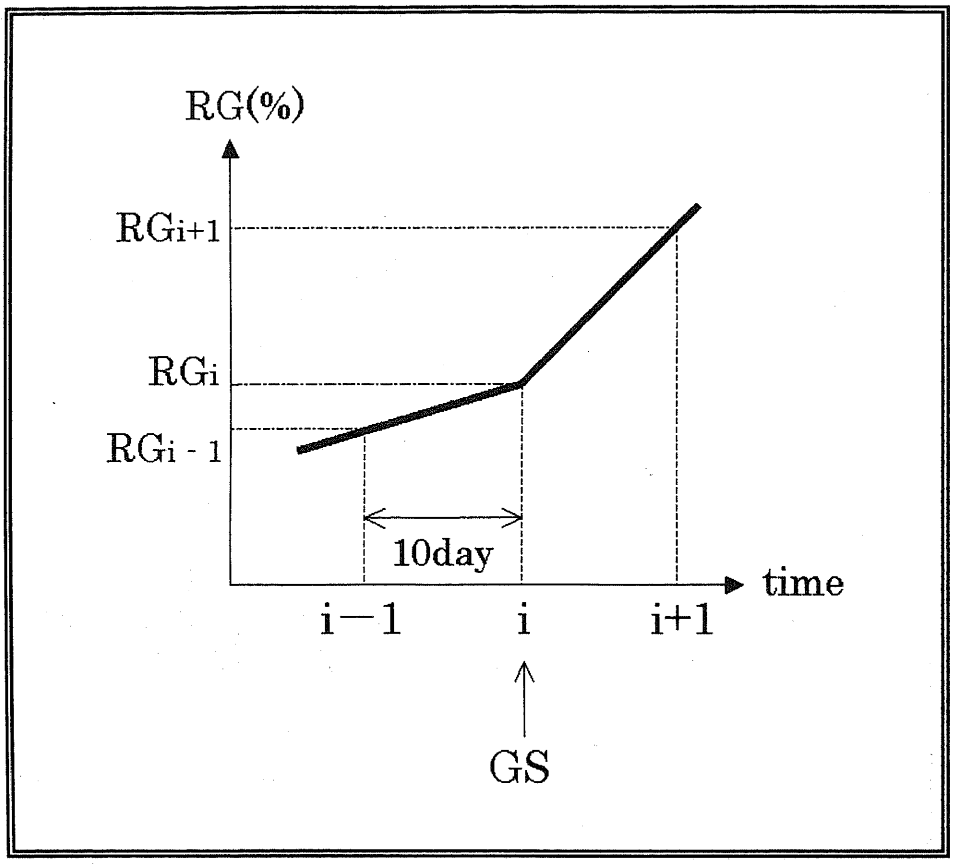


Figure 2.7.2 A schematic graph of phenological phases

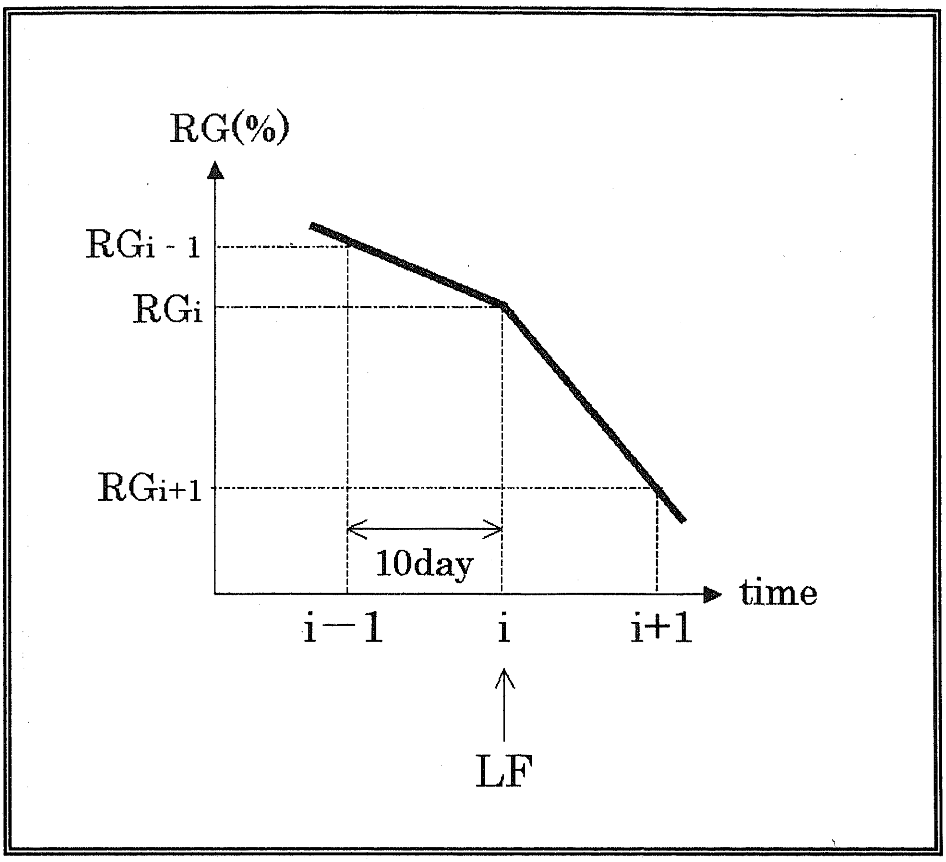


Figure 2.7.3 Detection of end of leaf fall (LF)

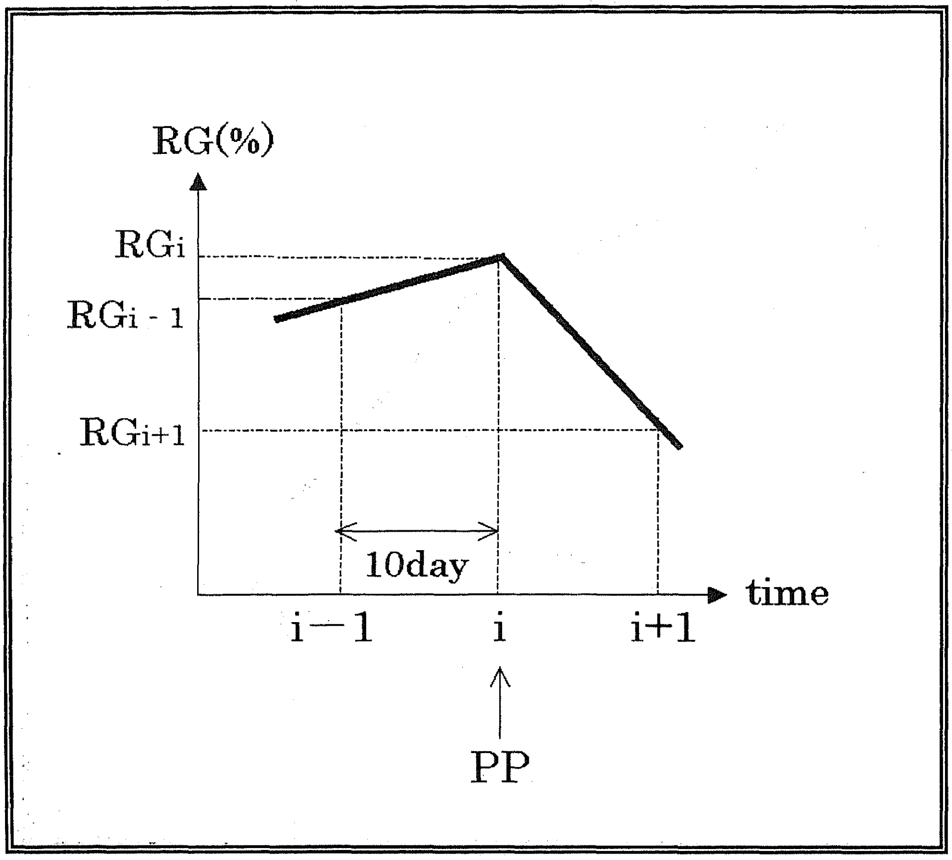


Figure 2.7.4 Detection of peak period (PP)

RG_{i+1} in the order of time, which has the maximum value of (RG_{i-1} + RG_i + RG_{i+1}) among all sets of three consecutive RG.

Figure 2.7.5 shows how to detect starting period of full leaf season (FL) and starting period of leaf coloration (LC). The FL and LC are defined as the times crossing the RG line of 92% in a seasonal RG curve. The time of increasing RG is FL and decreasing one is LC. The RG value of 92% was decided from the ground observations of birch leaves in Krasnoyarsk territory in 1950-1970 which is shown in **Table 2.1.2.**

Figures 2.7.6(a), 2.7.6(b), 2.7.6(c), 2.7.6(d), 2.7.6(e) show phenological phases of forests of Russia detected by the above method using AVHRR NDVI data (1982-1999). These figures show the average of 10 years which have middle values (time of 10-day unit) during 1982 and 1999. In the legend of the figures, for example, "4B", "4M", and "4E" mean 1-10 April, 11-20 April, and 21-30 April, respectively.

2.8. Practical application of the maps of seasonal aspects in forestry of Russia

The conceptual approach is based on the previous study of aerial and space photos obtained by photographic and non-photographic remote sensors during different seasons of the year.

Winter and "black spring" periods are not suitable for aerial photography, except some special cases. During the spring period the recognition features for identification of forest species are not stable, varying from place to place. So, aerial (space) photos can not give a standard uniform information about the composition of forest stands, crown density and status of forests, especially if photos are used in vast areas.

In summer, tree species have the highest spectral reflectance in visible and near infrared regions. During this season, the recognition features, especially tonal and color are more or less stable. But in the end of the growing season, when the green chlorophyll pigments are lost, the leaves increase markedly their reflectance in the green region of spectrum, and decrease it in near-infrared region.

Other seasons of the year are not suitable or less suitable for aerial photography, except special cases when users of remote sensing data need a specific information about forest stands or about processes occurred in forest ecosystems. In these cases, the given phenological maps, including the map of the starting period of growing season, can be used.

A methodology of estimation of the proper seasons of aerial (space) photographic missions is given in **Appendix IV** (PHENOTAIGA).

Our phenological maps can be used for identification of the pyrological seasons of the year. As known, "forest pyrology" is a science of forest fire control. According to study of M. A. Sofronov and A. V. Volokitina (1990), phenological indicators can be used for assessment of pyrological seasons of the year. Pyrological characteristics of mixed (coniferous-deciduous) forests correlate with seasonal status of forest stands, undergrowth and soil cover. These pyrological characteristics concern forests with grass soil cover. These forest types are mainly located in the southern regions of the taiga sub – zone. Ground vegetation consisting of sedge (*Carex* sp.) and wood – reed (*Calamagrostis* sp.) stimulate the initiation of forest fires in autumn when these plants are dry and form a kind of dry matter (forest litter). Litter can be transformed next summer into so called "leaf fall" and than – into "forest floor".

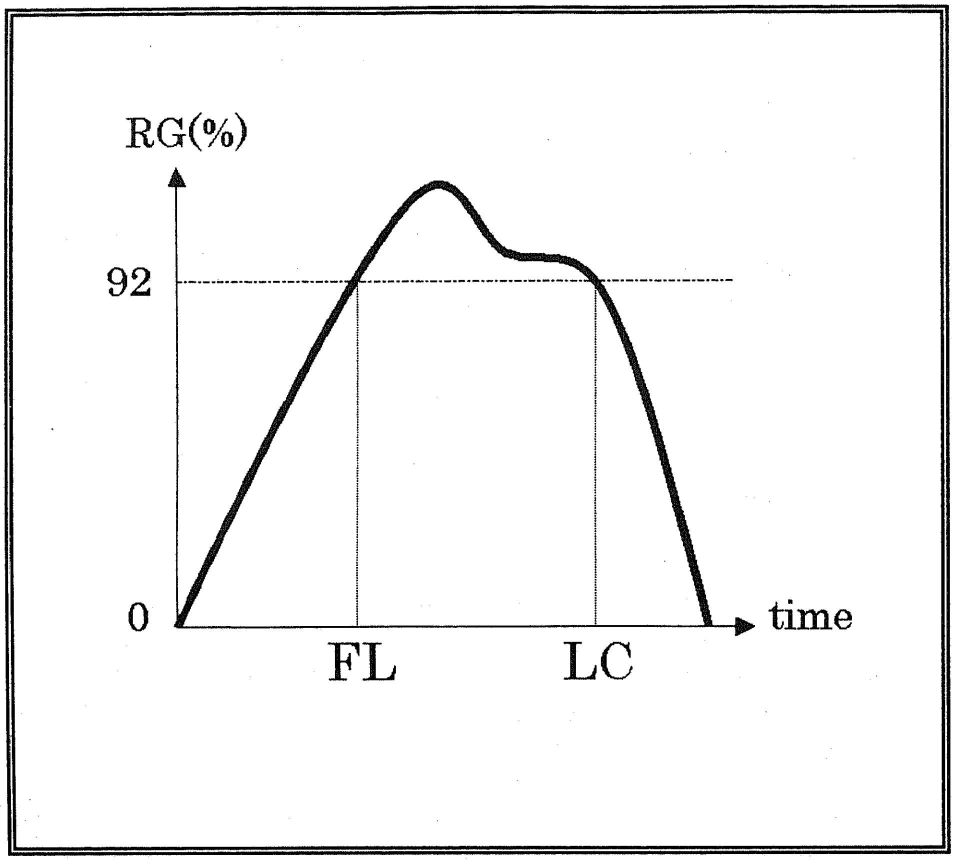


Figure 2.7.5 Detection of starting period of full leaf season (FL) and starting period of leaf coloration (LC)

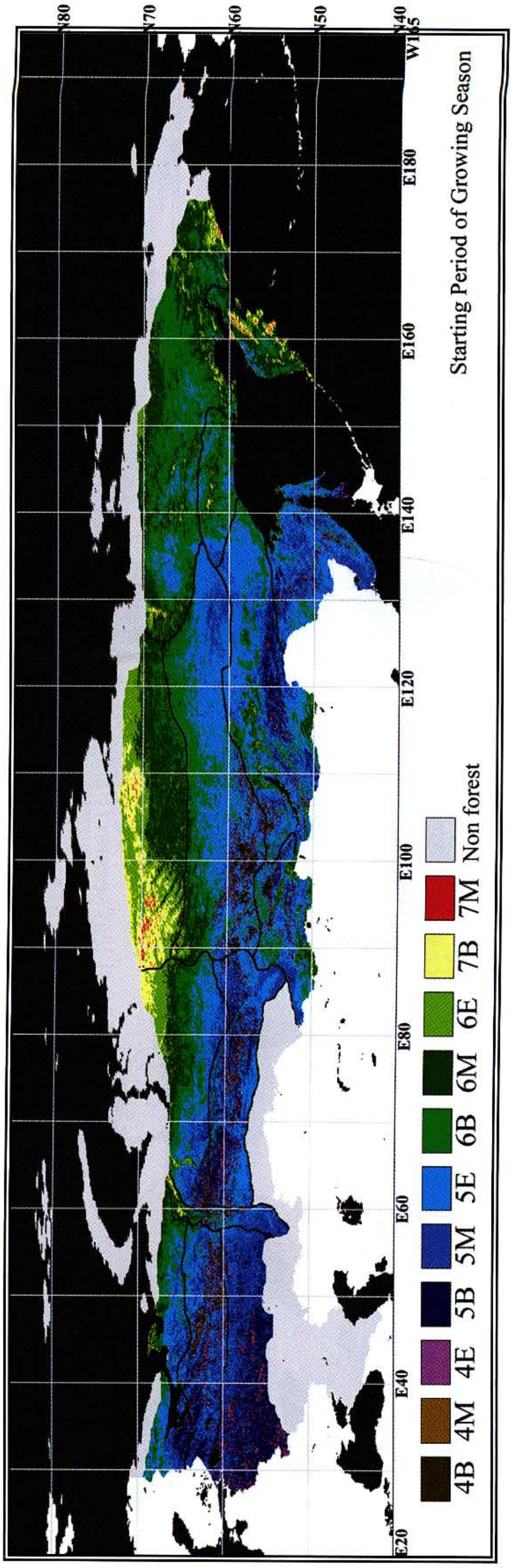


Figure 2.7.6 (a) Estimated starting period of growing season (GS) by AVHRR NDVI (1982 -1999)

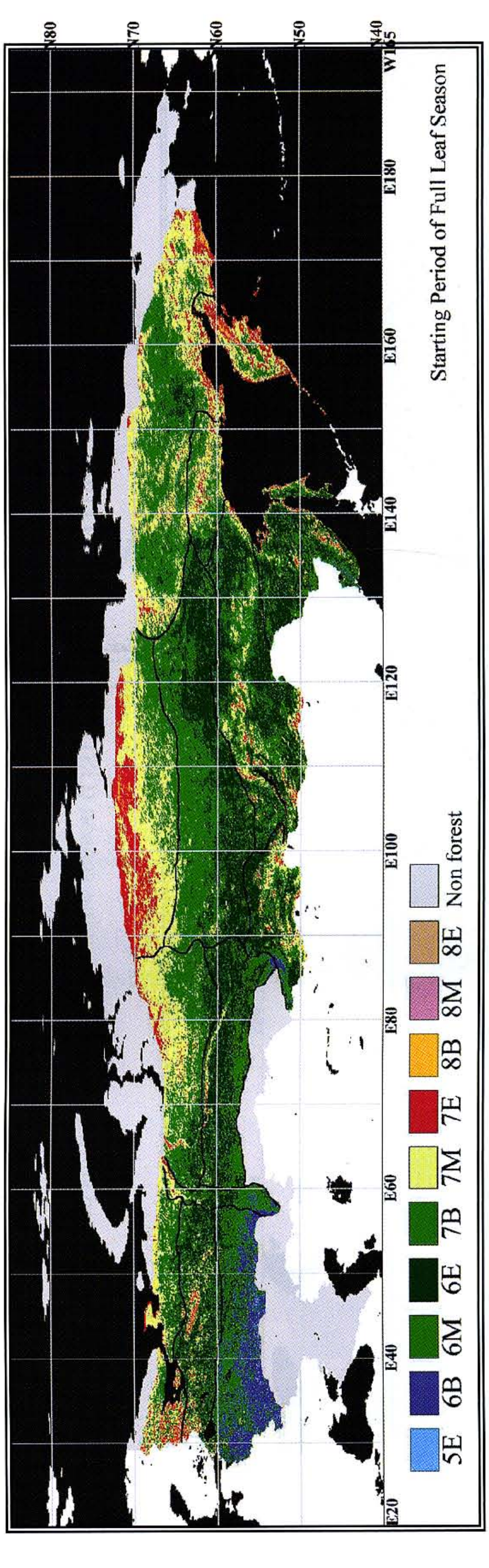


Figure 2.7.6 (b) Estimated starting period of full leaf season (FL) by AVHRR NDVI (1982 -1999)

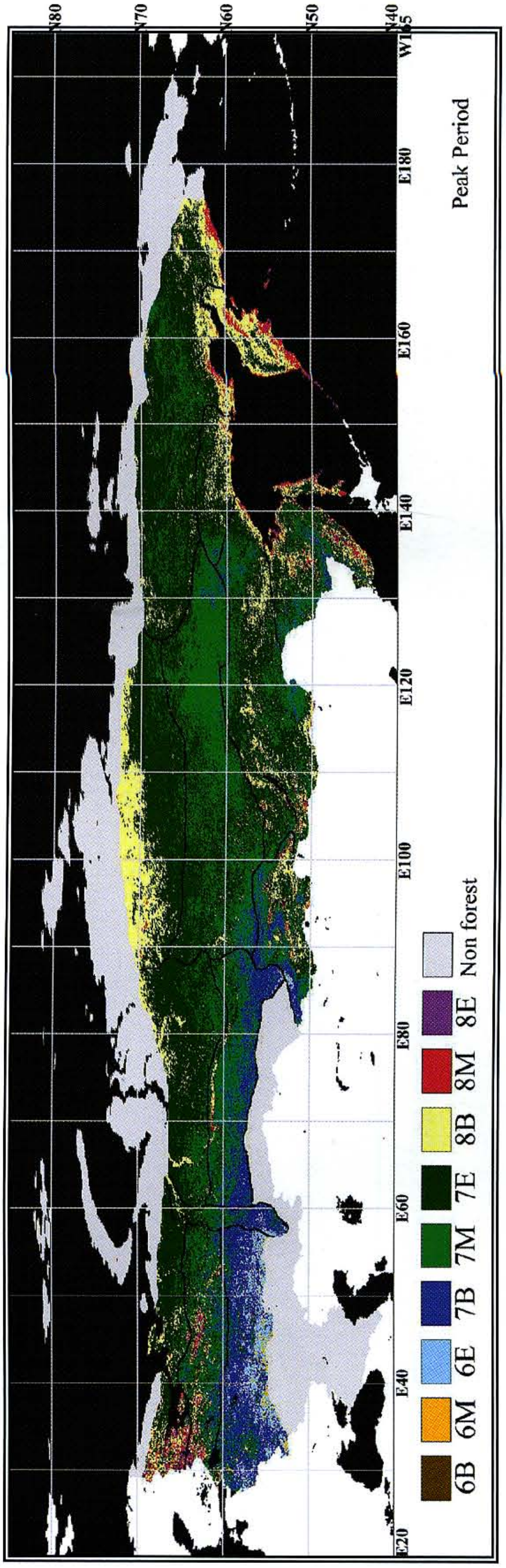


Figure 2.7.6 (c) Estimated peak period (PP) by AVHRR NDVI (1982 -1999)

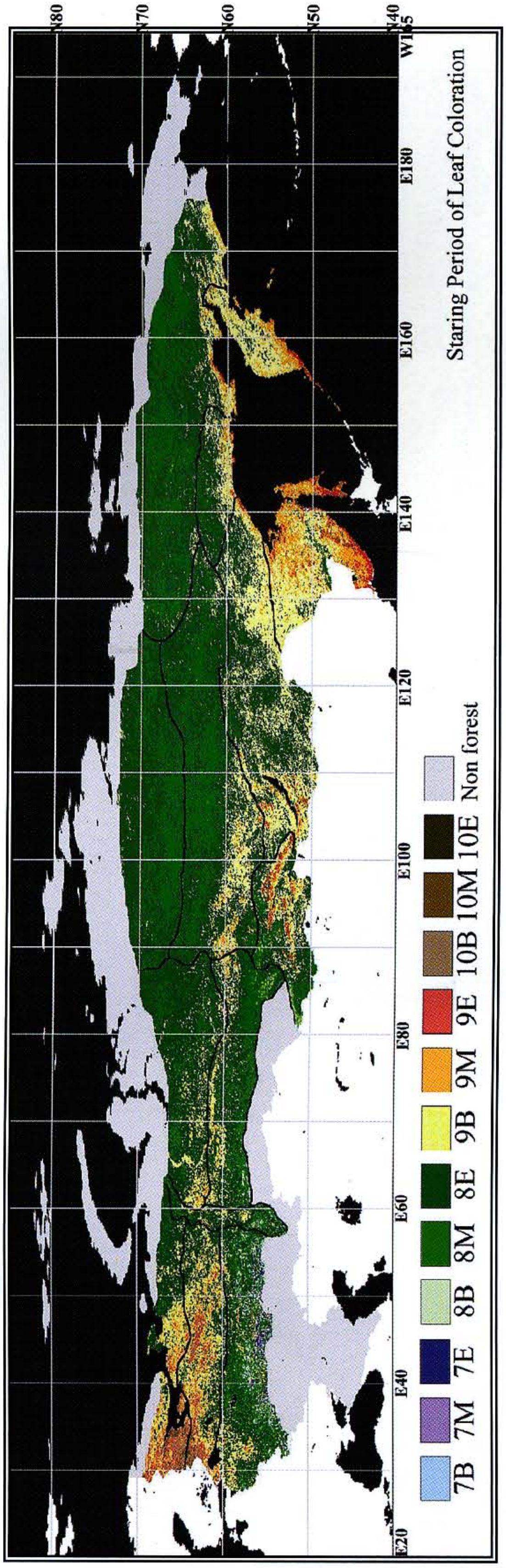


Figure 2.7.6 (d) Estimated starting period of leaf coloration (LC) by AVHRR NDVI(1982 -1999)

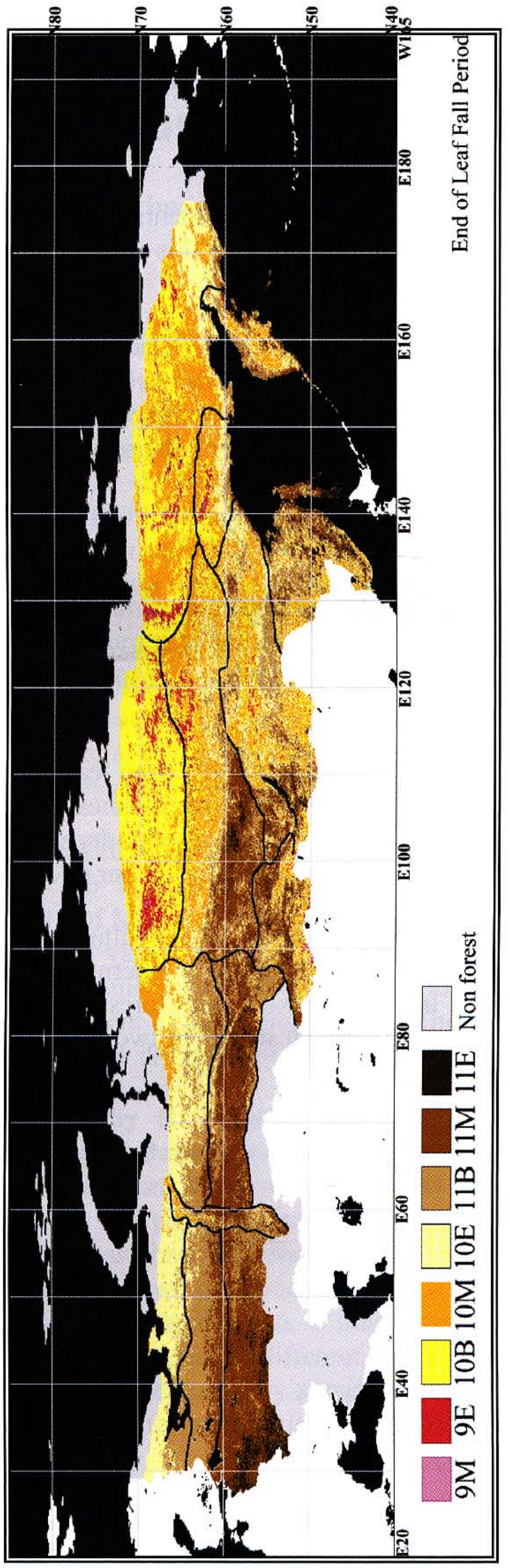


Figure 2.7.6 (e) Estimated end of leaf fall (LF) by AVHRR NDVI (1982 -1999)

A layer of forest floor is formed in autumn, being in some cases dry and soft, and it can be inflamed by forest fire. The leafless forest canopy is permeable for sun rays; and if the weather is dry fire dander is increased. The leafless forest canopy is also permeable for wind which can stimulate the spreading of forest fire in hill country.

So the authors mentioned above have identified the following five pyrological seasons of the year :

1. That is the season of "black spring" which is identified by the seasonal aspect of the same name drawn by NDVI. The end of this season is marked by the map (**GS**);

2. The second period is marked by two phenological indicators : beginning of leafing out deciduous trees, and the end – by the day when the phytomass of green herbaceous vegetation (in dry weight) becomes equal to phytomass of decomposed leaf fall. This period coincides with the seasonal aspect (**FL**);

3. The third pyrological season lasts until the day when forest fire can burn dry wood–reed and sedge (in case of dry weather);

4. The fourth period is called "golden autumn", it coincides with the aspect of leaf coloration identified by NDVI. (**LC**) Grass cover is transformed during this period into litter, but fire danger is not so high because of forest canopy is reduced only in the end of this season;

5. Pre-winter period is a period of "black autumn", from leaf fall until snowfall. The layer of litter and fallen leaves has the maximum thickness during this period. Fire danger is low during this time, except some days with dry weather. But this period is very short and it cannot be identified each year by our phenological maps.

It should be indicated here that "the brown wave" in agricultural lands appeared earlier than in forests. That is especially characteristic for the southern regions of the forest zone where many pixels of agricultural lands are mixed with forest pixels. So, one can see in this map great variations in timing "the brown wave" in two types of lands – forest and agricultural land.

Chapter 3

USE OF SEASONAL NDVI AS INDICATORS OF LAND DEGRADATION IN THE DESERTS OF ASIA

3.1. Interpretation of NDVI imagery.

Formation of NDVI imagery

Spectral reflectance of ground objects within a pixel, structure of plant communities and optical properties of background play an important role by forming the final mixed NDVI signal. The total cover of vegetation in the desert is low, being 10 – 30% depending on physical conditions and degradation. As known, vegetation is adapted to specific soils, depending on seasonal periods of saturation. So, the seasonal changes of vegetation have influence of the final imagery. Several examples of the changes of seasonal aspects in the desert zone are given in sections 3.2, 3.3. and 3.4 of this chapter. Temporary changes of soil moisture in the desert can also change the imagery. For example, in the deserts of Central Asia, temporary flooding the rangelands around oases by irrigation water stimulate the growth of vegetation and the change of plant species composition. As a result, the oasis bordering areas have higher NDVI to be compared with desert land. The places with permanent moisture saturation can be identified by higher value of NDVI. In these places vegetation coverage can reach 50 – 60% and even more. Oases with cultural vegetation and river valleys with shrub thickets belong to these land cover types.

Correlation between rainfall and NDVI was studied in the deserts of Central Asia by N. G. Kharin et al. (1988). In this study correlation was established between the sum of precipitations in April and May and NDVI values for May 21 – 31. Correlation coefficient was 0.62 – 0.726. NDVI values were also correlated with the degree of land degradation in Central Asia. The experiment testified the fact that low resolution imagery could be used for desertification assessment at the regional level. This concept was used by preparation of desertification map of the dry lands of Asia (N. G. Kharin et al., 1999).

Investigations conducted by H. Schmidt and A. Karmeli (2000) in two semi-desert environments of the Negev desert approved this approach. They used NOAA/AVHRR satellite data, 1.1 km resolution. Relationship between monthly maximum NDVI data and monthly rainfall in sandy and rocky environment was established. The highest correlation coefficient (0.46 – 0.55) was observed between NDVI values and amount of rainfall during the concurrent month and the two previous months. The satellite – observed peak of NDVI was registered at the same time as the peak of the delayed response of vegetation to rainfall. They also studied the contribution of different life forms of plants to the mixed NDVI signal. Perennial plants did not show any significant role in forming the NDVI . Annuals changed their contribution to the mixed signal of NDVI with a peak in the first month of the rainy season.

Bare soil surfaces, common in the desert, have specific features which can influence on the final signal of NDVI. Fine-grained soils are commonly darker than coarse-grained soils. Sandy desert is always pictured by lighter tone on NDVI imagery. Solonchak, avoid of vegetation, have always stable spectral reflectance (except the days after rainfall) and they are pictured by uniform gray tone. Other physical features which can change the final NDVI signal include topography, slopes, bedrock composition, drainage pattern etc., if they appear in vast areas. Shape and form of natural objects, especially by interpretation of 1km resolution imagery, can be used as identification criteria by mapping of different land cover types, e.g. river deltas, oases, alluvial fans, vegetation in river valleys etc.

Traces of human activities can also change of the final NDVI signal. Concentration of livestock near watering points in the desert is resulted in destruction of the vegetative cover. These areas can be pictured on small resolution imagery by specific oval form and light tone. Plowing up sandy soils in semi-desert zone for dry agriculture, leading to wind erosion, can be also identified by low resolution imagery.

Landscape concept of photo interpretation

Landscape concept of photo interpretation is widely used in Russia by thematic mapping, especially by application of remote sensing. Landscape, as an object of landscape survey, can be seen as a spatial phenomenon, as an object of classification and survey. As R. J. Chorley and B. A. Kennedy (1971) indicated, earth observation data, in their raw form are internally and externally inconsistent. They say :"Geography is concerned with medium scale systems; those lying somewhere between the scales of the atom and the universe". This general consideration does not contradict the landscape theory developed by Russian scientists.

As known, each landscape has several specific features which are in general unique. But some of these features can be common for several landscapes. So, physico–geographical classification of landscapes can be typological and regional. The theory and methodology of landscape survey was developed by Russian geographers (I. S. Berg, 1952, A.G.Isachenko, 1976, B. V. Vinogradov, 1966). The concept in landscape science, known as "landscape ecology" was developed by B. V. Vinogradov (1998) and used as a theoretical basis of landscape mapping. The terms denoting spatial dimension of landscape units and used in Russia, are the following : zone, sub-zone, province, landscape, mestnost', urochishe and fascia. English analogues of the last three units are the following :

Mestnost'	-	Land system
Urochishe	-	Land unit
Fascia	-	Site

Geographical fascia is usually regarded as an elementary topological units. This smallest geographical unit has homogenous sites and habitat conditions as well as single biocoenosis. Urochishe is an association of fascia united by a common drainage, transfer of solid matter and the migration of chemical elements. Mestnost' is an association of genetically and geochemically related urochishe. Landscape (in Russian "landshaft") is an association of similar mestnost'.

Landscape theory is a basic concept in photo interpretation and thematic mapping. Extrapolation of certain regularities from place to place plays an important role in landscape survey and by compilation of thematic maps, including the maps of desertification. Certain physical characteristics studied in key areas *in situ* can be extrapolated by photo interpretation to unvisited vast areas. Elements known from key plots are called "analogues". B. V. Vinogradov (1966) distinguished:

- long–distance (zonal) extrapolation along geographical zones over distances of thousand kilometers by types of landscape–analogues,
- zonal extrapolation over hundred of kilometers by classes of landscape–analogues,
- local extrapolation over tens of kilometers by local analogues.

This concept was used by compilation of desertification map of Asia (N. G. Kharin et al., 1999). Long distance extrapolation of NDVI values was used for several geographical regions of Asia which were considered as landscapes–analogues. This approach was first of all, developed for Central Asia which had sufficient thematic maps and ground truth information.

The initial data used for compilation of this map included different sources of information : thematic maps, desertification maps, aerial and space photos, data collected in the field, etc. The list of sample plot provided with this information is given in **Appendix I** of this monograph. These data can be used for desertification monitoring in future.

Classification of deserts of Central Asia was developed by A. P. Zhumashov (1990). His classification was base on assessment of several factors : lithology, morphology of desert lands, age of landscape, types of vegetation etc. In general, he identified in the deserts of Central Asia six litho – edaphic types of deserts and published the map which included :

- Sandy desert, developed on thick alluvial and maritime sands;
- Sandy pebbled desert, confined to ancient accumulative or denudation plains which were formed on sandstones, conglomerates and pebbles of the Neogen age and more ancient deposits;
- Gypsiferous desert; the surface deposits were formed here by limestone, sandstone, conglomerate and clay;
- Loess desert mainly located in central and southern parts of the region, between the mountains ; loess deposits were usually confined to river terraces, foothill plains and plateaus;
- Clay desert, it usually occupies gentle slopes of Neogen and Quaternary deposits;
- Solonchak (saltbush) desert, it is met in all parts of Central Asia, in the places with shallow ground water.

The map of desert types was used as a part of database by assessment of desertification. NDVI values, for the most common desert types of Central Asia are given in **Table 3.1.1**. These types of desert were considered as landscapes – analogues by interpretation of desertification by NDVI imagery, classified by non supervised approach.

Table 3.1.1
Classes of NDVI , 8 km resolution, 21 – 31 May 1992, for the main desertification types of Central Asia within landscapes– analogues

Types of Desert	Degradation classes	NDVI classes							
		0.00-0.04	0.05-0.09	0.10-0.14	0.15-0.19	0.20-0.24	0.25-0.29	0.30-0.34	0.35-0.39
Sandy desert	V1			+					
	V2				+				
	V3				+				
	E2		+						
	E3		+						
Salt bush desert	V1			+					
	V2			+	+				
	V3				+				
Gypsiferous desert	V1	+							
	V2		+						
	V3			+					
Clay desert	E1	+							
	E2	+	+						
Sandy pebble desert	E1							+	+
	E2	+							
Deltas and river valleys	I1	+	+						
	I2	+	+						
	I3		+	+					

Note : The symbols (V1, V2... etc.) are explained in **Appendix I**.

3.2. Seasonal aspects of sandy desert in Central Asia

Desertification, being a destructive process, has caused the change of plant communities. Plant species composition, productivity, density and other characteristics of ecosystems are changed under the impact of desertification. Logically, we can suppose that seasonal development of vegetation is also changed in these desertified plant communities. So, we have studied the seasonal changes of vegetation in degraded plant communities. By analysis of seasonal values of NDVI in Central Asia we used the previous information collected by compilation of desertification maps and other publications. Three experimental areas were selected in sandy desert of Central Asia with different degree of desertification.

Central Karakum desert

The experimental area was located in the Central Karakum (the coordinates : 38° 25' N–58° 27' E). In the vicinity of Karrykul village. It was severely degraded desert land with mean precipitation rate 150 mm per year. Climax communities of white Saxaul (*Haloxylon persicum)* were destroyed here under the impact of human activities, and now secondary communities of *Calligonum cetosum* and *C. rubens* dominated here. From desert trees and shrubs the following species were common : *Salsola richtery, Ammodendron conollyi, Ephedra strobilacea.* Ephemeroid *Carex physodes* was the most common plant species which stabilized sand surface and gave valuable forage for livestock. Stabilized sand dunes were combined with moving sands, salina (solonchak) and takyr (clay surface) with sparse vegetation. In general, plant cover had low density, the area being the subject for severe overgrazing (**Figure 3.2.1**). NDVI profile of this plot is given in **Figure 3.2.5.**

P. Z. Radziminsky (1975) conducted here phenological observations and studied spectral reflectance of desert plants. The results of these observations included the seasonal cycle of vegetation development during the growing season of 1974 (**Figure 3.2.2**). Using his publication and these data we have identified the following seasonal aspects :

1. Early spring aspect (April 1 – April 15),

2. Full spring aspect (April 16 – May 25). All plants continue their growth, and several herbaceous plants are in generative stages.

3. Summer aspect (May 16 – October 5) is characterized by the stage of dormancy of ephemeral plants (*Carex physodes* and some others) or by generative stages of *Astragalus* species and some other herbs. Several other species (shrubs, semi-shrubs and dwarf semi-shrubs continue their growth).

4. The autumnal aspect is formed by the fruiting stage of the following plant species :

- Shrubs : *Salsola arbuscula, S. richteri* (10 October – 5 November), *Aellenia subaphylla* (October 5 – October 30),

- Dwarf semi-shrubs : *Artemisia kemrudica* (October 5 – October 25), *Salsola gemascens* (October 10 – October 30), *S. orientalis* (October 5 – October 25),

- Herbaceous plants of summer – autumnal growth : *Agriophyllum latifolium* (August 30 - October %), *A. minus* (August 30 – October 5), *Salsola sclerantha* (October 10 - November 10).

Phenological spectrum, given above, characterizes the seasonal development of desert plants within one year growing season. N. T. Nechaeva et al. (1973) studied phenology of vegetation in the same area during 10 years (1960–1970). They published a limited information on phenology of desert vegetation, giving only the earliest and the latest dates of seasonal development of plant species. They indicated the great variation of rainfall in the region, ranging from 53 mm/year to 175 mm/year. In connection with that, the annual fluctuations in timing seasonal events are great. That confirms **Table 3.2.1** , in which phenological phases of the indicator plants are given.

According to the investigations of spectral reflectance conducted by P. Z. Radziminsky (1975) spectral reflectance coefficients (SRC) of indicator plants are given in **Figure 3.2.3.**

Plant species in the first column belong to psammophyte shrubs, in the central column to psammophyte semi-shrubs, and in the right column to halophytes. All plants have comparatively low SRC, especially in summer and winter seasons. The author of this study came to conclusion that last ten days period of May is the most suitable season of remote sensing in the region of 600 – 700 nm. In the end of May, the contrast between different plant species is the strongest because of their difference in phenological status. He also identified two other contrast spectral regions: 400 – 480 mkm and 760 – 840 mkm.

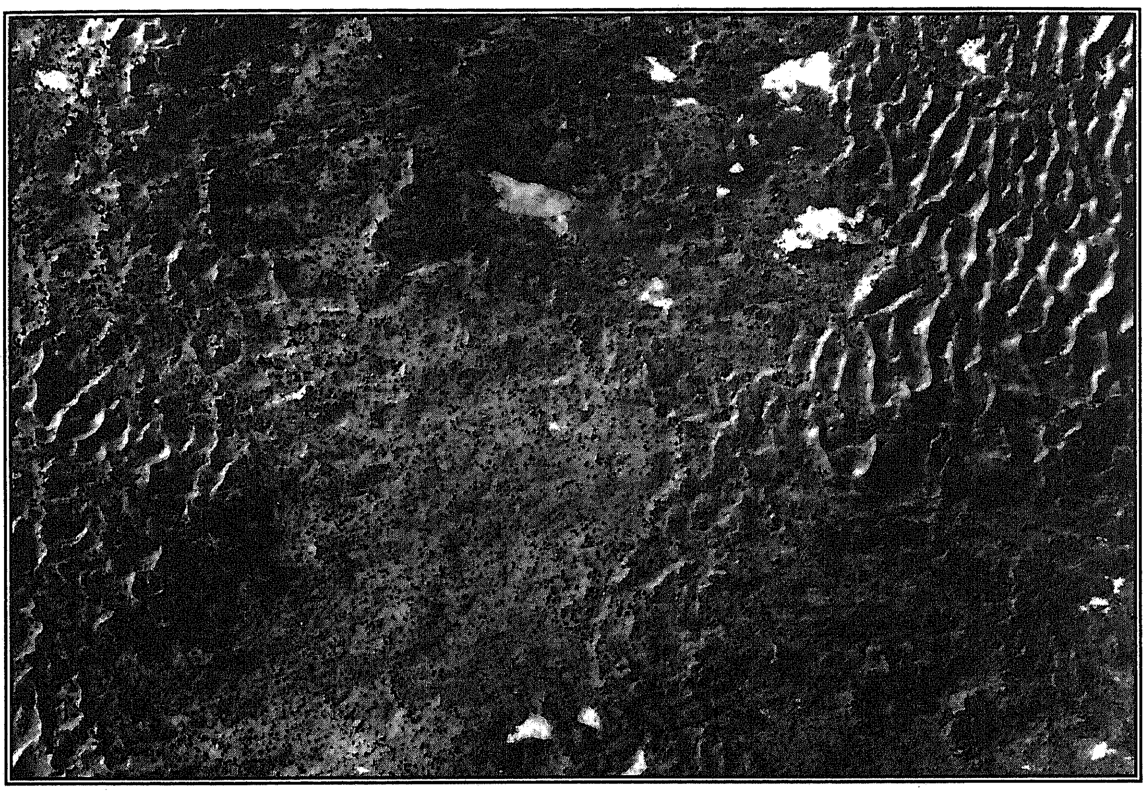


Figure 3.2.1. Aerial photo (scale 1 : 5,000) covering severely degraded sandy desert. From the personal archives of N. G. Kharin.

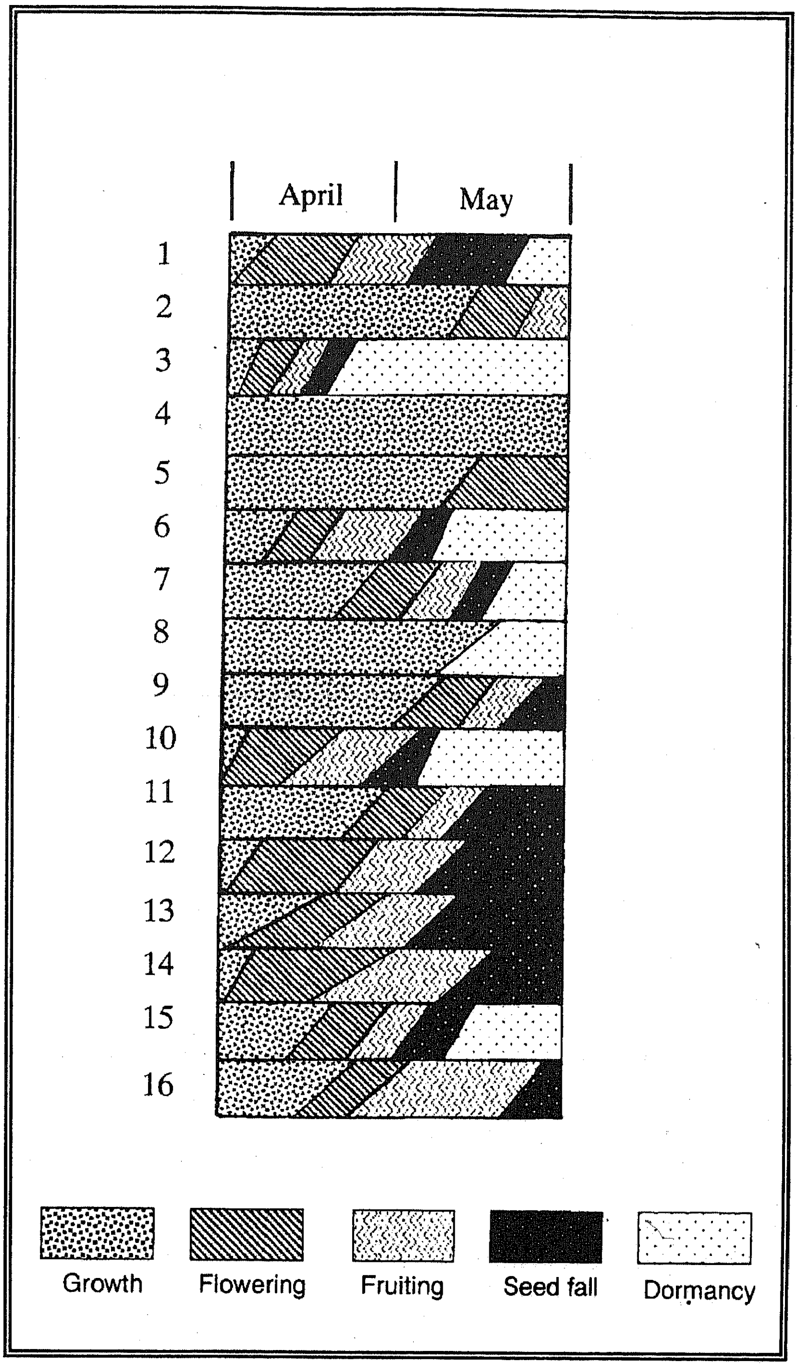


Figure 3.2.2. Phenological spectrum of plant species in the Central Karakum desert in 1974 (P. Z. Radziminsky, 1975) The names of plant species : 1 – *Haloxylon persicum,* 2 – *Salsola paletzkiana,* 3 – *Calligonum sp.,* 4 – *Aelennia subaphylla var. typical,* 5 – *Salsola arbuscula,* 6 – *S. orientalis,* 7 – *S. gemascens,* 8 – *Astragalus maximovitczii,* 9 – *A. unifoliatus,* 10 – *A. agameticus,* 11 – *Ammothamnus lehmanii,* 12 – *Carex pachistilis,,* 13 – *Artemisia kemrudica,* 14 – *Carex physodes,* 15 – *Aristida karelinii,* 16 – *Ferula microloba.*

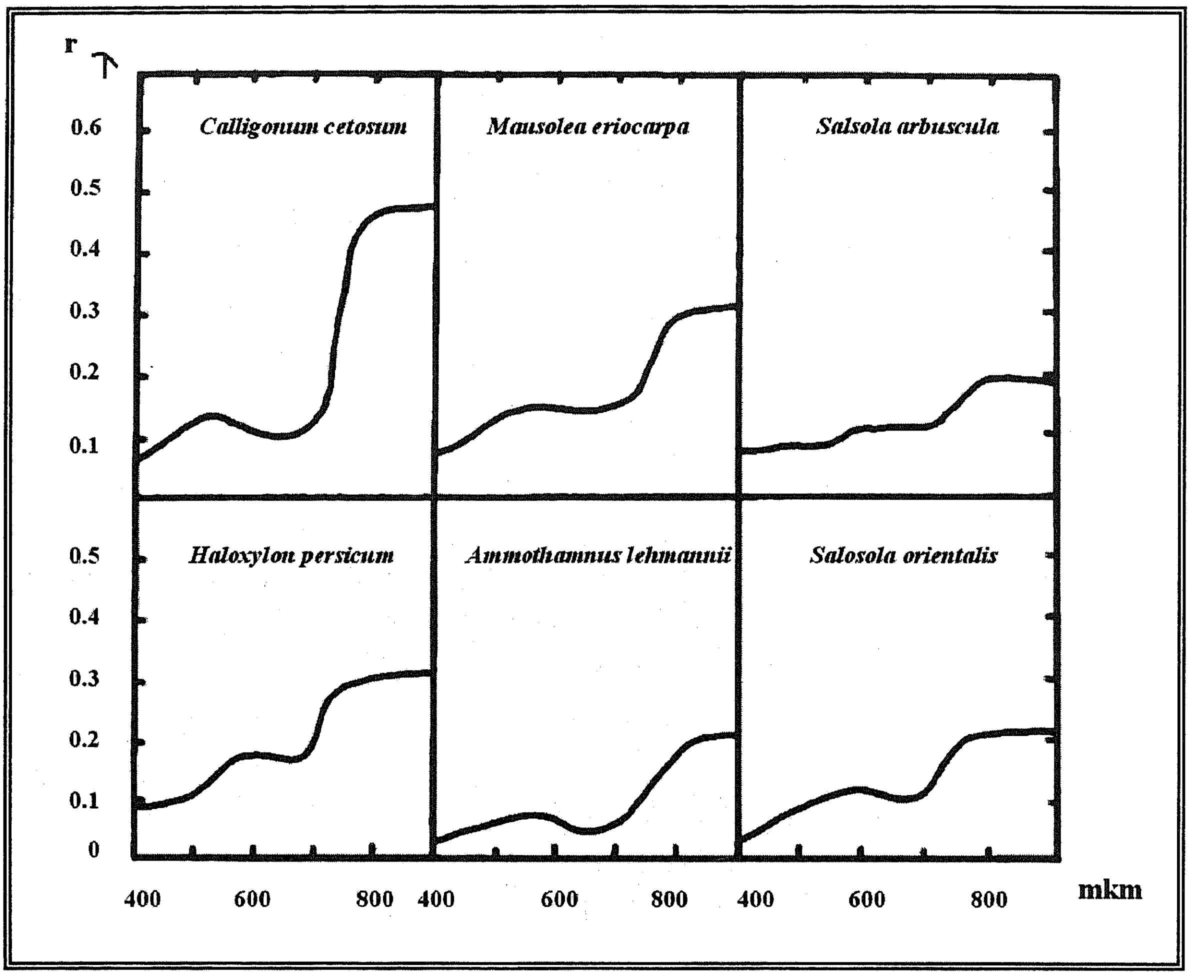


Figure 3.2.3. Spectral reflectance of desert plants measured the field by P. Z. Radziminsky (1975).

Table 3.2.1
Annual fluctuation in timing seasonal events in Central Karakum
(N. T. Nechaeva et al, 1973)

	Beginning of growth		Flowering		Fruiting		End of growth	
Plant species	**Earliest**	**Latest**	**Earliest**	**Latest**	**Earliest**	**Latest**	**Earliest**	**Latest**
				Shrubs				
Salsola richtery	10.03	5.04	20.05-10.06	20.07-15.09	30.05-20.06	5.10-30.03	10.11	25.12
Calligonum cetosum	30.02	5.04	5.04-20.04	30.04 20.05	10,04-30.04	30.05-10.06	22.07-22.08	25.07-15.10
				Semi – shrubs				
Astragalus longipetiolatus	15.11	5.03	5.04-5.05	5.05-5.06	10.04-10.05	15.05-20.06	20.06	25.08
Smirnovia turkestanica	30.01	30.03	10.04-30.04	5.05-20.06	15.04-5.05	25.05 16.06	30.10	13.12
				Dwarf semi-shrubs				
Artemisia kemrudica	15.09	30.02	30.09-20.10	20.10-5.11	5.10-25.10	15.11-25.11	20.11	20.12
Salsola gemascens	25.02	5.04	25.05-25.06	20.07-30.08	30.05-30.06	10.10-30.10	30.11	10.12
				Perennial grasses				
Carex physodes	20.10-	10.02	15.02-30.03	15.03-20.04	25.02-20.04	10.04-10.05	5.05	5.06
Alhagi persarum	10.02	10.04	20.04-30.05	25.06-5.07	30.04-10.06	20.08-30.9	20.10	30.11
				Summer annual plants				
Salsola sogdiana	15.03	5.04	10.05-30.05	30.05-20.06	15.05-5.06	25.06-5.08	30.06	10.08

Key plot in Chilmamedkum desert

Two other key plots in sandy desert of Central Asia were taken. The first key plot was located in Chilmamedkum desert, Turkmenistan, where desertification process was slightly developed. It included community of desert shrubs (*Haloxylon persicum* and *H. aphyllum*) with ephemeral herbaceous plants and comparatively stable sand surface. Phenological spectrum of this plot is given in **Figure 3.2.4**, and the seasonal NDVI profile is given in **Figure 3.2.5**. The following seasonal aspects were identified in this area :

1. Early spring aspect, mainly formed by ephemeroid *Carex physodes;* that plant species creates the dominant coverage during spring aspect. Other early spring herbs included : *Anisanthe tectorum, Eremopirum bounapartis, Erodium oxyrrhynchum, Koelpinia linearis* and some other annuals. During autumn–winter periods 1981 – 1982 and 1982 – 1983, ephemeral vegetation created green aspects; during theses seasons winter aspect was not registered. In the

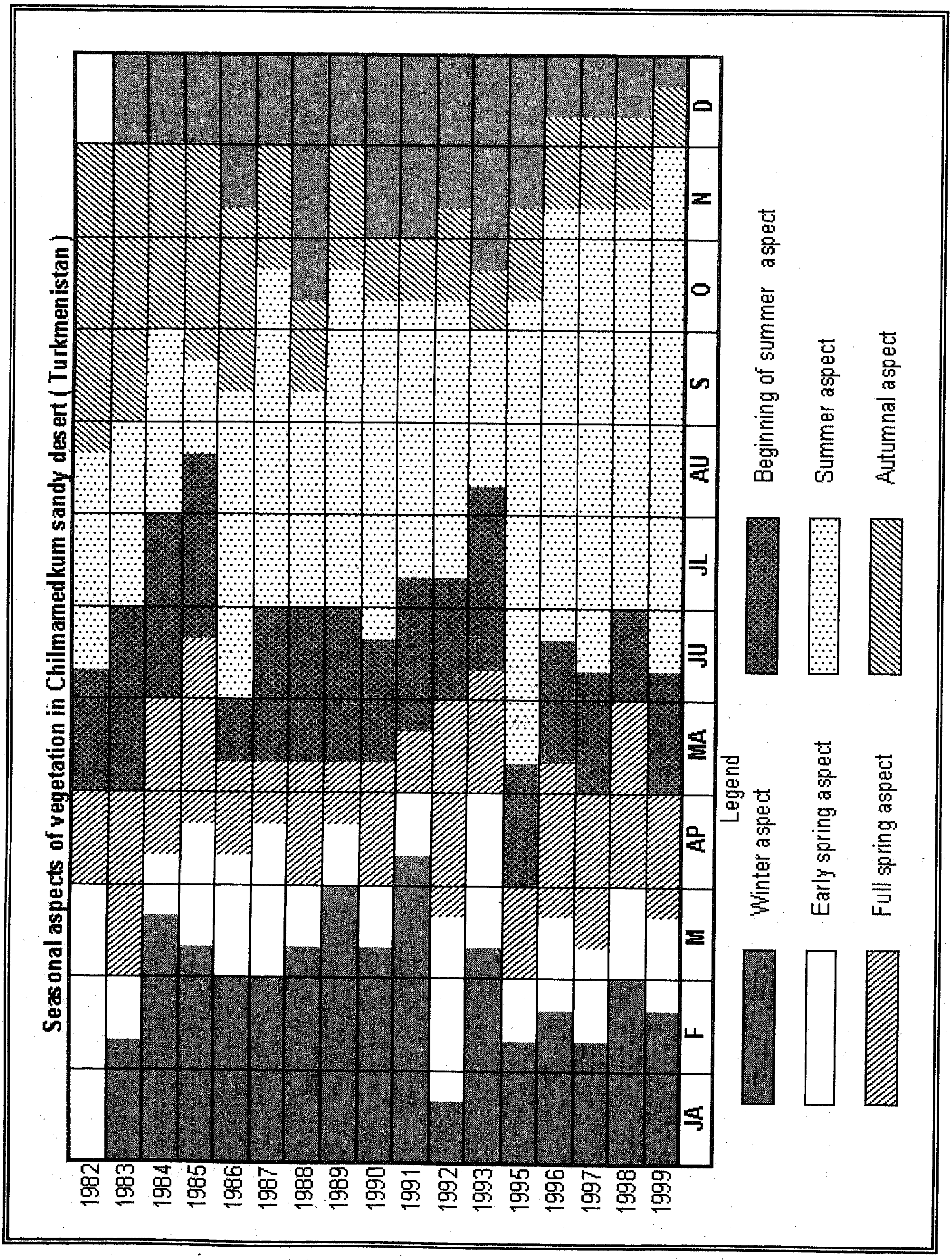


Figure 3.2.4. Seasonal aspects of the Chilmamedkum sandy desert, Turkmenistan, as estimated from NDVI imagery, 8 km resolution.

deserts of Central Asia this phenomenon is observed during the years with plentiful precipitations;

2. Full spring aspect, formed by dominants and subdominant shrubs (*Haloxylon persicum, H. aphyllum, Calligonum cetosum, C. rubens, C. arborescens*), semi-shrubs and herbaceous plants;

3. Beginning of summer aspect, when the main part of herbaceous plant began to wither;

4. Summer aspect, when many herbaceous plans are in stage of dormancy; shrubs and semi-shrubs continued their growth;

5. Autumnal aspect formed by fruiting stage of *Haloxylon* species, *Salsola richteri* and some other shrubs and semi-shrubs;

6. Winter aspect, during this period the main part of species is in stage of dormancy, except an evergreen plant *Ephedra strobilacea.*

Key plot in the Amudarya sandy belt

The second key plot was located in the Amudarya barkhan strip, on the periphery of oasis, in 30 km northwest of Chardzhou, Turkmenistan. It was very severely degraded sandy desert with barkhans and inter-dune depressions. Vegetation cover was here fully destroyed under the impact of man. Only several plants of *Aristida karelinii* were met on sand dunes. *Tamarix sp.* and Camel's thorn (*Alhagi persarum*) grow in low places, temporarily filled with the Amudarya water during spring and summer floods. During the years with abundant watering, Camel's thorn forms a summer aspect distinguished by phenological profile (**Figure 3.2.5**). During the dry years, when bare surface dominates, phenological profile looks like a profile of bare soil.

In conclusion we can say that seasonal profiles of NDVI can be used as an indicators of land degradation. Two criteria confirm that: absolute values of NDVI and its seasonal dynamics during the growing season. The absolute values of NDVI are decreased by desertification because of the destruction of the vegetative cover. The form of phenological profile is also changed by severe desertification; the profile is changed because of presence of thorn plants (like Camel's thorn) or it looks like a profile of bare soil.

3.3. Seasonal aspects of semi-savanna of Badkhyz

This experimental area was located in the Badkhyz reserve of Turkmenistan. The Badkhyz hilly country, with precipitation rate of 250 mm per year, belonged to the belt of subtropical steppe or semi-savanna where Pistachio tree (*Pistacia vera*) was the dominant plant species (**Figure 3.3.1**). According to the investigations conducted by P. Z. Radziminsky (1975), vegetation of the area had the following specific features. In April herbaceous plants began their growth, while Pistachio trees were leafless,

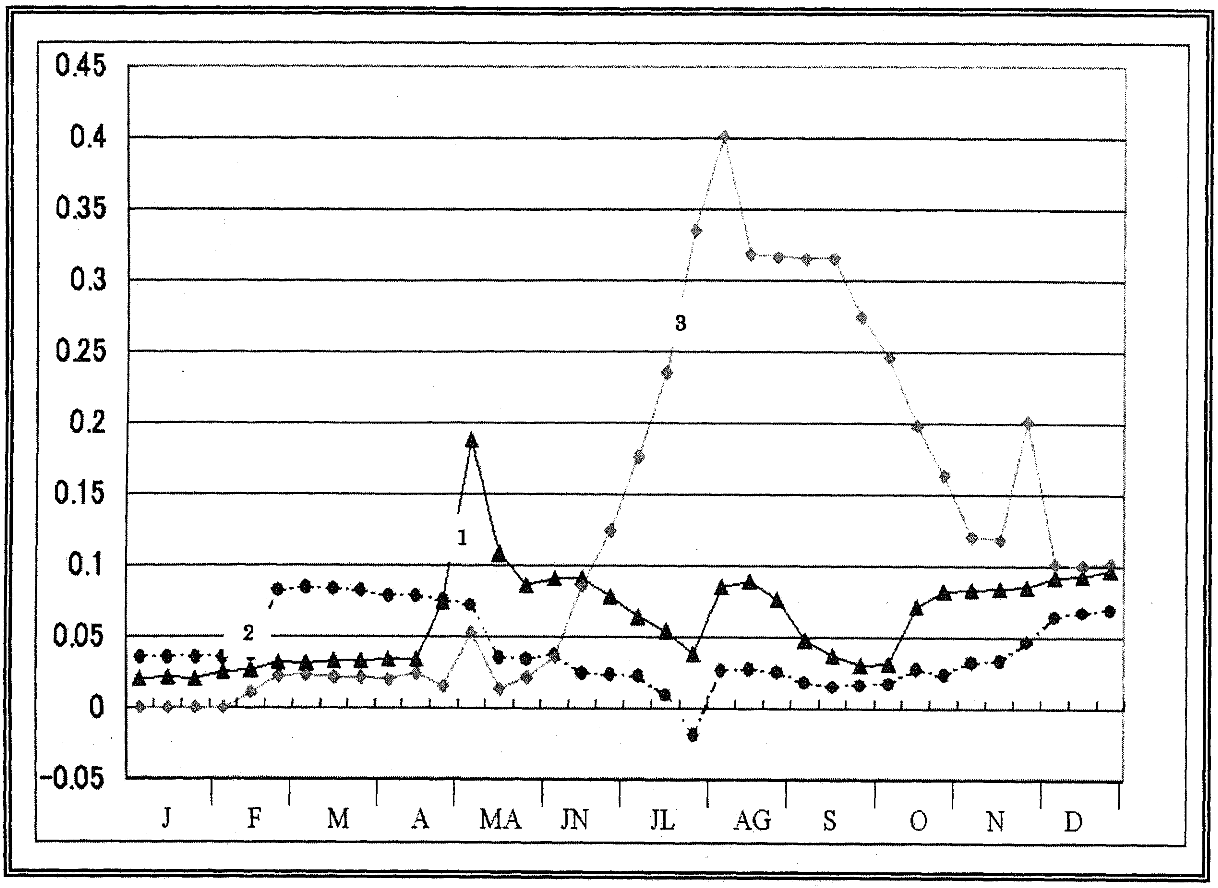


Figure 3.2.5. Seasonal profiles of NDVI of sandy desert by different degree of desertification. 1– slightly degraded desert vegetation in Chilmamedkum desert, 2–severely degraded desert vegetation, Central Karakum, 3- very severely degraded sandy desert with barchans and inter-dune depressions (Amudarya sandy belt).

but had flowers. Leafing out stage of Pistachio began in May. During summer, the main part of herbaceous plants dried up and were in the stage of dormancy. In autumn, some plants were in stage of growth forming the autumnal aspect. Leaves of Pistachio trees changed their color and fall during this period. Phenological observations were conducted during the growing season in 1973. Phenological spectrum of herbaceous plants is given in **Figure 3.3.2**. The graphs indicate the beginning and the end of each phenological phases. The plants of the autumnal growth were not included into this spectrum, but observations were made also in summer and in autumn. The following herbaceous plants formed an autumnal aspect (growth and reproductive stages): *Ferula badrakema*, *Artemisia scoparia, Cousinia schistoptera.* Besides that, Pistachio trees had the autumnal coloration during this season of the year. According to the observations of 1973, the following seasonal aspects were identified:

1. Early spring aspect (April 5 – April 20), formed mainly by ephemeral plants which form the dense cover (*Carex pachystilis, Delphinium semibarbatum, Trigonella laziflora, Avena barbata),*

2. Full spring aspect (April 21 – April 30), formed mainly by ephemeral plants which continue their growth, some of them enter into the flowering stage (*Carex pachystilis, Hordeum spontaneum, Trigonella laxyflora),*

3. Aspect of the beginning of summer (May 1 – May 15), formed by perennial species which have flowers and fruits (*Cousinia congesta, C. schisoptera, Astragalus barrowianus, Ferula badrakema*). Ephemeral plants begin drying up.

4. Summer aspect (May 16 – 1 November); during this period of year some perennial plants are in stage of fruiting, and the rest herbaceous plants are in stage of dormancy.

5. Autumnal aspect (November 2 – November 25), formed by summer and autumnal growth plants which also are in regenerative stage (*Ferula badrakema, Cousinia congesta, C. schisoptera, Artemisia badkhysi*).

6. Winter aspect (later than 25 November). During this period the main part of desert plants are in stage of dormancy.

If we compare these aspects with ones identified by NDVI (**Figure 3.3.3**), we can see that NDVI changes during the growing season reflects the real situation observed in the field. Our ground observations were conducted in 1973, so the differences in timing of seasonal aspects during single years are the results of variability of weather conditions and especially that of precipitations.

Spectral reflectance of plants and soils, not covered with vegetation, was studied in the field by application of field spectrophotometer (**Figure 3.3.4**). SRC were measured in the region of 400 – 840 nm. The results of these measurements for some indicator plants are given in **Figure 3.3.5.** During the summer aspect the values of SRC were the lowest because of the drying up the green parts of species. So, the full spring aspect (1– 25 April) was the most suitable period for application of all types of remote sensors. The spectral region of 500 – 650 nm was the most informative for aerial photography of semi-savanna in the Badkhyz.

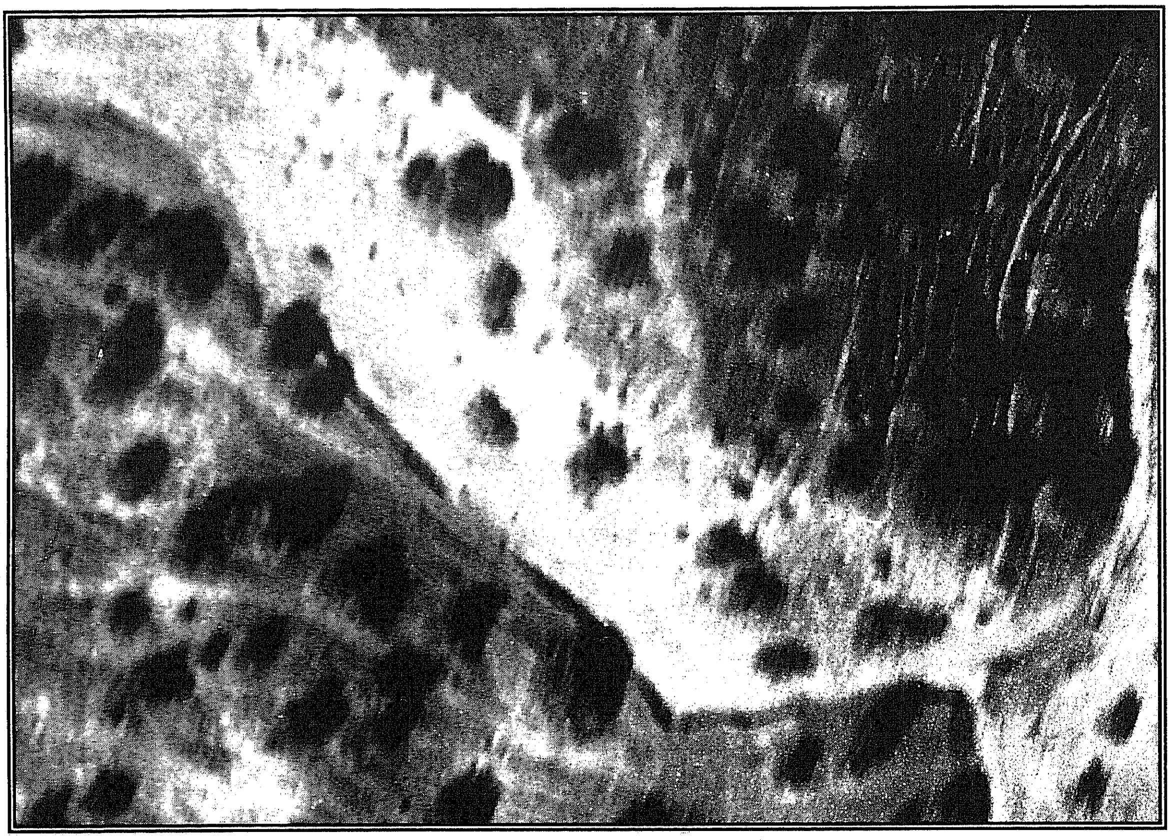


Figure 3.3.1. Large scale aerial photo covering stands of *Pistacia vera* in the Badkhyz reserve. From the personal archives of N. G. Kharin.

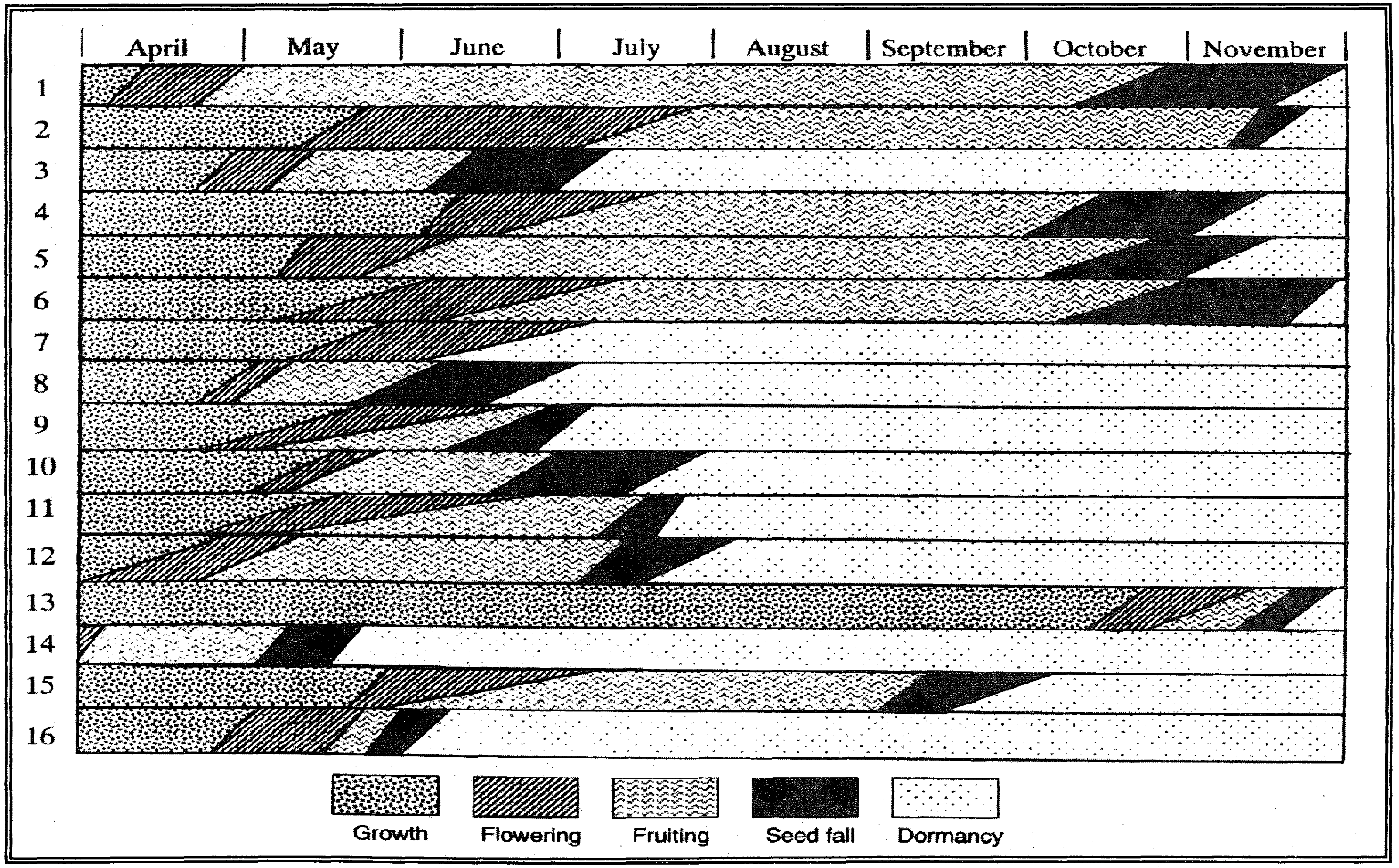


Figure 3.3.2. Phenological spectrum of plant species in the Badkhyz region in 1973 (P.Z. Radziminsky, 1975). The names of plant species : 1 – *Astragalus barrovianus,* 2 - *A. unifoliatus,* 3 – *Carex pachystilis,* 4 – *Cousinia congesta,* 5 – *C. schistoptera,* 6 – *Delfinium semibarbatus,* 7 – *Eremostachys labiosa,* 8 – *Ferula badrakema,* 9 – *Trigonella laxiflora,* 10 – *Alyssum dasycarpum,* 11 – *Haplohpyllum sp.*, 12 – *Onobrychis sp.*, 13 – *Reamuria bilobus,* 15 – *Avena barbata,* 16 – *Hordeum spontaneum.*

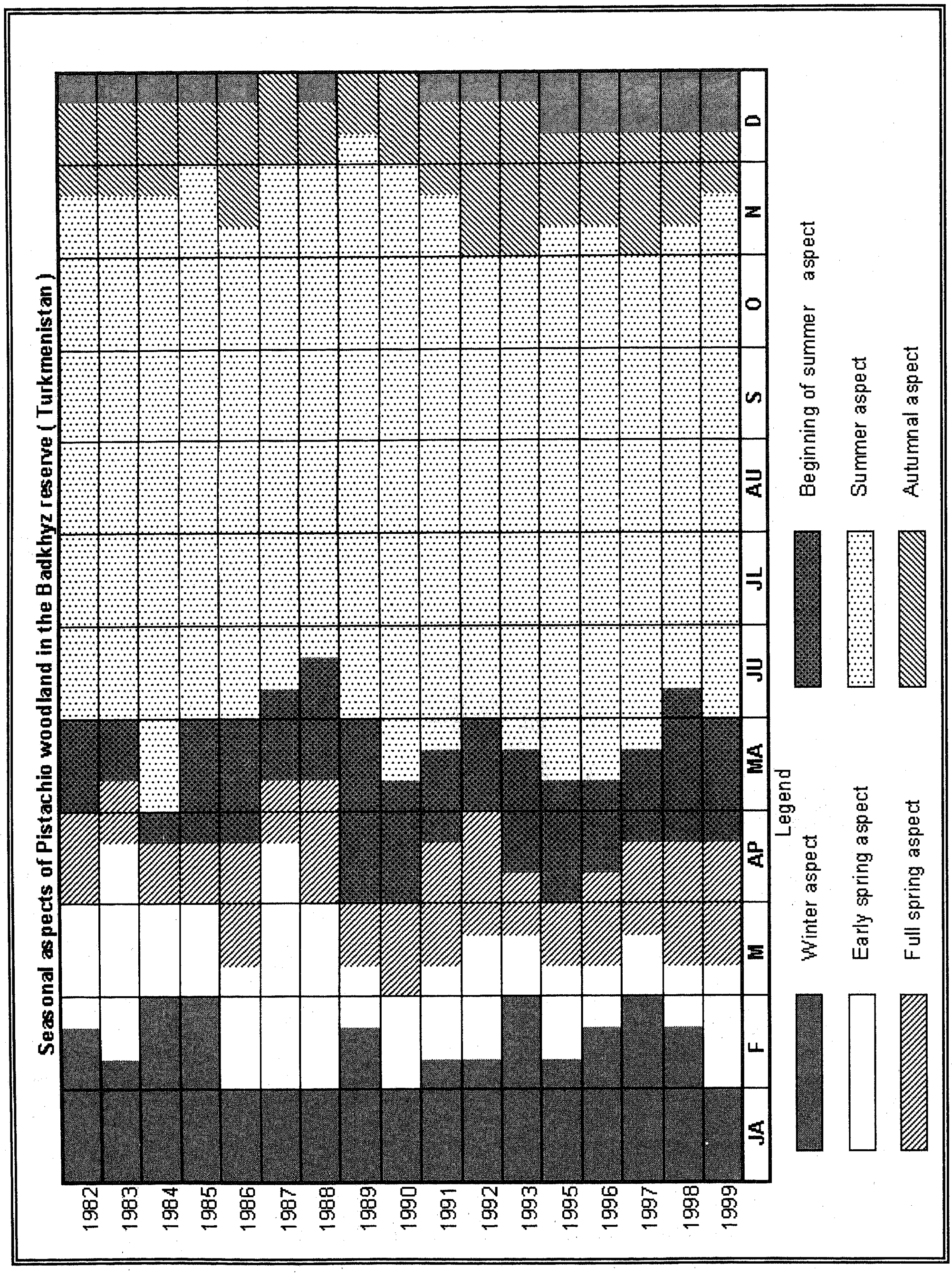


Figure 3.3.3. Seasonal aspects of *Pistacia vera* savanna of the Badkhyz reserve.

Figure 3.3.4. Measurement of spectral reflectance coefficients in the field.

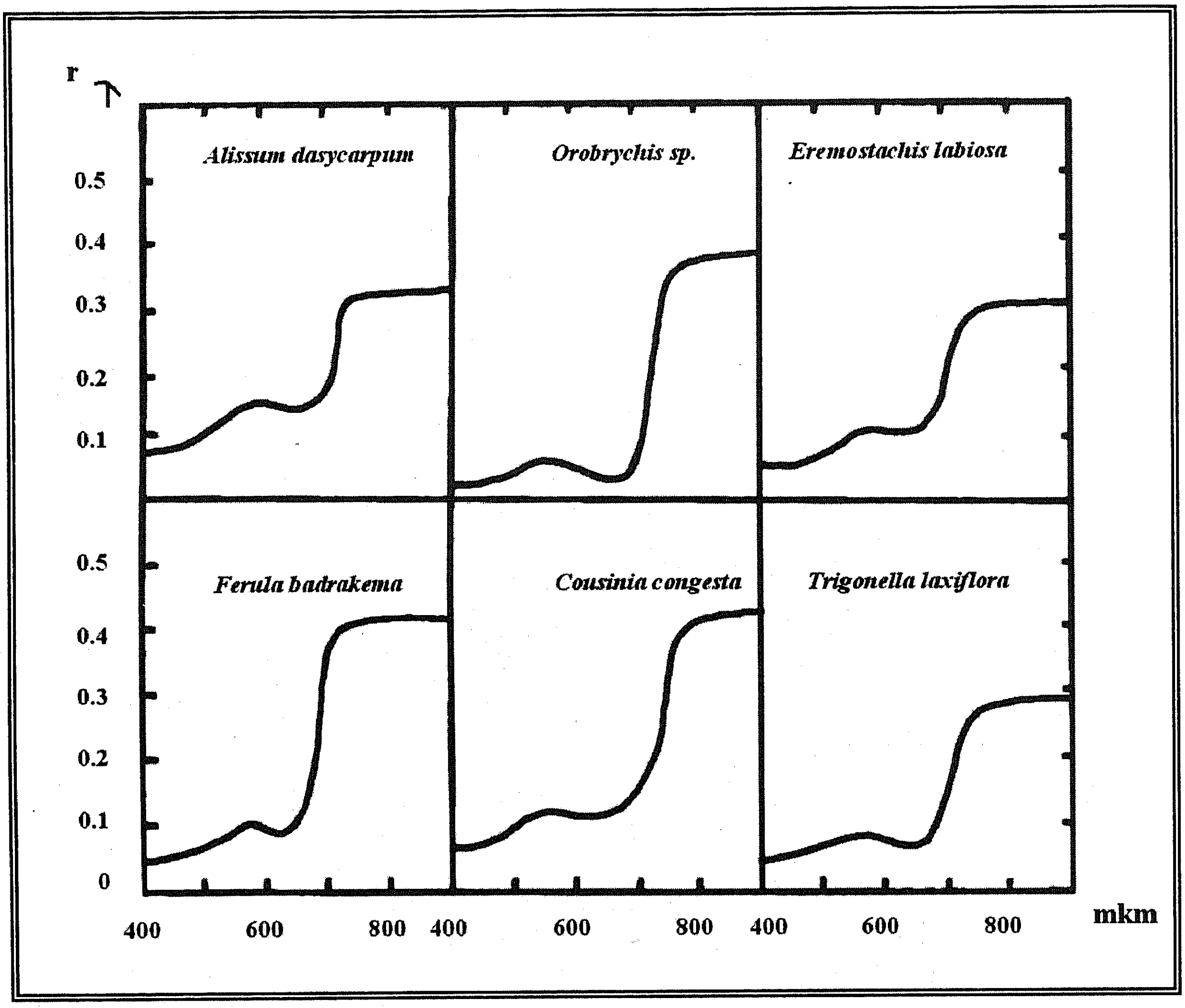


Figure 3.3.5. Spectral reflectance of plants in the Badkhyz reserve measured during the growing season of 1973 (P. Z. Radziminsky, N. G. Kharin, 1974). The upper row includes spectral reflectance coefficients (SRC) of the thickets of herbaceous plants (sites 1x1 m in size); in the lower row, SRC of single plants are given.

3.4. NDVI as indicator of land degradation in the deserts of Asia

Gobi desert

Gobi desert, or Eastern Gobi which occupies the southern part of the Mongolian People's Republic (MPR) and a part of the Chinese territory (Inner Mongolia), belongs to one type of landscape – analogue by assessment of desertification. In its turn, Gobi can be divided into two landscape sub-classes: gravel desert and sandy desert. The climate is severe continental, precipitation rate varies within 50 – 100 mm/year. Local population has adapted to severe climatic conditions (**Figure 3.4.1**). Ceaspidose grasses dominate in plant cover *(Stipa gobica, Cleistogenes dzhungarica, C. squarrosa, Achanttherum splendis)*. From *Chenopodiacea* family, the most common plant species are the following : *Anabasis brevifolia, Salsola passeriana, Nanophyton erinaceum.* From *Compositae* family, several plant species of *Artemisia* are met (*A. frigida, A. xerophytica*) are common on shallow sand dunes. On sand dunes also such species form communities, like *Nitraria sibirica, Agriophyllum pungens* and *Calligonum mongolicum.* Ground surface covered with *Heteropappus hispidus* is shown in **Figure 3.4.2.**

Annual fluctuations in timing seasonal events in Gobi desert are great. For example, the year 1999 was very dry, and 20% of the Mongolian territory suffered from shortage of water. The winter of the previous year was very severe, such low frosts were not observed during the last 30 years. As a result, some 2 million head of livestock perished; and 500,000 people died from hunger. The government of Japan promised to provide more than ¥ 1 billion as aid to help repair the damage caused by severe snowfall and drought (Anonymous, 2000).

In the beginning of 2001 severe snow-storms raged in Inner Mongolia (China) and in joining areas of MPR. A considerable part of the territory was covered with snow, and 29 persons perished. The government of MPR asked UN for $11 million financial aid (Anonymous, 2001). Ground truth data on this region were taken from published sources which included desertification map published by N. G. Kharin et al. (1992, see **Appendix I**) and other publications (N.G. Kharin, 1997).

Very interesting proposal for ground truth collection was developed by H.Yamamoto et al. (1998). They installed a set of sensors on a special car-top arm and carried out ground survey in Mandal Gobi, Mongolia. These instruments included spectrometer, thermometer, SONY camera with digital recorder and some other equipment. They measured spectral reflectance within 520 – 920 nm and convolved broad band reflectance in red (580 – 680 nm) and in near infrared (725 – 920 nm) bands. They compared these data with vegetation characteristics of the Gobi desert, especially with its density. They said, the data obtained by this system had potential for comparison with satellite data, such as NOAA/AVHRR. NDVI classes for the main land degradation types are given in **Table 3.4.1**. Annual fluctuations of NDVI in this region are not so great probably because of low vegetation density.

Tar desert

Desert Tar is located in the border lands of India and Pakistan, occupying the area of 300 thousand km2; from this area about 200 thousand km2 are located in state Rajasthan. According to classification of deserts proposed by M. P. Petrov (1973), the desert Tar is

Figure 3.4.1. Mongolian yurtas in Gobi desert. Photo from the personal archives of N. G. Kharin.

Figure 3.4.2. Thicket of *Heteropappus hispidus* in Gobi desert. Photo from the personal archives of N. G. Kharin

mainly sandy desert of subtropical belt in the north; and its southern part belongs to the belt of tropical deserts.

Table 3.4.1

NDVI classes, 8 km resolution, 21 – 31 May 1992 for some desert lands in Gobi desert, within landscapes–analogues

Types of desert	**Types of land de-gradation**	**NDVI classes**				
		0.0 – 0.04	**0.05 – 0.09**	**0.10-0.14**	**0.15-0.19**	**0.20-0.25**
Gravel desert	E2	+	+			
	W2		+	+		
	V2		+	+		
Sandy desert	E2			+	+	
	E3				+	
	V2		+	+		
	V3				+	+

We have identified the three principal landscapes – analogues in the Indian part of the Tar desert, according to description given by Surrenda Singh et al. (1992). They are the following :

1. Sandy desert with eolian sands which form dunes and hummocks. The main dominant plant species are : *Avena persica, A. pseudomentosa, Grotularia burhia, Diptericum glaucum, Indigofera argenica, Panicum turgidum, Calligonum polygonoides, Calotropis procera, Acacia jacguemontii, Haloxylon salicornicum* (I. Prakish et al., 1992),

2. Ancient alluvial plain located in the south-east part of the Tar desert. Rangelands and dry agriculture are common land use types of this landscape,

3. Valley of the Indus river with alluvial gray soils which are subjects to salinization. NDVI values for the Tar desert are given in **Table 3.4.2** . The annual standard deviation is greater in sandy desert (**See Appendix II**).

In the Pakistan part of the Tar desert, the climate is more drier; and barkhan sands occupy vast areas. According to A. C. Millington et al. (1994), dry land ecosystems of Pakistan are characterized by scarcity of precipitation and great inter – annual variability of climate. Several example of land cover study using NDVI are given in this publication. The authors say that not only rainfall but also other factors contribute to the dynamic nature of the vegetative cover, like land degradation processes, woodland clearance, expansion of irrigation systems, reclamation of waterlogged and soil-affected lands.

All natural ecosystems, according to this study, are not stable from the ecological point of view : arid lands are stable on 50.7 % of total area, semi-arid and sub-humid – on 53.2%, and irrigated lands – on 36.6%. All land cover types have high inter-annual fluctuations in their area extent.

Table 3.4.2
NDVI classes, 8 km resolution, 21 – 31 May 1992 for some desert lands in Tar desert, within landscapes – analogues

Landscapes	**Degradation classes**	**NDVI classes**				
		0 – 0.04	**0.05 – 0.09**	**0.10 – 0.14**	**0.15 – 0.19**	**0.20 – 0.24**
Sandy desert	V2	+	+	+		
	E1		+			
	E2	+	+			
Alluvial plain						
Rangeland	W2	+	+			
Dry agriculture			+	+		
Valley of the Indus river:						
Indian part	I2			+	+	
Pakistan part	I1			+	+	+
					+	+

Other deserts of Asia

NDVI classes for several other physical regions of Asia less provided with ground truth information are given in **Table 3.4.3**. The Table demonstrates variation in NDVI values for different types of land degradation. As known, unsupervised classification of NDVI was used by preparation of desertification map of Asia (N. G. Kharin et al., 1999). Each landscape region has its own combinations of NDVI classes; but in general, the main part of these combinations is confirmed to three lowest NDVI classes : 0.05 – 0.09, 0.10 – 1.14 and 1.15 – 1.19 (but the highest NDVI values were registered in Syrian desert). In general, that confirms the concept of low productivity of desert lands, especially that which are subject of desertification.

Lands of irrigated agriculture have highest NDVI to be compared with other land cover types. That can be explained by high density of agricultural crops cultivated in oases. NDVI values of irrigated farm lands totals : in Central Asia 0.22 – 0.28, in the Hindus valley 0.17 – 0.18, in Mesopotamia 0.19 – 0.20, in the valley of the Yellow river 0.12 – 0.20. By preparation of desertification map, the irrigated lands were identified in NDVI imagery by clear boundaries of oases and river valleys.

The rest values of NDVI by desertification classes are given in **Appendix I**, and in graphical form several examples are given in **Appendix II**. These key areas were used by compilation of desertification maps within landscapes – analogues; and in each case the final map was checked by initial sources of information (large scale desertification maps, thematic maps, ground truth data, etc.).

Inter-annual fluctuations of NDVI

Inter-annual fluctuations of NDVI of different land cover classes depend upon several factors : annual precipitations, differences in exploitation of desert lands during different years, for example, differences of animal pressure on grazing lands, and from different cycles of seasonal development of desert vegetation during single years. It is very difficult

Table 3.4.3

NDVI classes, 8 km resolution, 21 – 31 May 1992 of some lands in several deserts of Asia

Landscape regions	**Degradation classes**	**NDVI classes**									
		0 – 0.04	**0.05-0.09**	**0.10 - 0.14**	**0.15 - 0.19**	**0.20 - 0.24**	**0.25 - 0.29**	**0.30 - 0.34**	**0.35 - 0.39**	**0.40 - 0.44**	**0.45-0.49**
Iranian plateau	V2	+	+								
	V3		+								
	W2		+								
Syrian desert	V2				+	+	+	+	+	+	+
	V3		+								
	E2		+	+							
	E3		+	+							
	W2						+	+			
	Ex4		+								
Mesopotamia	V2		+								
	E2	+	+	+							
	E3		+	+							
	W2		+	+							
	I1			+	+	+	+				
	I3			+	+	+	+				
Nefud desert	V2		+	+							
	E2		+	+							
	E3	+	+								
	Ex4	+	+								
Wadi Hadramawt (Yemen)	V2		+	+							
	V3		+	+	+						
	E3	+									
	W1		+	+	+	+					
	W2		+	+	+						

to analyze these factors without special investigations which are beyond of our task. The only investigation which concerned this problem was conducted in Central Asia. It confirmed the correlation between precipitations in spring months and NDVI (N. G. Kharin et al., 1998).

We can see from **Appendix II** that inter-annual fluctuations are characteristic features for NDVI of all desertification types. These variations are especially great in sandy desert of Central Asia. The most wet years here (1985, 1988, 1993 and 1998) can be identified by the highest NDVI values and the highest variations between plots within the same year. Comparatively dry years were 1986 and 1996. Sandy soil had high water capacity, and vegetation is more productive during wet years.

Sandy pebble desert of Central Asia is less sensitive to precipitations. Desertified lands have lowest inter-annual fluctuations of NDVI because the soil has lower water capacity, and productivity of desert vegetation here is very low.

NDVI values of irrigated lands mainly depend upon the irrigation practice, and NDVI is not correlated with annual precipitations.

It is also very interesting to compare the annual variations of NDVI of some land cover types not used in national economy, i. e. the lands which are not subject of desertification. We may suppose that in this case only physical characteristics affect the NDVI values. Solonchak **(salina)** belongs to these land cover classes. We have taken 8 solonchak plots in Central Asia. Mean NDVI and standard deviation of these plots are given in **Table 3.4.4**

Table 3.4.4

Mean NDVI, 8 km resolution, 21– 31 May 1992 and standard deviations of Solonchak in Central Asia

Years	Mean	Standard deviation
1982	0.0780	0.0502
1983	0.0980	0.0730
1984	0.0780	0.0692
1985	0.0940	0.0659
1986	0.0680	0.0502
1987	0.0960	0.0627
1988	0.1020	0.0464
1989	0.0900	0.0625
1990	0.0780	0.0573
1991	0.0990	0.0671
1992	0.0810	0.0574
1993	0.1050	0.0656
1995	0.0950	0.0356
1996	0.0510	0.0345
1997	0.0860	0.0720
1998	0.1000	0.0254
1999	0.0780	0.0600

The first impression of this Table is that standard deviation id rather great. The years 1985, 1988, 1993 and 1998 were wet years when annual precipitations exceeded the mean annual rate. The years 1986 and 1996 were dry years. Standard deviation totaled ± 50% for wet years and ± 70% for dry years. Probably the reasons of these variation included geo-chemical processes occurred in solonchak. As known, solonchak is characterized by its genesis and age. According to M. P. Petrov (1973), there are the following types of solonchak in Central Asia : soda, sulphate, chloride-sulphate, sulphate-chloride and chloride. As the same author indicates, two different processes take place in the desert at present time – destruction of ancient saline crusts and formation of new crusts. Up-to-date solonchak are confined to closed depressions, and ancient crusts occupy plateaus, remnants, hills and low mountains.

By the assessment of desertification, all solonchak types belongs to one land cover type, not used in national economy. Detailed classification of solonchak is not subject of our study. All solonchak types as object of classification by NDVI imagery have some common features : they can be identified as smooth objects with clear boundaries, especially by application of 1 km resolution imagery.

Inter-annual fluctuations of NDVI in other deserts of Asia are given in **Appendix II.** Inter –annual fluctuations of NDVI in Iranian and in Syrian deserts are not significant. These fluctuations are within the accuracy of the NDVI processing. On the other hand, that testifies to the fact that the period 21 – 31 May was a stable phenological period during 1982 – 1999. The number of observation points in other deserts of Asia is not great and we can not draw a conclusion about inter–annual fluctuations on NDVI in these regions.

CONCLUSION

Seasonal aspects of vegetation are specific phenomena which characterize plant communities and produce deep impression on the people because of their reaches in colour. During the age of the technical progress, the application of aircraft and remote sensing gave a new impetus to study the seasonal changes occurred in the nature..

Visual observations from aircraft improved the methodology of phenological assessment of vegetation. Application of aerial and space photos of different types (black-and-white, colour, colour infrared etc.) was the next step in registration of the phenological status of plant communities. These new points of observations gave a new information about landscape features

Application of NDVI data gives a possibility for registration of the integral status of plant communities within one pixel, occurred during a definite period of time. Phenological profiles drawn from these data show the dynamics of seasonal aspects within each pixel. The spectrum of seasonal aspects is a new phenological characteristic of vegetation.

The possibility of studying the seasonal aspects by NDVI are defined by two parameters : by the technical specifications of remote sensor (first of all, the size of pixel; for example, 8 km2) and by the time interval of phenological profiles (for example, 10 days). On the basis of our case study, we can say that these parameters are suitable for phenological investigations on a regional level. Phenological aspects of vegetation, at the level of plant formations can be studied by this scale.

We also have issued an idea about a retrospective monitoring of seasonal changes and the status of vegetation by NDVI data. As known, these data are registered since 1982 and are available to all countries of the world. Deviations from a standard phenological profiles can be used as indicators of disturbances in the vegetative cover. Retrospective monitoring allows to study these changes during the whole period of observations.

Plant communities in the desert zone are very sensitive to all agents causing the land degradation (desertification). NDVI changes under the impact of human activities and drought take place especially during specific seasons of the year. So, the seasonal NDVI data can be used for assessment of land degradation in the arid zone of Asia and probably in other geographical regions of the world.

We have given several examples of application of seasonal NDVI imagery for practical purposes, for example for assessment of land degradation and for estimation of the optimal seasons of remote sensing in forestry.

In our opinion, the further tasks in application of NDVI data for phenological investigations should include the use of 1 km resolution imagery and the imagery of more detailed resolution. We also need a special ground truth methodology for registration of phenological status of plant communities in the field. Such methodology is discussed in Chapter 1 of this book. This approach will allow to study seasonal spectra of plant associations, that means the studying phenology at the next, more detailed level.

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Appendix I

NDVI DATA, 21 – 31 May 1992, 8 km RESOLUTION

I. Coding system

LAND COVER TYPES

R Rangeland and meadow
F Forest
D Dryland agriculture
A Land of irrigated agriculture

TYPES AND CLASSES OF DESERTIFICATION

Desertification types	**Indices**	**Desertification classes**		
		Slight	***Moderate***	***Severe and very severe***
Degradation of the vegetative cover	V	V1	V2	V3
Wind erosion	E	E1	E2	E3
Water erosion	W	W1	W2	W3
Salinization of irrigated Land	I	I1	I2	I3
Salinization of soils caused by the drop of the Aral Sea level	S	S1	S2	S3
Waterlogging of Rangelands	L	L1	L2	L3

CAUSES OF DESERTIFICATION

C1 Cutting trees and shrubs
C2 Overgrazing
C3 Excessive annual cropping
C4 Over-irrigation
C5 Movement of machinery
C6 Drainage of irrigation water
C7 Regulation of river flow

LANDS EXCLUDED FROM ASSESSMENT

Ex1 Extra-arid lands
Ex2 Stone surfaces
Ex3 Bogs
Ex4 Solonchak (Salina)

COUNTRIES

Cen Countries of Central Asia
Chi China
Ind India
Ira Iran
Mon Mongolia
Pak Pakistan
Sau Saudi Arabia and countries of Middle East
Tur Turkey

SOURCES OF INFORMATION

Countries	**Numbers of sample plots**			
	Desertification maps	**Thematic maps**	**Photo inter-pretation**	**Combined**
Central Asian Countries	69 – 144, 152 –172, 179 –270	1 – 68, 145 –151	173 – 178, 566 – 579	
Mongolia	271 – 337			
China	338 – 348, 365- 400, 406 – 426	349 – 364, 401 – 405, 424 – 432		
Saudi Arabia		503 – 551		
Iran		580 – 587	604 - 648	556 – 565
Pakistan				474 – 502
India	433 – 474			
Turkey				649 – 661

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Note : *Besides the sources mentioned above, the authors have used the results of their field studies conducted in the countries of Central Asia, in Iran, Mongolia, India and China.*

III. Database

Number	Country	Coordinates, degree, minute		Land cover type	Deserti-fication type	Deserti-fication class	Deserti-fication cause	NDVI avarage of 5 pixels
		N	E					
1	Cen	49-40	52-35	R	V	1	C2	0.304
2	Cen	48-50	53-36	R	E	2	C2	0.264
3	Cen	50-48	52-46	R	E	2	C2	0.352
4	Cen	50-30	58-00	D	E	1	C3	0.312
5	Cen	50-30	56-00	D	E	1	C3	0.36
6	Cen	51-15	53-27	D	E	1	C3	0.304
7	Cen	50-55	51-24	D	E	1	C3	0.4
8	Cen	50-31	59-16	D	E	1	C3	0.248
9	Cen	50-11	59-40	R	E	2	C3	0.192
10	Cen	49-04	57-20	R	E	3	C2	0.32
11	Cen	48-29	59-20	R	V	2	C2	0.216
12	Cen	53-36	61-52	D	E	1	C3	0.296
13	Cen	53-27	64-32	D	E	1	C3	0.096
14	Cen	59-04	64-42	A	I	3	C4	0.232
15	Cen	53-38	64-50	A	I	3	C4	0.2
16	Cen	52-12	64-39	A	I	3	C4	0.176
17	Cen	50-37	61-48	D	E	2	C3	0.216
18	Cen	49-42	62-15	D	E	2	C3	0.152
19	Cen	50-13	64-21	A	I	2	C2	0.224
20	Cen	49-48	66-40	R	V	2	C2	0.272
21	Cen	49-09	66-35	R	V	2	C2	0.224
22	Cen	49-17	64-35	R	V	2	C2	0.224
23	Cen	54-33	65-51	D	E	2	C3	0.224
25	Cen	53-51	69-06	D	E	1	C3	0.152
26	Cen	50-20	68-55	Ex3				-0.36
27	Cen	52-53	73-10	F	V	2	C1	0.176
28	Cen	53-48	72-50	Ex3				0.152
29	Cen	52-46	74-25	F	V	2	C1	0.232
30	Cen	53-25	74-00	F	V	2	C1	0.192
31	Cen	53-33	71-50	F	V	2	C1	0.176
32	Cen	53-16	73-25	Ex3				0.224
33	Cen	52-23	69-40	D	E	1	C3	0.232
34	Cen	51-49	67-03	D	E	2	C3	0.152
35	Cen	49-45	69-20	R	V	1	C2	0.32
36	Cen	54-00	76-05	A	I	3	C4	0.312

37	Cen	53-17	75-32	F	V	3	C1	0.208
38	Cen	54-52	69-10	R	V	2	C2	0.344
39	Cen	50-52	72-10	R	V	2	C2	0.224
40	Cen	52-00	77-25	R	V	2	C2	0.248
41	Cen	49-48	72-21	R	V	2	C2	0.376
42	Cen	52-23	75-15	A	I	3	C4	0.232
43	Cen	53-27	77-02	D	E	2	C3	0.24
44	Cen	51-00	80-32	D	E	1	C3	0.24
45	Cen	51-46	78-55	R	V	1	C2	0.28
46	Cen	50-16	80-00	R	V	2	C2	0.176
48	Cen	49-35	73-45	R	V	2	C2	0.36
49	Cen	49-12	75-51	R	V	2	C2	0.304
50	Cen	49-20	77-56	R	V	2	C2	0.152
51	Cen	48-48	80-29	R	V	2	C2	0.296
52	Cen	49-50	81-00	R	V	2	C2	0.304
53	Cen	49-30	81-45	R	V	2	C2	0.296
54	Cen	47-00	53-10	Ex4				0.096
55	Cen	45-50	53-50	Ex4				0.04
56	Cen	44-45	53-52	R	V	1	C2	0.104
57	Cen	43-45	52-29	R	V	1	C2	0.112
58	Cen	47-52	58-40	R	V	2	C2	0.288
59	Cen	46-36	56-25	R	V	1	C2	0.128
60	Cen	46-35	62-40	R	E	2	C2	0.136
61	Cen	47-00	66-02	R	E	2	C2	0.208
62	Cen	44-02	68-40	R	E	2	C2	0.064
63	Cen	45-42	68-20	R	E	1	C2	0.192
64	Cen	45-25	73-15	Ex4				0.064
65	Cen	45-15	74-55	R	V	1	C2	0.152
66	Cen	44-48	76-10	R	V	1	C2	0.112
67	Cen	46-10	75-50	R	V	2	C2	0.016
68	Cen	44-40	72-25	R	V	2	C2	0.056
69	Cen	46-05	77-49	Ex4				0.032
70	Cen	40-32	53-07	Ex4				0.048
71	Cen	40-31	54-32	Ex4				-0.008
72	Cen	40-49	56-41	Ex4				0.008
73	Cen	42-30	53-00	R	V	2	C5	0.04
74	Cen	42-16	52-47	R	V	2	C5	0.048
75	Cen	42-50	54-03	R	V	1	C2	0.056
76	Cen	42-54	56-00	R	V	2	C2	0.048
77	Cen	42-41	56-20	R	V	2	C2	0.04
78	Cen	42-00	56-12	R	V	1	C2	0.001
79	Cen	42-36	57-18	R	V	2	C2	0.032
80	Cen	40-15	52-48	R	E	2	C5	0.056
81	Cen	40-35	53-13	R	V	2	C5	0.024
82	Cen	41-05	57-50	R	V	1	C5	0.048
83	Cen	40-00	55-00	R	V	1	C2	0.024
84	Cen	40-00	57-00	R	V	1	C2	0.024
85	Cen	38-00	53-54	Ex4				-0.04

86	Cen	37-27	54-30	A	I	2	C4	0.104
87	Cen	38-30	54-16	R	E	2	C2	-0.024
88	Cen	38-20	54-55	R	E	2	C2	0.064
89	Cen	38-00	54-40	R	V	1	C2	-0.016
90	Cen	39-34	55-00	R	E	2	C5	0.008
91	Cen	39-30	54-18	R	E	2	C1	0.001
92	Cen	39-40	53-35	R	E	2	C1	-0.048
93	Cen	39-44	55-48	R	E	2	C1	0.008
94	Cen	39-18	55-40	A	I	1	C4	0.048
95	Cen	39-00	56-29	A	I	1	C4	0.08
96	Cen	39-45	58-35	R	E	2	C4	0.032
97	Cen	38-24	57-30	A	I	1	C4	0.08
98	Cen	38-24	55-11	R	W	2	C1	0.144
99	Cen	39-30	54-40	R	W	2	C1	0.001
100	Cen	39-47	54-35	R	W	2	C1	-0.16
101	Cen	38-07	55-20	R	W	2	C1	0.144
102	Cen	38-47	55-08	R	W	2	C1	0.024
103	Cen	39-08	55-46	R	W	2	C1	0.001
104	Cen	38-37	57-00	R	W	2	C1	0.08
105	Cen	38-38	57-35	R	V	2	C2	0
106	Cen	39-15	58-40	R	V	1	C1	-0.008
107	Cen	38-22	58-35	R	V	2	C2	0.024
108	Cen	40-42	57-06	R	V	1	C2	0.024
109	Cen	39-55	59-25	R	V	2	C5	0.08
110	Cen	37-46	58-48	A	I	1	C4	0.232
111	Cen	38-10	58-03	A	I	1	C4	0.208
112	Cen	41-03	57-54	R	E	2	C5	0.056
113	Cen	42-07	59-00	A	I	2	C4	0.08
114	Cen	42-35	58-37	A	I	2	C4	0.056
115	Cen	42-11	59-24	A	I	2	C4	0.088
116	Cen	41-45	60-00	A	I	2	C4	0.104
117	Cen	41-00	59-00	R	V	1	C2	0.096
118	Cen	41-12	60-18	R	E	2	C1	0.08
119	Cen	41-02	60-18	R	E	2	C1	0.088
120	Cen	40-41	60-52	R	E	2	C1	0.088
121	Cen	40-43	61-50	R	E	2	C1	0.096
122	Cen	40-17	61-22	R	E	3	C1	0.072
123	Cen	39-57	62-18	R	E	2	C1	0.056
124	Cen	38-15	60-50	R	V	2	C2	0.072
125	Cen	38-22	59-27	R	V	2	C2	0.024
126	Cen	37-48	60-10	R	L	2	C7	0.128
127	Cen	38-12	69-09	R	L	2	C7	0.136
128	Cen	38-07	61-20	R	L	2	C7	0.048
129	Cen	38-24	61-30	R	L	2	C7	0.128
130	Cen	38-04	62-30	R	L	2	C7	0.056
131	Cen	38-04	62-00	R	L	2	C7	0.072
132	Cen	37-24	60-00	R	V	2	C2	0.088
133	Cen	37-12	59-55	R	E	2	C1	0.12

136	Cen	37-16	60-04	A	I	3	C4	0.12
137	Cen	37-00	61-18	A	I	1	C4	0.136
138	Cen	36-40	60-40	R	W	2	C1	0.056
139	Cen	44-47	56-05	R	V	3	C5	0.072
140	Cen	45-00	55-58	R	V	3	C5	0.056
141	Cen	44-15	57-00	R	V	3	C5	0.032
142	Cen	43-48	57-42	R	V	3	C5	0.016
143	Cen	44-54	58-02	R	V	3	C5	0.168
144	Cen	44-32	58-00	R	V	3	C5	0.048
149	Cen	43-17	59-20	R	S	3	C7	0.072
150	Cen	46-47	61-58	R	S	3	C7	0.096
151	Cen	46-18	59-20	R	V	2	C2	0.152
152	Cen	47-11	60-50	R	V	2	C2	0.224
153	Cen	47-15	60-53	R	V	2	C2	0.232
154	Cen	42-25	62-30	R	V	2	C2	0.056
155	Cen	47-44	63-42	R	V	1	C2	0.104
156	Cen	44-25	61-47	R	V	2	C2	0.08
157	Cen	43-40	64-00	R	V	2	C2	0.08
158	Cen	43-41	65-25	R	V	2	C2	0.072
159	Cen	45-14	65-25	R	V	2	C2	0.08
160	Cen	42-37	63-55	R	E	3	C2	0.104
161	Cen	42-00	65-40	R	E	3	C2	0.08
162	Cen	42-57	60-20	R	V	3	C1	0.168
163	Cen	42-40	60-55	R	V	3	C1	0.072
164	Cen	48-18	61-20	R	V	3	C1	0.128
165	Cen	43-28	58-55	R	V	2	C1	0.088
166	Cen	43-04	59-13	F	V	1	C1	0.192
167	Cen	40-46	61-00	R	V	2	C1	0.088
168	Cen	41-00	61-38	R	V	1	C1	0.072
169	Cen	40-25	61-30	R	V	1	C2	0.096
170	Cen	39-24	63-17	F	V	2	C1	0.096
171	Cen	39-04	63-06	R	E	3	C1	0.016
172	Cen	38-48	63-12	R	E	3	C1	0.032
173	Cen	38-58	62-07	R	E	3	C2	0.056
179	Cen	37-47	60-50	R	V	2	C1	0.048
180	Cen	37-42	61-12	R	V	2	C1	0.072
181	Cen	37-12	61-27	R	V	2	C1	0.072
182	Cen	36-27	61-13	F	V	2	C1	0.096
183	Cen	35-46	61-32	F	V	1	C2	0.216
184	Cen	36-33	61-27	R	V	2	C1	0.08
185	Cen	37-12	62-10	R	V	2	C1	-0.12
186	Cen	36-36	62-22	R	V	2	C1	0.16
187	Cen	36-08	62-16	R	V	2	C1	0.24
188	Cen	36-00	62-00	R	V	2	C1	0.264
189	Cen	35-44	62-16	R	V	1	C1	0.208
190	Cen	35-40	62-42	R	V	1	C1	0.24
192	Cen	38-07	64-52	A	I	1	C4	0.16
193	Cen	38-42	64-05	A	I	1	C4	0.152

194	Cen	38-17	63-42	R	V	1	C2	0.048
195	Cen	38-10	64-22	R	V	1	C1	0.112
196	Cen	37-50	65-04	R	V	1	C1	0.152
197	Cen	37-18	62-31	R	V	2	C1	0.088
198	Cen	37-09	63-30	R	V	1	C1	0.152
199	Cen	37-37	65-27	R	V	2	C1	0.168
200	Cen	36-36	63-50	R	V	1	C2	0.304
201	Cen	37-45	66-08	A	I	1	C4	0.152
202	Cen	38-56	64-17	R	E	2	C2	0.08
203	Cen	38-38	64-15	R	E	2	C2	0.208
204	Cen	38-29	64-58	R	V	1	C1	0.096
205	Cen	42-34	59-40	A	I	2	C4	0.104
206	Cen	42-24	60-00	R	V	2	C1	0.088
207	Cen	41-40	61-18	R	V	1	C1	0.064
208	Cen	43-00	62-40	R	V	2	C2	0.096
209	Cen	41-40	61-55	R	V	1	C2	0.072
210	Cen	42-20	63-40	Ex2				0.128
211	Cen	41-30	64-12	Ex2				0.128
212	Cen	40-50	63-50	Ex2				0.096
213	Cen	41-17	64-50	Ex2				0.12
214	Cen	41-40	65-00	R	V	2	C2	0.088
215	Cen	41-55	62-50	R	V	1	C2	0.128
216	Cen	42-55	62-26	R	V	2	C2	0.104
217	Cen	41-22	63-15	R	E	2	C2	0.112
219	Cen	40-48	64-47	R	V	2	C2	0.096
220	Cen	40-48	65-10	R	V	2	C2	0.112
221	Cen	40-36	65-40	D	W	1	C3	0.208
222	Cen	40-10	65-28	D	W	1	C3	0.232
223	Cen	39-08	66-10	D	W	1	C3	0.296
224	Cen	39-37	66-20	D	W	1	C3	0.376
225	Cen	38-35	66-18	D	W	1	C3	0.328
226	Cen	38-28	64-56	R	V	1	C2	0.096
227	Cen	39-26	65-20	R	V	2	C1	0.112
228	Cen	38-48	65-38	A	I	2	C4	0.224
229	Cen	39-46	64-40	A	I	2	C4	0.112
230	Cen	38-00	66-00	R	W	1	C1	0.256
232	Cen	40-30	66-40	R	W	1	C1	0.256
233	Cen	37-23	65-35	Ex3				0.056
234	Cen	37-20	65-54	R	E	3	C1	0.056
235	Cen	37-06	65-53	R	V	3	C1	0.088
236	Cen	36-47	66-00	R	W	2	C1	0.128
237	Cen	43-00	66-00	R	V	2	C1	0.096
238	Cen	43-10	67-55	A	I	1	C4	0.152
240	Cen	41-45	68-05	A	I	1	C4	0.256
241	Cen	42-50	67-55	R	V	1	C1	0.112
242	Cen	43-38	68-40	R	W	1	C1	0.328
243	Cen	42-35	69-35	D	W	1	C3	0.48
244	Cen	41-35	69-10	D	E	2	C3	0.48

245	Cen	41-32	69-54	R	W	1	C1	0.448
246	Cen	41-50	70-15	Ex2				0.44
247	Cen	41-45	70-23	A	I	1	C4	0.216
248	Cen	41-03	69-00	A	I	1	C4	0.32
249	Cen	40-47	68-40	A	I	2	C4	0.256
250	Cen	41-20	66-40	R	V	2	C1	0.144
251	Cen	40-27	70-43	A	I	1	C4	0.224
252	Cen	40-18	71-40	A	I	1	C4	0.208
253	Cen	40-26	71-00	R	E	3	C1	0.24
254	Cen	40-10	68-45	A	I	1	C4	0.248
255	Cen	40-00	68-04	D	E	1	C3	0.44
256	Cen	39-55	68-30	R	W	1	C1	0.472
257	Cen	40-05	69-08	R	W	2	C1	0.296
258	Cen	38-45	65-50	A	I	1	C4	0.272
259	Cen	39-33	67-00	A	I	2	C4	0.312
260	Cen	39-55	66-30	A	I	2	C4	0.248
261	Cen	39-26	64-08	R	V	2	C1	0.048
262	Cen	39-46	64-30	A	I	2	C4	0.184
263	Cen	39-30	61-40	R	W	1	C1	0.072
265	Cen	40-28	68-20	A	I	1	C4	0.208
266	Cen	40-15	65-30	R	W	2	C1	0.216
267	Cen	37-43	66-40	R	W	1	C1	0.192
268	Cen	37-40	67-00	A	I	1	C4	0.208
269	Cen	37-47	67-30	A	I	2	C4	0.192
270	Cen	37-30	67-30	R	V	2	C1	0.104
271	Mon	50-38	92-33	F	V	1	C1	0.192
272	Mon	50-27	94-00	F	V	1	C1	0.104
273	Mon	50-12	93-25	R	V	2	C1	0.112
274	Mon	49-48	92-44	R	W	2	C1	0.272
276	Mon	49-00	92-27	R	V	1	C2	0.032
277	Mon	49-00	93-15	R	V	2	C2	0.008
278	Mon	48-33	93-15	R	V	2	C2	0.032
279	Mon	48-22	95-30	R	E	2	C1	0.12
280	Mon	48-05	91-47	R	W	2	C1	0.088
281	Mon	48-00	92-40	R	V	2	C2	0.064
282	Mon	47-43	92-25	R	W	2	C1	0.12
283	Mon	47-44	93-10	R	W	2	C1	0.008
284	Mon	47-24	94-00	R	V	2	C2	0.024
285	Mon	47-36	94-35	R	E	2	C2	0.048
286	Mon	47-25	95-35	R	E	2	C2	0.032
287	Mon	48-08	95-00	R	V	2	C2	0.072
288	Mon	47-50	95-50	R	V	1	C2	0.144
289	Mon	47-20	92-25	R	W	2	C1	0.168
290	Mon	47-03	92-57	R	W	2	C1	0.104
291	Mon	47-20	93-20	R	W	2	C1	0.024
292	Mon	47-05	94-10	R	V	1	C1	0.016
293	Mon	46-25	94-25	R	W	1	C1	0.08
294	Mon	46-30	94-52	R	V	1	C1	0.032

295	Mon	46-18	96-35	R	W	2	C1	0.128
297	Mon	46-05	97-20	R	W	2	C1	0.024
299	Mon	45-10	92-28	R	W	2	C1	-0.008
300	Mon	43-10	96-00	R	W	2	C1	-0.008
301	Mon	43-48	97-35	R	W	2	C1	-0.016
302	Mon	43-18	96-26	R	W	2	C1	0.008
303	Mon	46-32	99-00	R	V	2	C1	0.12
304	Mon	45-03	97-29	R	W	2	C1	0.072
305	Mon	46-12	101-52	R	E	1	C1	0.12
306	Mon	46-25	102-30	R	V	2	C2	0.192
307	Mon	45-35	101-30	R	V	2	C2	0.088
308	Mon	42-20	103-00	R	E	2	C1	0.024
309	Mon	42-50	101-10	R	W	2	C1	-0.016
310	Mon	43-20	102-15	R	E	2	C1	0.016
311	Mon	43-32	103-00	R	E	2	C1	0.096
312	Mon	43-15	103-02	R	V	1	C1	0.232
313	Mon	42-00	104-44	R	W	2	C1	-0.008
314	Mon	43-50	104-40	R	E	2	C2	0.016
315	Mon	43-20	104-50	R	E	2	C2	-0.008
316	Mon	45-30	104-45	R	V	2	C2	0.024
317	Mon	44-50	106-15	R	V	1	C2	0.024
318	Mon	43-50	105-30	R	E	2	C2	0.008
319	Mon	43-15	105-55	R	E	2	C2	0
320	Mon	42-10	105-40	R	E	2	C2	0.032
321	Mon	42-40	107-00	R	E	2	C2	0.016
322	Mon	43-00	106-20	R	V	2	C2	0.008
323	Mon	43-12	110-25	R	V	2	C2	0.032
324	Mon	42-35	108-15	R	E	2	C2	0.024
325	Mon	43-20	108-40	R	V	2	C2	0.056
327	Mon	44-48	109-50	R	V	2	C2	0.008
328	Mon	45-40	109-12	R	V	1	C2	0.016
329	Mon	45-52	109-53	R	V	2	C2	0.008
330	Mon	44-00	109-30	R	V	2	C2	0.016
331	Mon	43-25	108-27	R	E	2	C2	0.032
332	Mon	43-30	110-27	R	E	2	C2	0.056
333	Mon	44-10	110-40	R	E	2	C2	0.056
334	Mon	42-54	108-20	R	V	2	C2	0.024
335	Mon	44-40	108-43	R	V	2	C2	0
336	Mon	45-40	112-00	R	V	2	C2	0.064
337	Mon	45-10	111-40	R	V	1	C2	0.072
338	Chi	43-45	95-20	R	V	2	C2	-0.008
339	Chi	43-15	95-15	R	V	2	C2	-0.024
340	Chi	43-05	95-54	R	V	2	C2	-0.016
341	Chi	40-00	100-00	R	E	3	C2	0.016
342	Chi	40-40	101-10	R	E	3	C2	0.024
343	Chi	40-00	102-00	R	E	3	C2	0.024
344	Chi	41-23	101-00	R	V	1	C2	0
345	Chi	41-50	101-00	R	V	1	C2	0

346	Chi	42-15	99-50	R	V	1	C2	-0.016
347	Chi	42-40	95-10	R	V	1	C2	-0.008
348	Chi	40-05	94-45	A	I	1	C4	0.096
349	Chi	40-20	96-00	A	I	1	C4	0.08
350	Chi	40-00	92-15	R	E	3	C1	-0.024
351	Chi	41-10	93-00	Ex2				0
352	Chi	41-18	92-18	Ex2				-0.008
353	Chi	41-47	100-55	F	V	2	C1	-0.008
354	Chi	41-10	100-18	F	V	2	C1	0.04
355	Chi	39-15	104-15	R	E	3	C1	0.04
356	Chi	38-50	104-55	R	E	3	C1	0.04
357	Chi	40-37	105-00	R	E	3	C1	0.032
358	Chi	41-28	105-20	R	V	1	C2	0.032
359	Chi	39-40	105-30	R	E	1	C2	0.04
360	Chi	40-00	106-18	R	V	1	C2	0.024
361	Chi	39-20	106-10	R	V	1	C2	0.032
362	Chi	39-50	100-00	R	V	1	C2	0.024
363	Chi	40-30	90-45	Ex3				-0.032
364	Chi	39-55	90-10	Ex3				-0.032
365	Chi	44-00	94-00	R	V	1	C2	0
366	Chi	42-25	93-45	R	E	1	C2	0.008
367	Chi	42-50	93-50	A	I	1	C4	0.016
368	Chi	38-54	107-10	R	E	3	C2	0.032
369	Chi	39-44	107-40	R	V	2	C2	0.04
370	Chi	36-48	107-20	R	V	1	C2	0.064
371	Chi	41-30	103-10	R	V	1	C2	0.008
372	Chi	41-30	99-25	R	V	1	C2	-0.008
373	Chi	43-20	110-00	R	V	2	C2	0.032
374	Chi	43-18	111-20	R	V	2	C2	0.04
375	Chi	44-28	110-40	R	V	2	C2	0.056
376	Chi	44-52	112-20	R	V	1	C2	0.104
377	Chi	43-17	112-07	R	E	2	C1	0.056
378	Chi	42-50	115-25	F	E	2	C1	0.136
379	Chi	42-51	114-40	F	E	2	C1	0.12
380	Chi	43-05	120-00	F	E	2	C1	0.112
381	Chi	43-08	118-30	F	E	2	C1	0.184
382	Chi	44-15	120-00	F	E	2	C1	0.2
383	Chi	44-20	117-45	R	V	1	C2	0.232
384	Chi	41-04	108-05	A	I	2	C4	0.144
385	Chi	41-00	108-50	A	I	2	C4	0.12
386	Chi	40-42	108-56	A	I	2	C4	0.128
387	Chi	40-25	110-00	A	I	2	C4	0.136
388	Chi	40-25	109-05	R	E	2	C2	0.072
389	Chi	40-34	108-20	R	E	2	C2	0.032
390	Chi	46-00	118-50	R	V	1	C2	0.008
391	Chi	45-25	119-10	R	V	1	C2	0.232
392	Chi	40-00	110-00	R	V	2	C2	0.056
393	Chi	39-34	110-00	R	E	2	C2	0.072

394	Chi	39-35	110-00	R	E	2	C2	0.072
395	Chi	38-26	109-10	R	E	3	C2	0.072
396	Chi	37-45	109-50	R	V	2	C2	0.056
397	Chi	37-40	109-00	R	E	3	C2	0.104
398	Chi	36-50	109-20	R	V	2	C2	0.104
399	Chi	38-00	108-40	R	E	1	C2	0.08
400	Chi	39-00	108-50	R	E	3	C2	0.04
401	Chi	40-50	81-00	Ex3				-0.016
402	Chi	41-05	79-20	A	I	1	C4	0.04
403	Chi	40-42	80-17	A	I	2	C4	0.184
404	Chi	40-40	79-55	A	I	2	C4	0.064
405	Chi	43-30	80-00	R	V	1	C2	-0.096
406	Chi	43-30	77-55	R	V	1	C2	0.456
407	Chi	43-25	75-25	R	V	1	C2	0.192
408	Chi	38-20	77-20	A	I	2	C4	0.2
409	Chi	38-30	76-25	R	E	3	C2	0.016
410	Chi	38-50	77-00	R	E	3	C2	0.024
411	Chi	39-27	76-10	A	I	1	C4	0.272
412	Chi	40-08	75-25	R	V	2	C2	0.056
413	Chi	41-30	80-00	R	V	2	C2	0.008
414	Chi	41-10	82-00	F	V	2	C1	-0.032
415	Chi	40-55	82-00	F	V	2	C1	0.008
416	Chi	41-40	85-00	F	V	2	C1	-0.04
417	Chi	41-55	85-00	R	E	3	C2	-0.016
418	Chi	42-40	85-00	R	V	2	C1	0.024
419	Chi	43-00	86-50	R	V	2	C1	0.112
420	Chi	43-10	81-40	R	V	2	C1	0.312
421	Chi	45-00	86-03	R	E	1	C2	0.12
422	Chi	44-40	87-10	R	E	1	C2	0
423	Chi	45-30	86-40	R	E	1	C2	-0.024
424	Chi	44-00	88-00	A	I	2	C4	-0.184
425	Chi	44-35	85-15	A	I	2	C4	0.048
426	Chi	43-55	81-35	A	I	2	C4	0.352
427	Chi	43-45	81-50	A	I	2	C4	0.344
428	Chi	40-52	87-55	Ex3				-0.032
429	Chi	40-32	89-10	Ex3				-0.032
430	Chi	41-20	89-00	R	V	2	C2	-0.032
431	Chi	45-10	89-05	R	V	1	C2	-0.016
432	Chi	46-00	88-00	R	V	1	C2	0.024
433	Ind	27-44	70-20	R	E	2	C2	-0.048
434	Ind	27-42	71-21	R	E	1	C2	-0.032
435	Ind	26-46	69-48	R	E	3	C2	-0.048
436	Ind	26-40	70-15	R	E	3	C2	-0.056
437	Ind	29-50	73-37	A	E	1	C3	0.008
438	Ind	29-38	73-32	A	E	1	C3	0.008
439	Ind	29-40	73-55	A	E	1	C3	0
440	Ind	29-06	73-45	A	I	3	C4	-0.008
441	Ind	29-18	74-40	A	I	3	C4	0

442	Ind	29-42	73-55	R	V	2	C2	0
443	Ind	29-00	75-00	A	E	2	C3	0
444	Ind	29-00	74-40	R	E	2	C2	-0.008
445	Ind	28-30	74-15	R	E	2	C2	0.024
446	Ind	28-26	74-30	R	E	3	C2	0.008
447	Ind	28-15	74-40	D	E	1	C3	0.016
448	Ind	28-00	75-00	D	E	3	C3	0.032
449	Ind	28-00	75-50	A	W	3	C3	0.032
450	Ind	27-30	75-23	A	W	2	C3	0.04
451	Ind	27-30	74-48	D	E	1	C3	0.04
452	Ind	28-50	72-56	R	E	2	C2	-0.016
453	Ind	28-45	72-26	A	W	2	C3	-0.016
454	Ind	28-00	72-04	R	E	2	C2	-0.032
455	Ind	28-00	73-31	D	E	3	C3	0
456	Ind	27-05	75-00	R	V	1	C2	0.032
457	Ind	26-50	70-47	R	V	2	C2	-0.032
458	Ind	26-03	70-55	R	V	2	C2	-0.04
459	Ind	26-25	70-10	D	E	2	C3	-0.056
460	Ind	26-20	72-50	R	V	2	C2	0
461	Ind	26-50	73-40	R	W	1	C2	0.016
462	Ind	26-28	73-42	A	W	1	C3	0.008
463	Ind	26-52	74-30	A	W	1	C3	0.04
464	Ind	27-00	75-01	A	W	1	C3	0.008
465	Ind	26-13	74-00	A	W	1	C3	0.024
466	Ind	28-58	73-52	A	W	2	C3	0.024
467	Ind	25-52	73-45	A	W	2	C3	0.024
468	Ind	25-49	74-04	F	V	2	C1	0.024
469	Ind	25-00	73-08	F	V	2	C1	0.08
470	Ind	24-30	72-55	F	V	2	C1	0.048
471	Ind	26-00	72-00	D	E	2	C3	-0.032
472	Ind	25-20	72-00	D	E	2	C3	0.008
473	Ind	25-00	71-30	D	E	2	C3	-0.008
474	Pak	27-30	69-40	R	E	2	C2	-0.048
475	Pak	26-38	69-10	R	E	2	C2	-0.056
476	Pak	25-30	69-25	R	V	2	C1	0.04
477	Pak	26-35	69-30	R	V	2	C1	-0.056
478	Pak	31-48	71-20	R	E	2	C2	0.024
479	Pak	31-00	71-18	R	E	2	C2	0.064
480	Pak	30-40	71-18	R	E	2	C2	0.008
481	Pak	31-40	71-55	R	E	3	C2	-0.032
482	Pak	31-24	71-40	R	V	2	C2	-0.032
483	Pak	30-27	71-25	R	V	2	C2	-0.16
484	Pak	31-08	72-20	A	I	2	C4	0.072
485	Pak	31-48	72-40	A	I	1	C4	0.136
486	Pak	30-24	73-25	A	I	2	C4	0.088
487	Pak	31-10	65-08	R	E	2	C2	0.072
488	Pak	29-55	65-12	R	E	2	C2	0.032
489	Pak	28-10	64-15	R	E	2	C2	0.008

490	Pak	28-21	65-00	R	E	2	C2	-0.008
491	Pak	31-20	64-13	R	V	3	C2	-0.048
492	Pak	30-40	63-27	R	V	3	C2	0.016
493	Pak	24-50	67-32	A	I	1	C4	0.016
494	Pak	24-32	67-18	A	I	2	C4	0.024
495	Pak	24-32	67-48	A	I	2	C4	0.112
496	Pak	28-40	70-16	A	I	1	C4	0.072
497	Pak	27-11	67-58	A	I	1	C4	0.112
498	Pak	29-20	66-00	R	W	1	C1	0.016
499	Pak	26-42	63-04	R	W	1	C2	0.008
500	Pak	27-23	64-25	R	W	1	C2	0
501	Pak	25-40	64-00	R	V	2	C2	-0.04
502	Pak	25-42	66-00	R	V	2	C2	-0.048
503	Sau	33-24	44-08	A	I	3	C4	0.208
504	Sau	32-50	44-52	A	I	3	C4	0.176
505	Sau	31-54	46-37	A	I	3	C4	0.176
506	Sau	31-10	47-00	R	E	3	C2	0.608
507	Sau	31-15	45-44	R	E	3	C2	0.88
508	Sau	28-20	48-18	R	E	3	C2	0.04
509	Sau	27-31	49-00	R	E	3	C2	0.04
510	Sau	26-40	49-45	R	E	2	C2	0.064
514	Sau	32-10	38-29	R	E	3	C2	0.104
515	Sau	32-08	39-26	R	E	2	C2	0.088
516	Sau	31-30	39-12	R	E	2	C2	0.08
517	Sau	32-40	42-15	R	V	2	C2	0.064
518	Sau	32-00	43-20	R	V	2	C2	0.064
519	Sau	34-00	40-00	R	E	3	C2	0.072
520	Sau	33-55	41-30	R	V	2	C2	0.048
521	Sau	34-00	40-00	R	E	3	C2	0.088
522	Sau	28-00	40-00	R	E	3	C2	0.104
523	Sau	28-00	42-00	R	E	3	C2	0.128
524	Sau	28-00	44-00	R	E	2	C2	0.096
525	Sau	27-40	44-00	R	E	2	C2	0.088
526	Sau	30-00	41-00	R	V	2	C2	0.064
527	Sau	30-00	43-35	R	E	3	C2	0.056
528	Sau	25-50	41-16	R	V	2	C2	0.04
532	Sau	35-05	36-00	D	W	2	C3	0.416
533	Sau	32-00	36-00	D	W	2	C3	0.168
534	Sau	36-00	37-20	D	W	2	C3	0.144
535	Sau	34-00	37-00	D	W	2	C3	0.072
537	Sau	20-30	39-50	R	E	3	C2	0.008
538	Sau	20-40	41-40	R	W	2	C2	0.064
539	Sau	32-15	42-20	R	E	3	C2	0.08
540	Sau	20-00	41-30	R	W	2	C1	0.192
541	Sau	18-00	42-15	F	V	2	C1	0.024
542	Sau	15-50	44-00	F	V	2	C1	0.128
543	Sau	14-40	44-18	F	V	2	C1	0.136
544	Sau	15-05	42-52	R	E	3	C2	-0.016

545	Sau	13-40	46-50	R	E	3	C2	-0.008
546	Sau	15-40	52-00	R	E	3	C2	0.024
550	Sau	14-40	44-40	R	W	1	C2	0.104
551	Sau	13-35	43-50	F	V	3	C1	0.24
552	Sau	15-35	43-10	F	V	3	C1	0.032
556	Ira	35-59	56-50	F	V	2	C2	0.008
557	Ira	34-40	51-30	R	E	3	C2	-0.024
558	Ira	34-40	51-20	R	E	3	C2	-0.032
559	Ira	34-20	51-00	R	E	3	C2	0.016
560	Ira	34-00	51-30	A	I	1	C4	0.024
561	Ira	34-10	51-45	R	V	2	C2	0.008
562	Ira	34-30	51-25	R	V	2	C2	-0.032
563	Ira	34-30	52-30	R	V	2	C2	0.016
564	Ira	34-40	52-40	R	V	2	C2	0.024
565	Ira	33-30	53-00	R	V	2	C2	-0.016
566	Cen	37-15	54-20	R	V	2	C2	0.016
567	Cen	37-22	54-46	A	I	2	C4	0.12
568	Cen	37-27	54-50	A	I	2	C4	0.056
569	Cen	37-43	55-58	R	V	2	C2	0.368
570	Cen	37-50	55-14	R	W	2	C2	0.08
571	Cen	37-55	55-25	R	W	2	C2	0.056
572	Cen	37-05	54-40	A	I	1	C4	0.176
573	Cen	37-08	54-54	A	I	1	C4	0.2
574	Cen	37-04	55-03	F	V	1	C1	0.552
575	Cen	36-56	54-42	F	V	1	C1	0.44
576	Cen	36-40	65-50	A	I	1	C4	0.144
577	Cen	36-45	65-15	A	I	1	C4	0.072
578	Cen	36-40	68-40	R	V	2	C2	0.208
579	Cen	37-10	70-00	R	V	2	C2	0.184
580	Ira	34-18	61-55	A	I	2	C4	0.336
581	Ira	34-00	61-10	R	V	3	C2	0.112
582	Ira	32-25	61-20	R	V	3	C2	0.176
583	Ira	30-08	61-25	R	V	3	C2	0.04
584	Ira	29-10	61-50	R	E	2	C2	0.04
585	Ira	31-22	61-25	R	V	3	C2	-0.032
586	Ira	31-00	61-45	R	V	3	C1	0.16
587	Ira	26-00	61-40	F	V	3	C1	0.016
589	Sau	33-00	37-20	Ex4				0.04
590	Sau	35-03	36-10	D	W	2	C3	0.456
591	Sau	35-02	36-05	D	W	2	C3	0.424
592	Sau	33-00	36-00	R	V	2	C2	0.36
593	Sau	33-30	39-00	R	E	2	C2	0.096
594	Sau	35-00	40-00	R	E	3	C2	0.064
595	Sau	35-30	39-00	R	E	3	C2	0.104
596	Sau	35-30	40-25	D	E	2	C3	0.056
597	Sau	35-00	40-25	A	I	3	C4	0.208
598	Sau	34-35	40-30	R	E	3	C1	0.096
599	Sau	33-00	37-06	R	V	3	C1	0.08

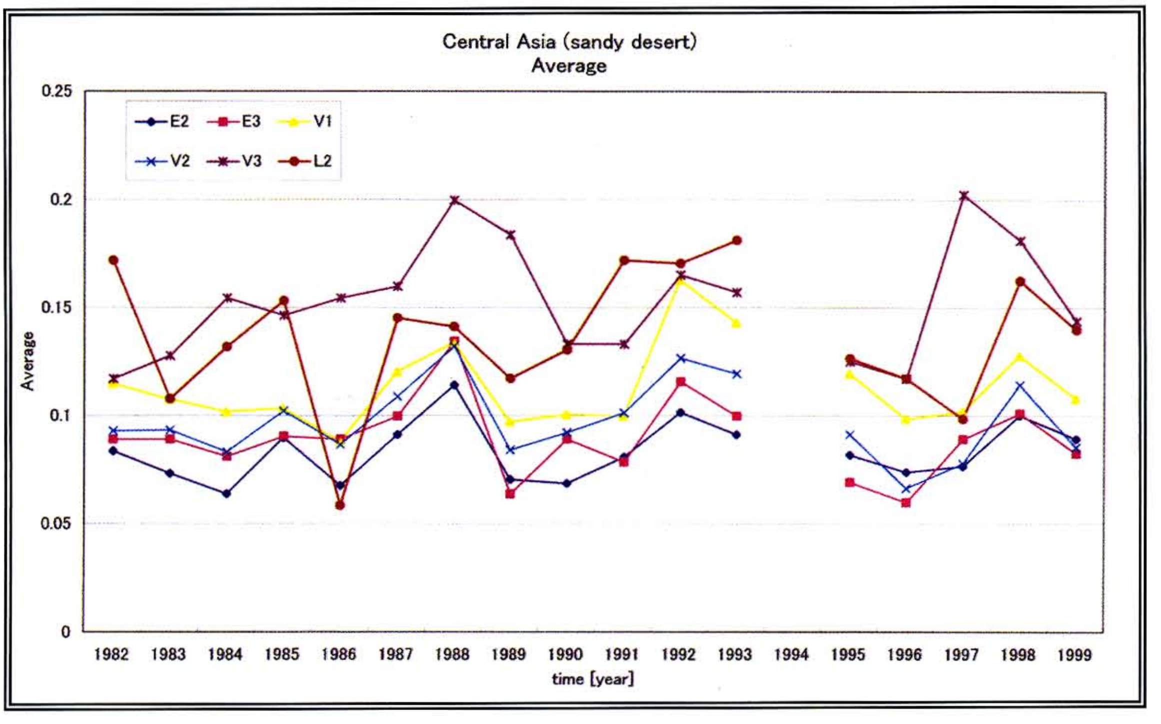
600	Sau	36-30	41-00	D	W	2	C3	0.088
601	Sau	35-00	37-30	D	W	2	C3	0.144
602	Sau	37-00	39-00	D	W	2	C2	0.232
603	Sau	32-42	37-30	R	V	2	C1	0.096
605	Ira	37-05	49-50	F	V	1	C1	0.472
606	Ira	36-20	52-00	F	V	1	C1	0.096
607	Ira	28-20	56-40	R	V	2	C2	0.016
608	Ira	28-40	55-00	R	V	3	C1	0.104
609	Ira	28-35	53-30	F	V	3	C1	0.08
610	Ira	26-15	60-00	R	V	3	C2	-0.048
611	Ira	26-50	60-15	F	V	3	C1	-0.032
612	Ira	27-45	60-00	F	V	3	C1	-0.024
615	Ira	28-00	59-30	R	V	3	C1	-0.016
616	Ira	33-50	60-20	R	W	2	C2	0.032
617	Ira	33-10	58-50	Ex4				0.024
618	Ira	36-20	60-00	A	I	1	C4	0.088
619	Ira	33-00	56-00	R	V	3	C2	-0.032
620	Ira	34-00	56-30	R	V	3	C2	-0.008
621	Ira	32-00	58-00	R	V	3	C2	-0.04
623	Ira	28-50	59-00	R	V	3	C2	-0.024
624	Ira	27-20	58-00	F	V	3	C1	-0.016
625	Ira	27-10	54-25	R	V	3	C1	0.04
626	Ira	26-00	61-45	R	V	3	C2	-0.056
627	Ira	25-55	61-00	R	V	3	C1	-0.04
629	Ira	30-30	49-20	R	V	3	C1	-0.024
630	Ira	26-00	58-00	R	V	3	C1	-0.04
631	Ira	26-00	57-40	R	V	3	C1	-0.032
633	Ira	28-00	62-00	R	V	3	C2	-0.016
634	Ira	28-00	62-40	R	V	3	C2	-0.04
635	Ira	30-20	60-55	R	V	3	C2	-0.048
639	Ira	30-00	60-05	F	V	3	C1	-0.024
640	Ira	35-30	60-35	D	W	2	C3	0.128
641	Ira	33-00	60-15	F	V	3	C1	0.032
642	Ira	33-30	58-00	R	V	3	C2	0.008
643	Ira	37-30	59-00	F	W	3	C1	0.168
644	Ira	36-45	57-00	F	V	2	C1	0.08
645	Ira	36-20	58-00	R	V	2	C2	0.056
646	Ira	35-30	52-00	R	V	3	C2	0.056
647	Ira	36-30	52-30	A	I	2	C4	0.08
648	Ira	37-20	50-00	A	I	2	C4	0.208
649	Tur	39-30	36-00	D	W	2	C3	0.28
650	Tur	37-00	34-00	Ex2				0.152
651	Tur	40-00	34-30	Ex2				0.24
652	Tur	39-50	34-00	D	W	2	C3	0.256
653	Tur	38-30	34-05	D	W	2	C3	0.2
654	Tur	39-30	33-10	D	W	2	C3	0.208
655	Tur	39-30	33-00	D	W	2	C3	0.272
656	Tur	38-55	33-40	D	W	2	C3	0.248

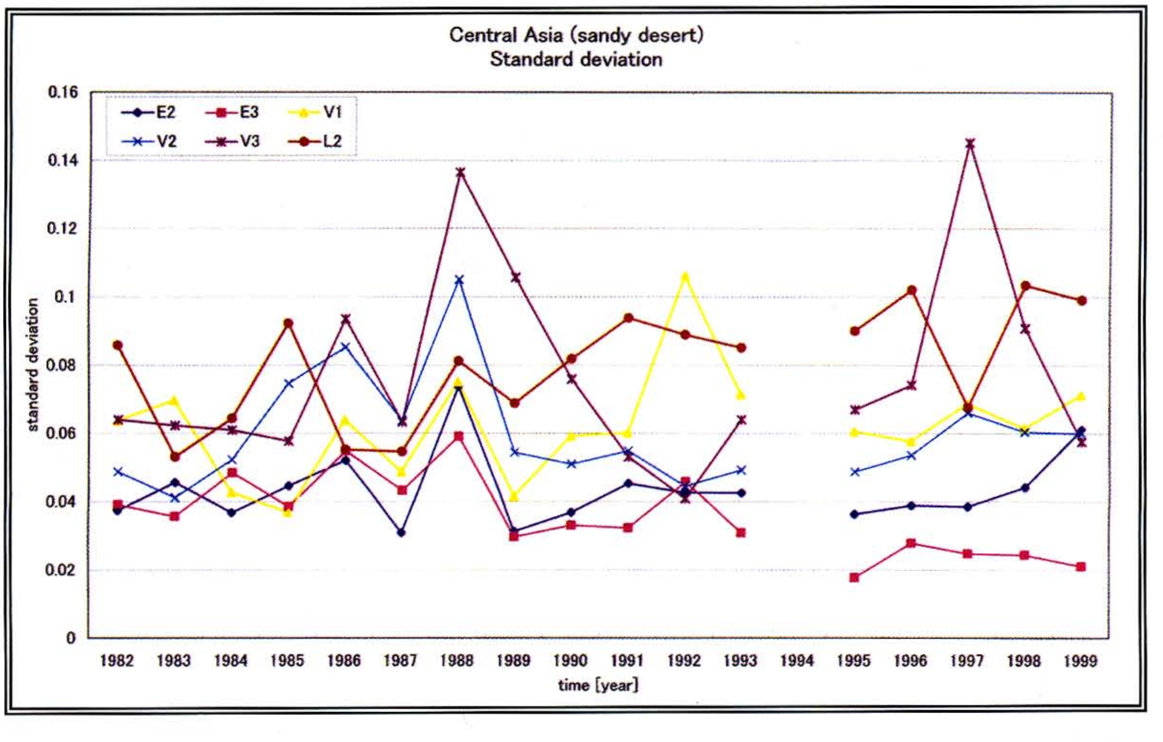
657	Tur	38-00	34-10	D	W	2	C3	0.184
658	Tur	38-30	36-00	D	W	2	C3	0.248
659	Tur	38-00	33-00	D	W	2	C3	0.136
660	Tur	38-25	35-00	D	W	2	C3	0.168
661	Tur	38-30	36-00	R	W	1	C2	0.248

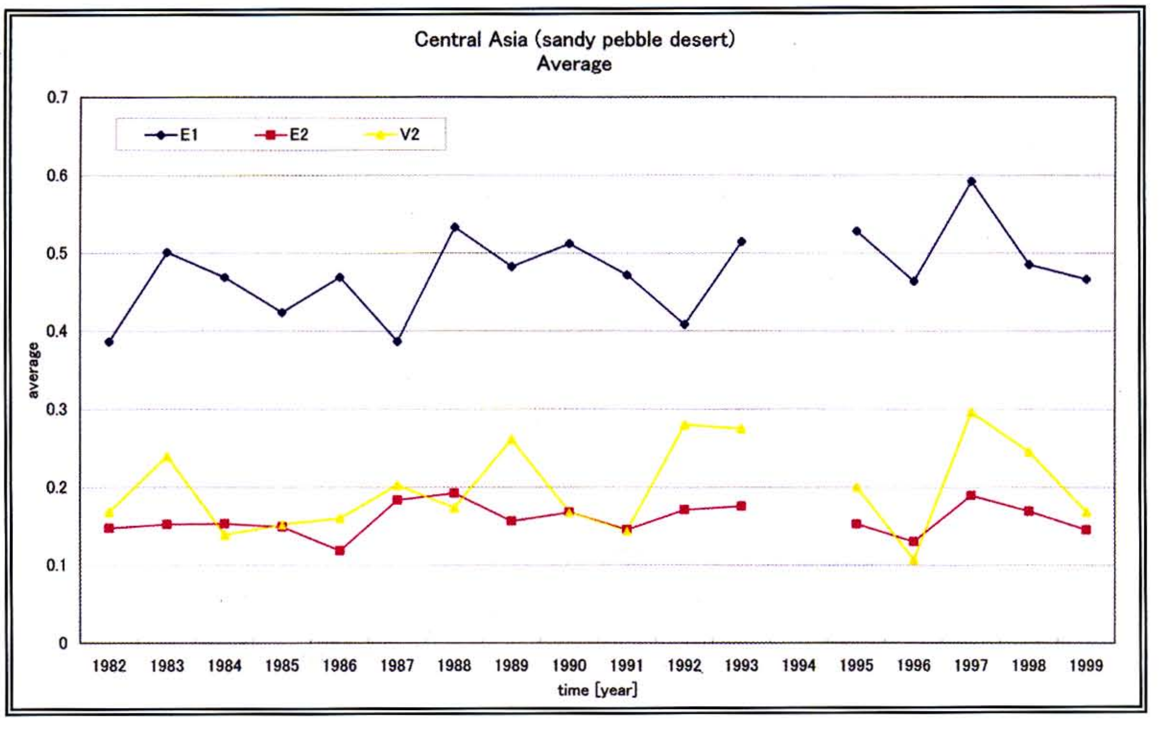
Appendix II

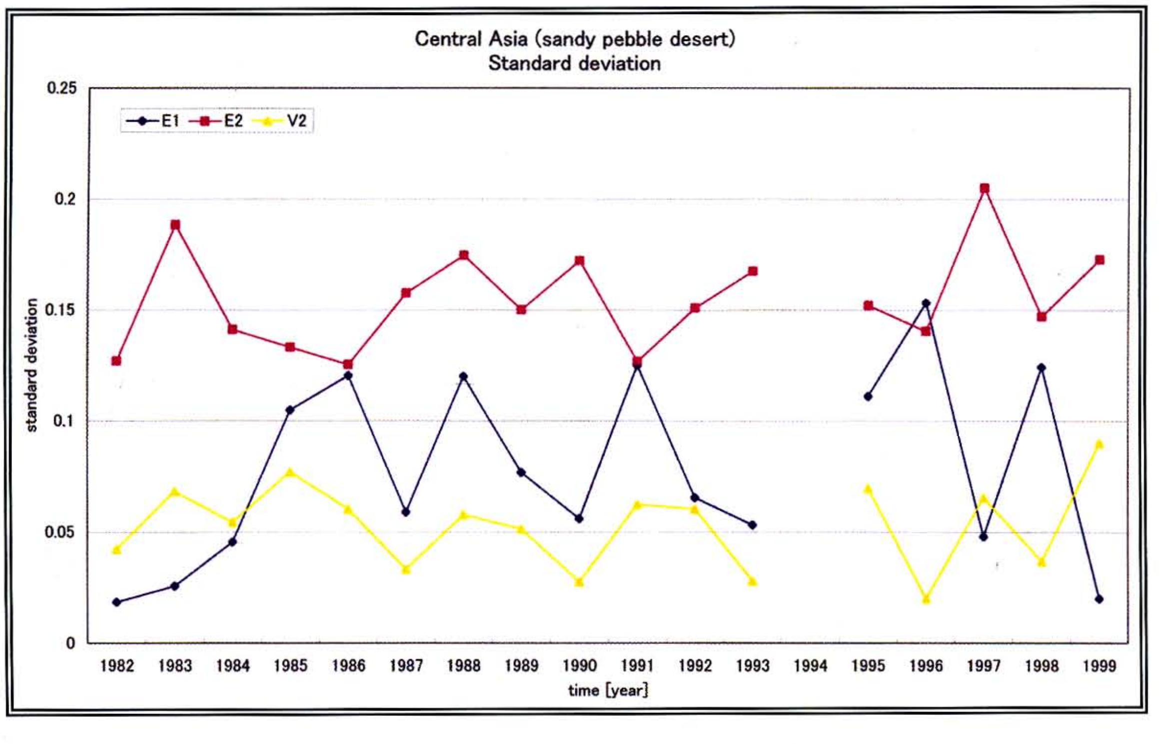
ANNUAL VALUES AND STANDARD DEVIATIONS OF NDVI (21 – 31 MAY 1982 – 1999, 8 km RESOLUTION) IN THE DRYLANDS OF ASIA

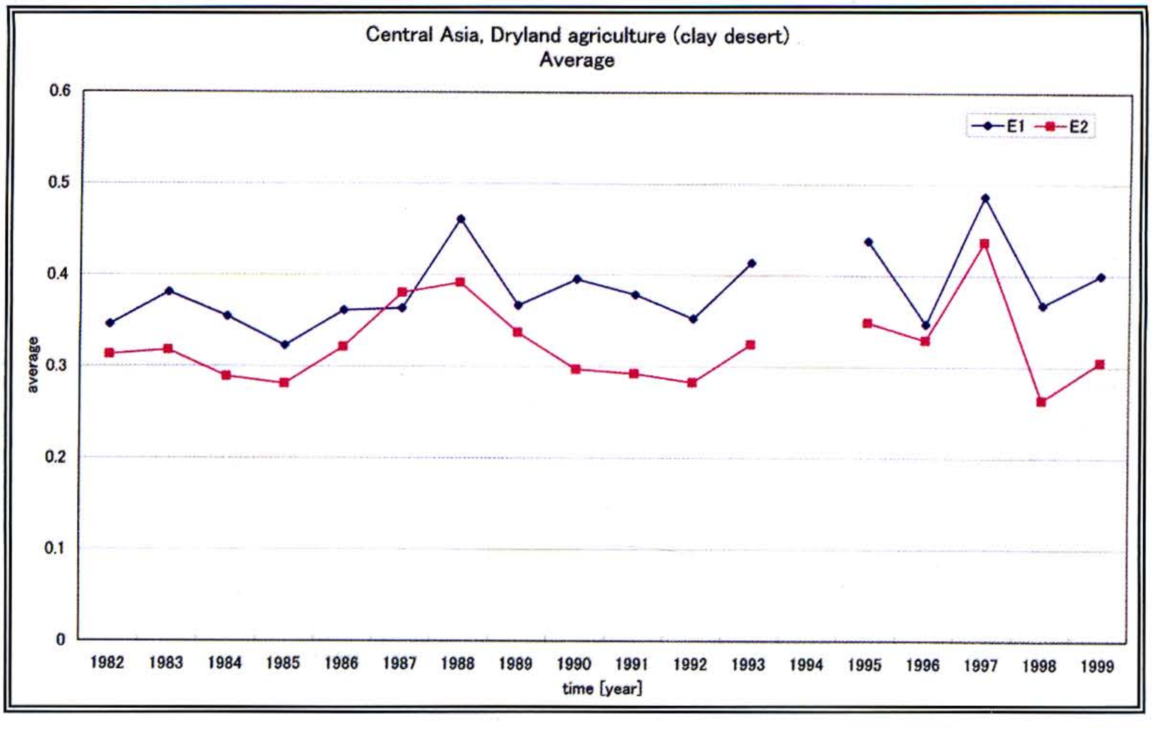
Note: Characteristics of sample plots are given in Sections 3.1 and 3.4

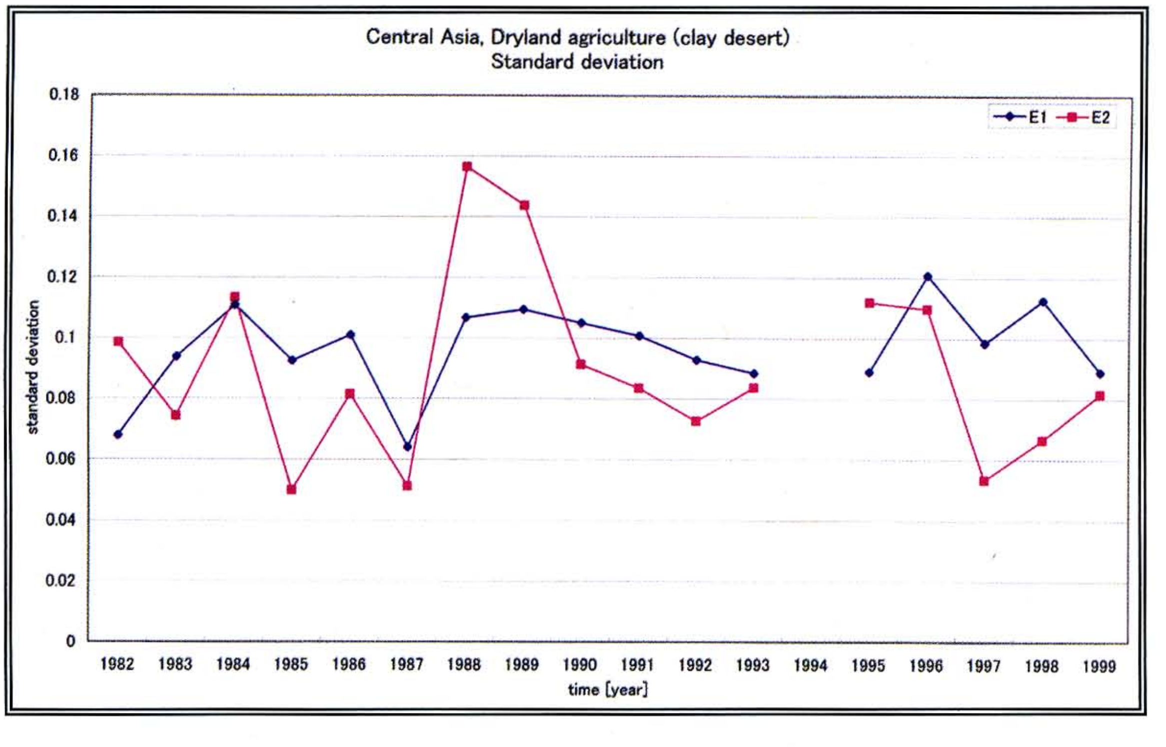


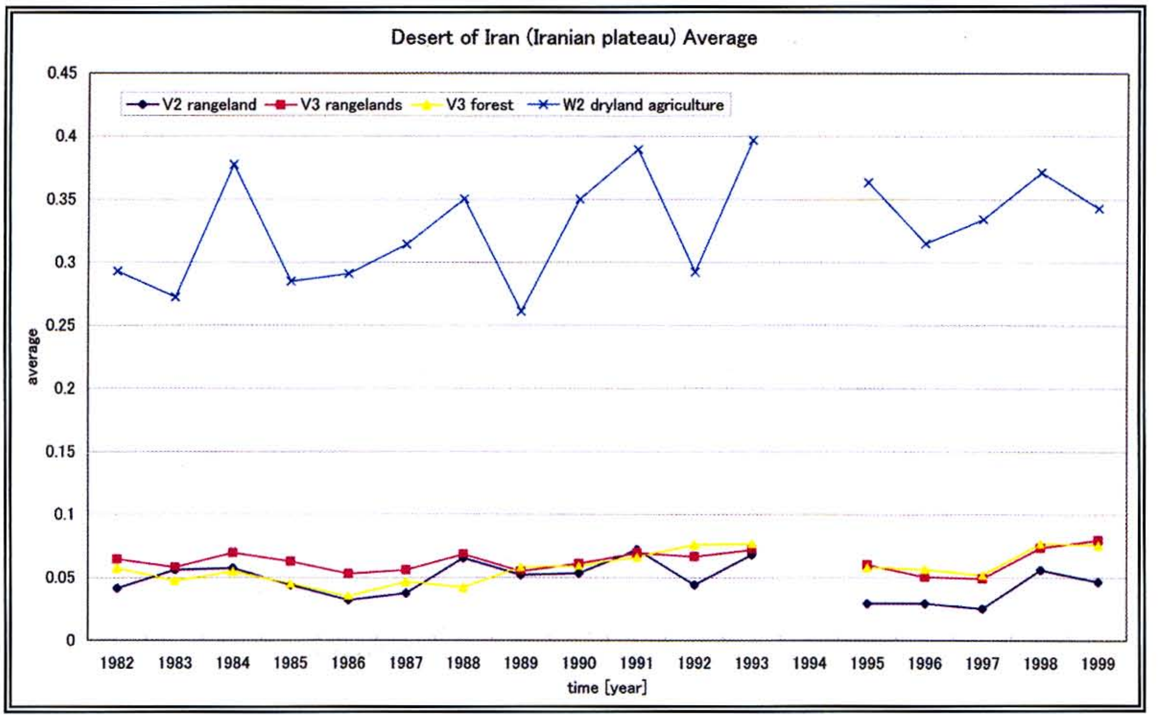



Central Asia (sandy pebble desert)
Average
E1
E2
V2
average
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999
time [year]

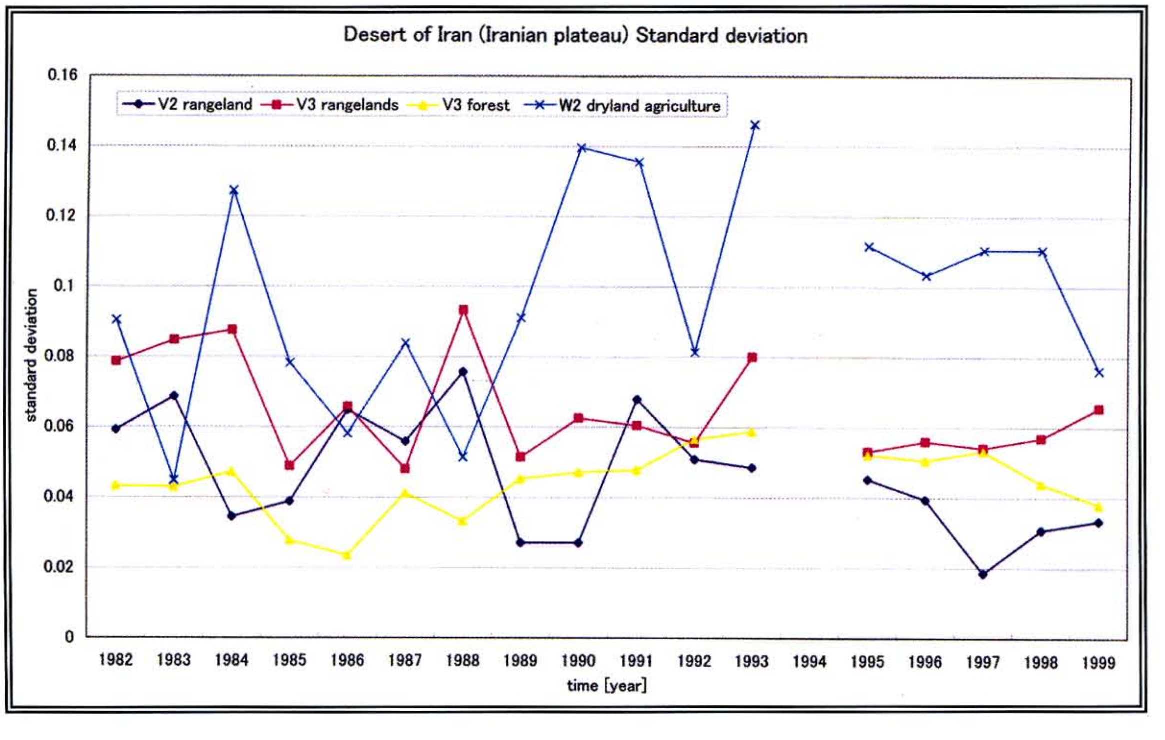

Central Asia (sandy pebble desert)
Standard deviation
E1
E2
V2
standard deviation
0
0.05
0.1
0.15
0.2
0.25
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999
time [year]


Central Asia, Dryland agriculture (clay desert)
Average
E1
E2
average
0.6
0.5
0.4
0.3
0.2
0.1
0
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999
time [year]

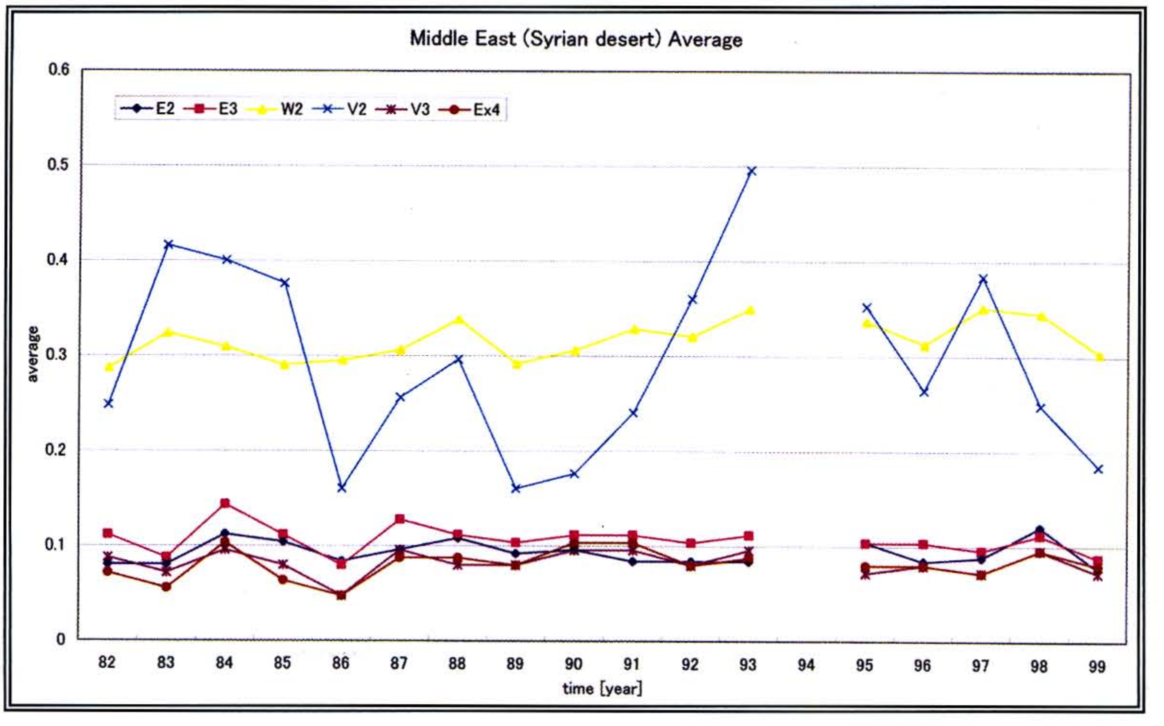

Central Asia, Dryland agriculture (clay desert)
Standard deviation
E1
E2
standard deviation
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999
time [year]

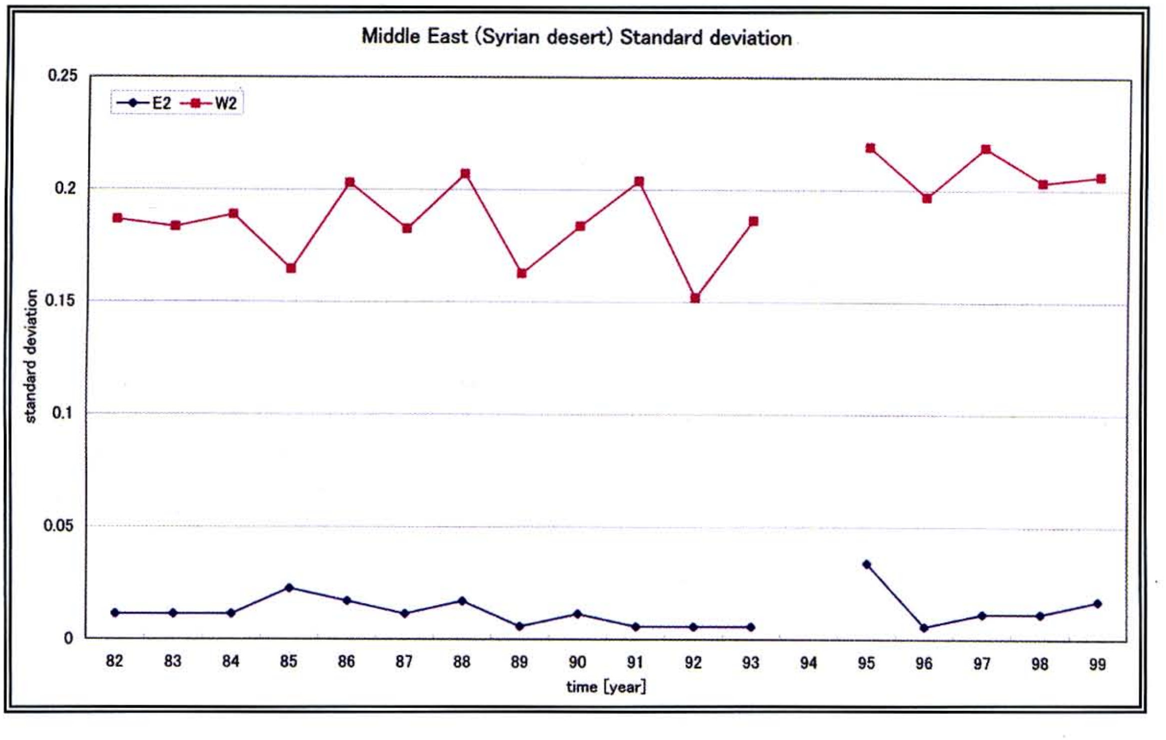


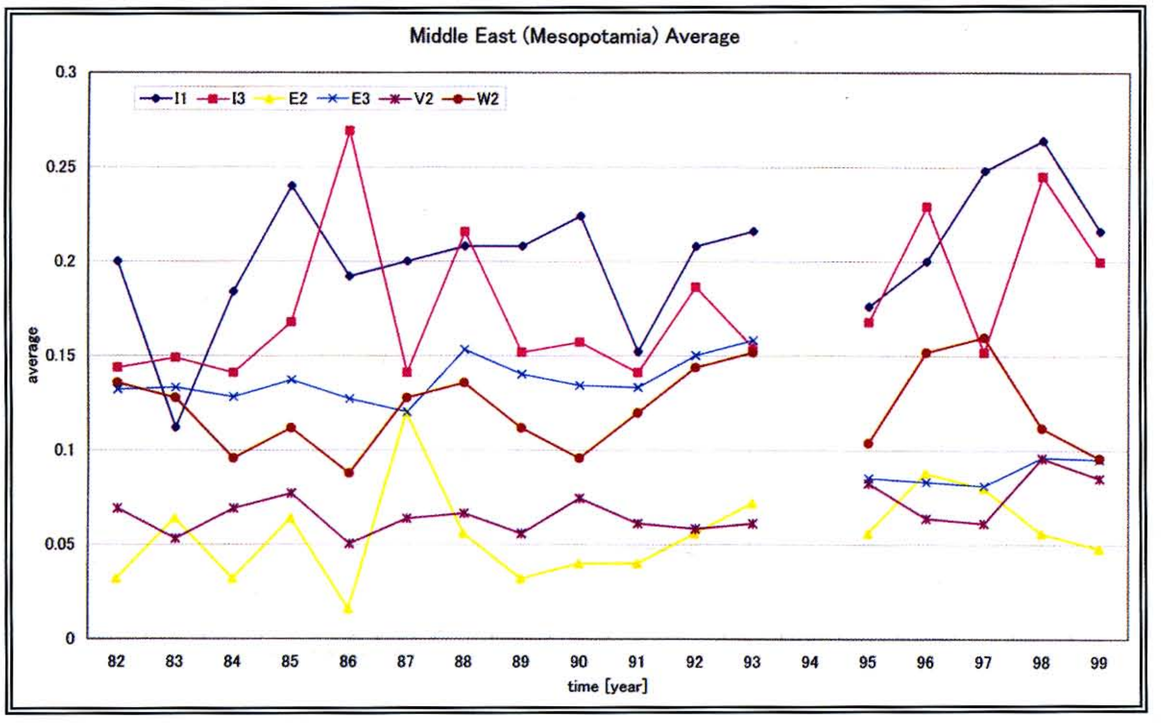
Desert of Iran (Iranian plateau) Average
V2 rangeland
V3 rangelands
V3 forest
W2 dryland agriculture
average
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999
time [year]



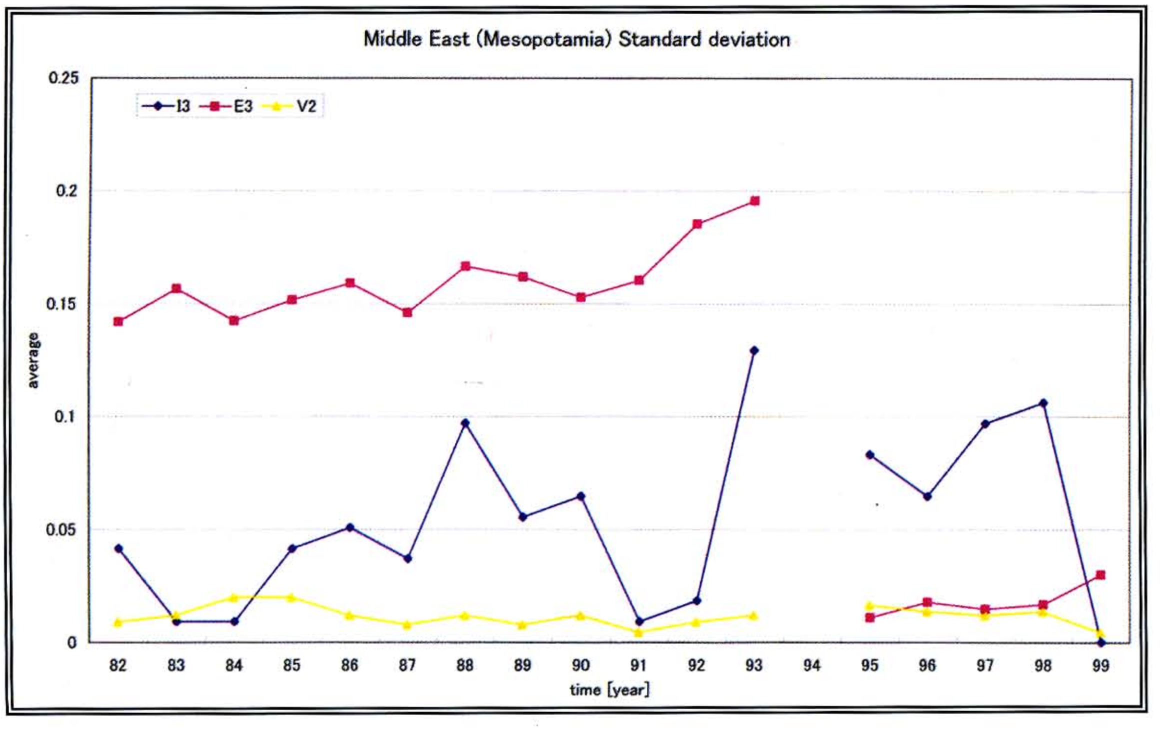
Desert of Iran (Iranian plateau) Standard deviation
V2 rangeland
V3 rangelands
V3 forest
W2 dryland agriculture
standard deviation
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999
time [year]


Middle East (Syrian desert) Average
E2
E3
W2
V2
V3
Ex4
average
0.6
0.5
0.4
0.3
0.2
0.1
0
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99
time [year]

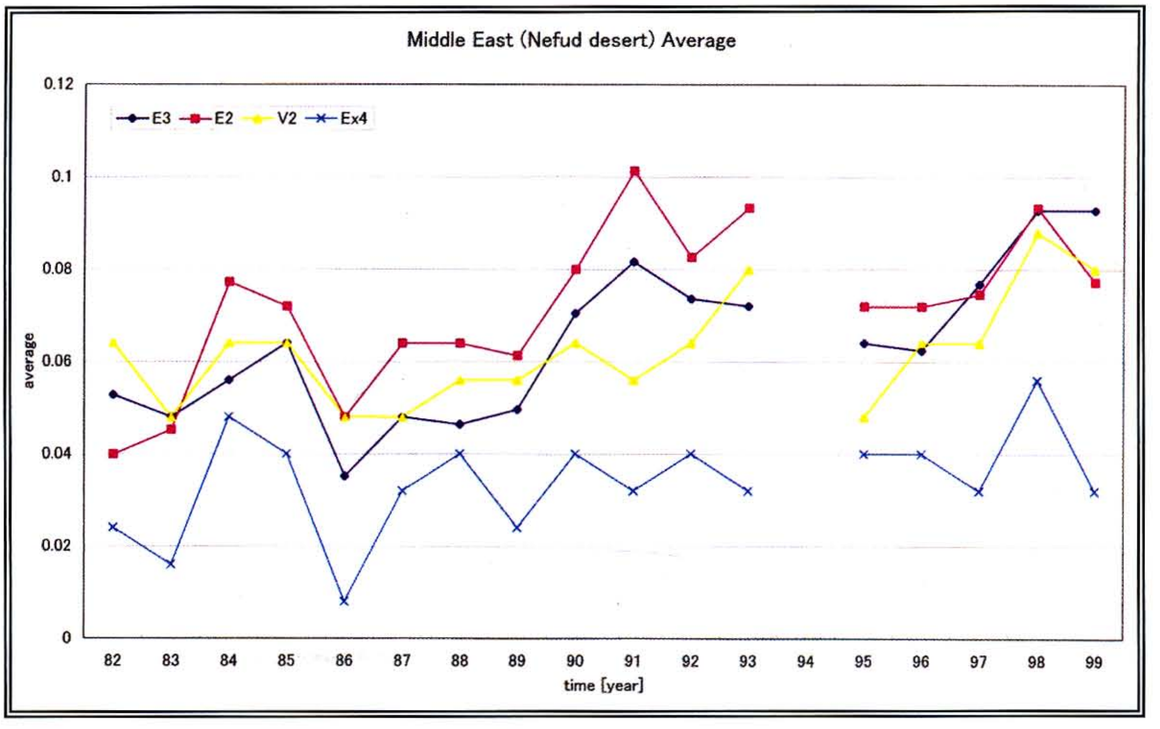

Middle East (Syrian desert) Standard deviation
E2
W2
standard deviation
0.25
0.2
0.15
0.1
0.05
0
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99
time [year]

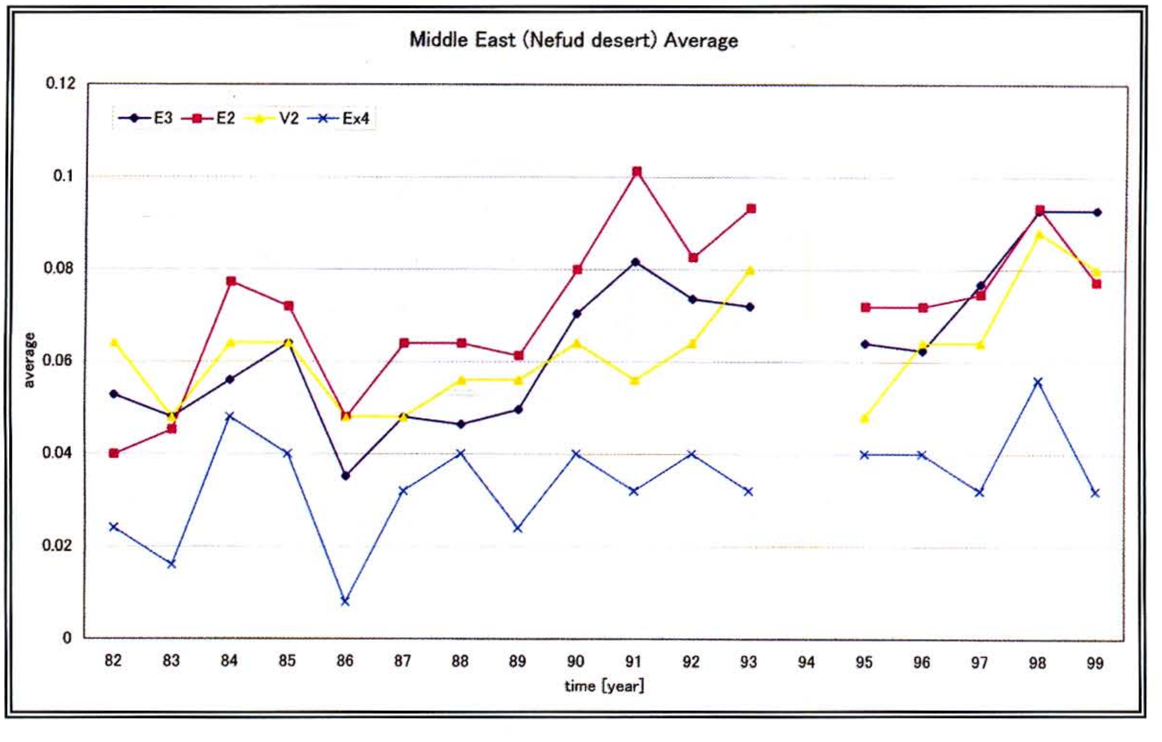


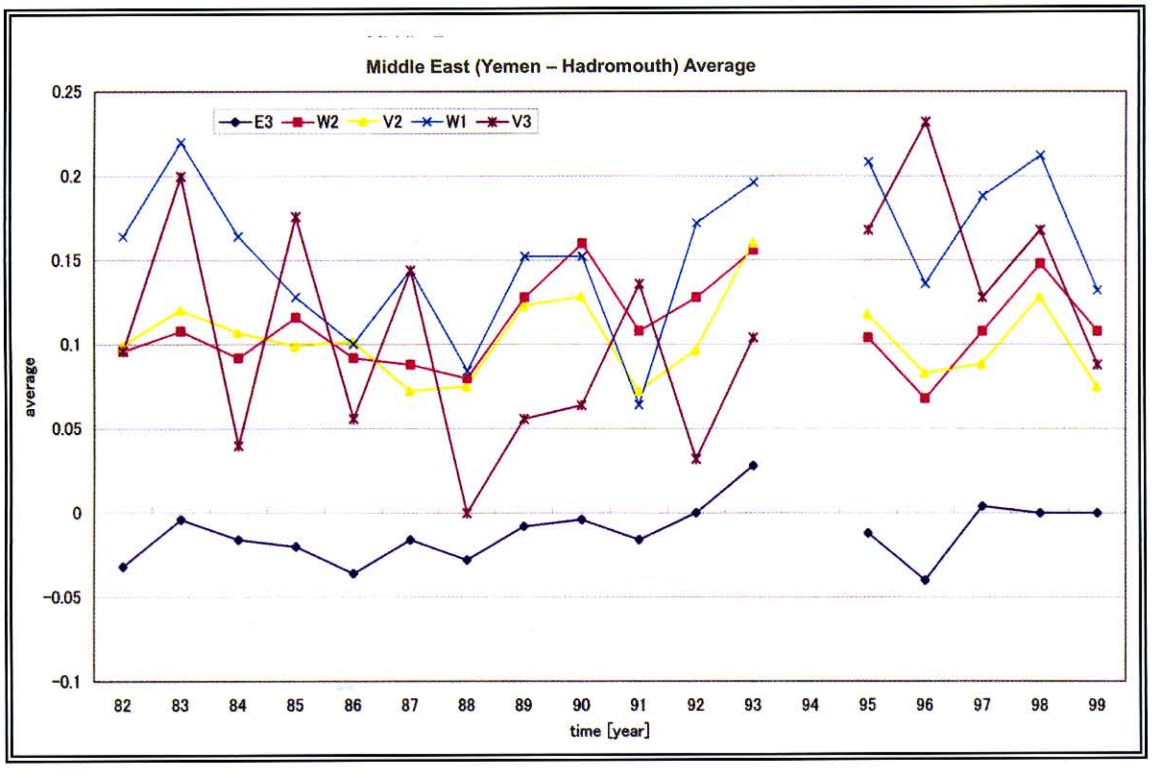
Middle East (Mesopotamia) Average
I1
I3
E2
E3
V2
W2
average
time [year]
0.3
0.25
0.2
0.15
0.1
0.05
0
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99

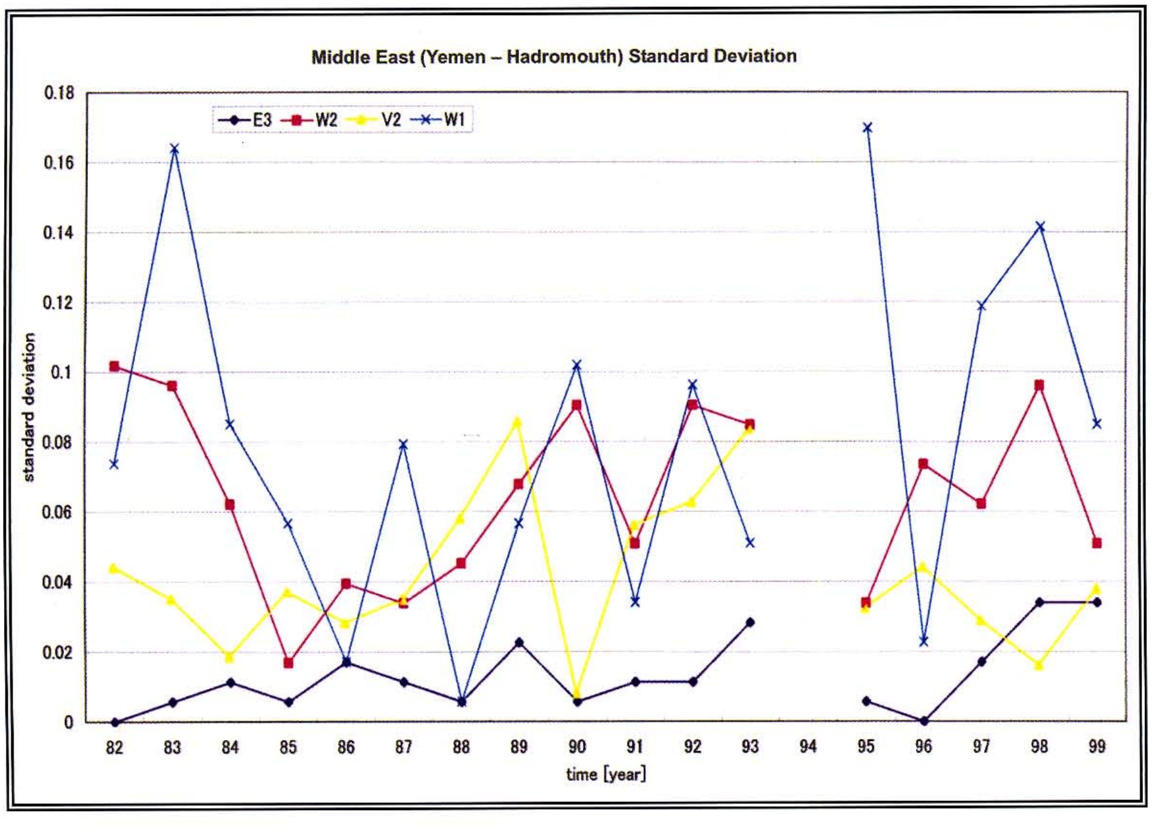


Middle East (Mesopotamia) Standard deviation
I3
E3
V2
average
time [year]
0.25
0.2
0.15
0.1
0.05
0
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99


Middle East (Nefud desert) Average
E3
E2
V2
Ex4
average
0.12
0.1
0.08
0.06
0.04
0.02
0
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99
time [year]


Middle East (Nefud desert) Average
E3
E2
V2
Ex4
average
0.12
0.1
0.08
0.06
0.04
0.02
0
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99
time [year]

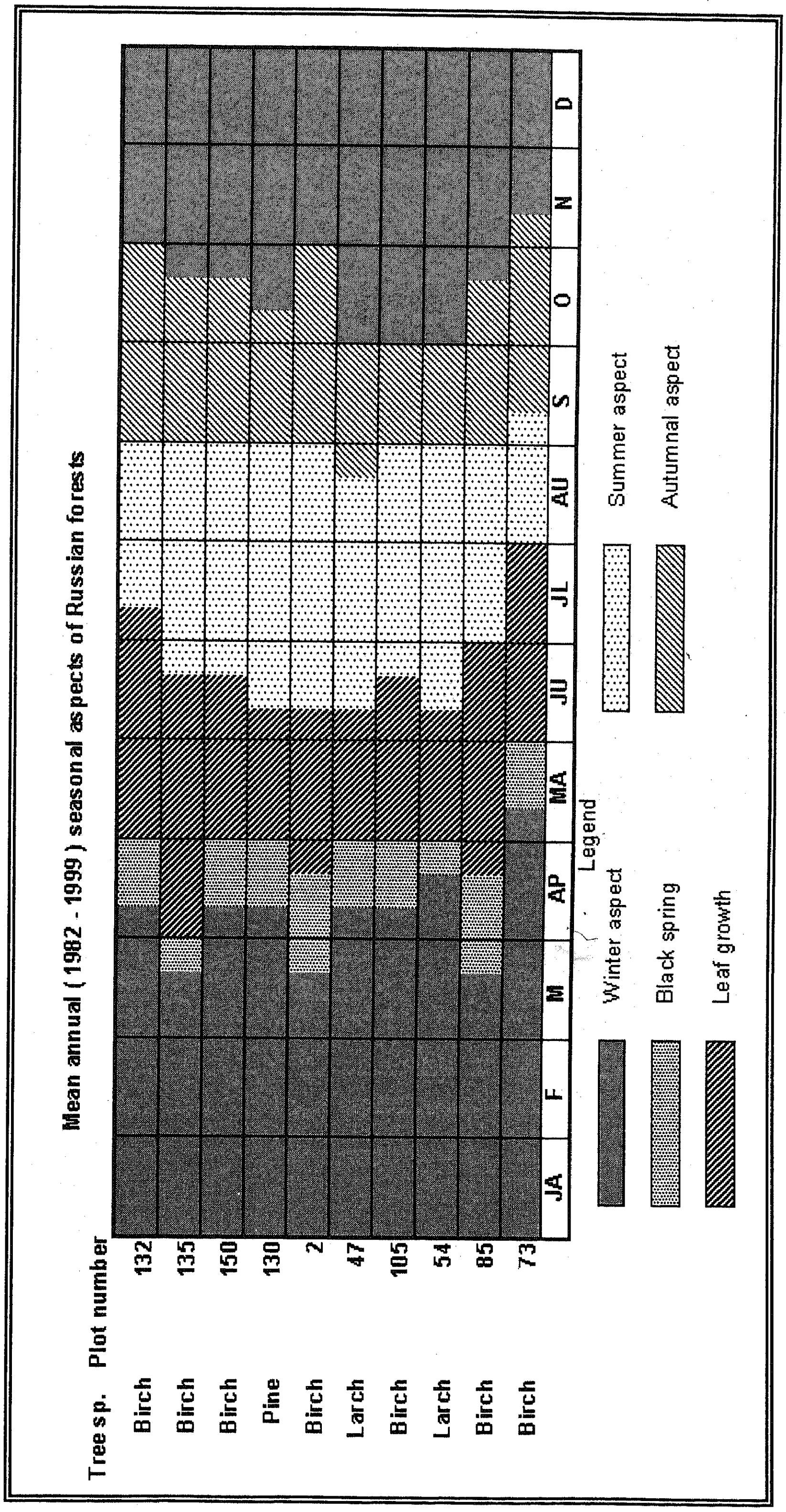

Middle East (Yemen – Hadromouth) Average
E3
W2
V2
W1
V3
average
time [year]
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99

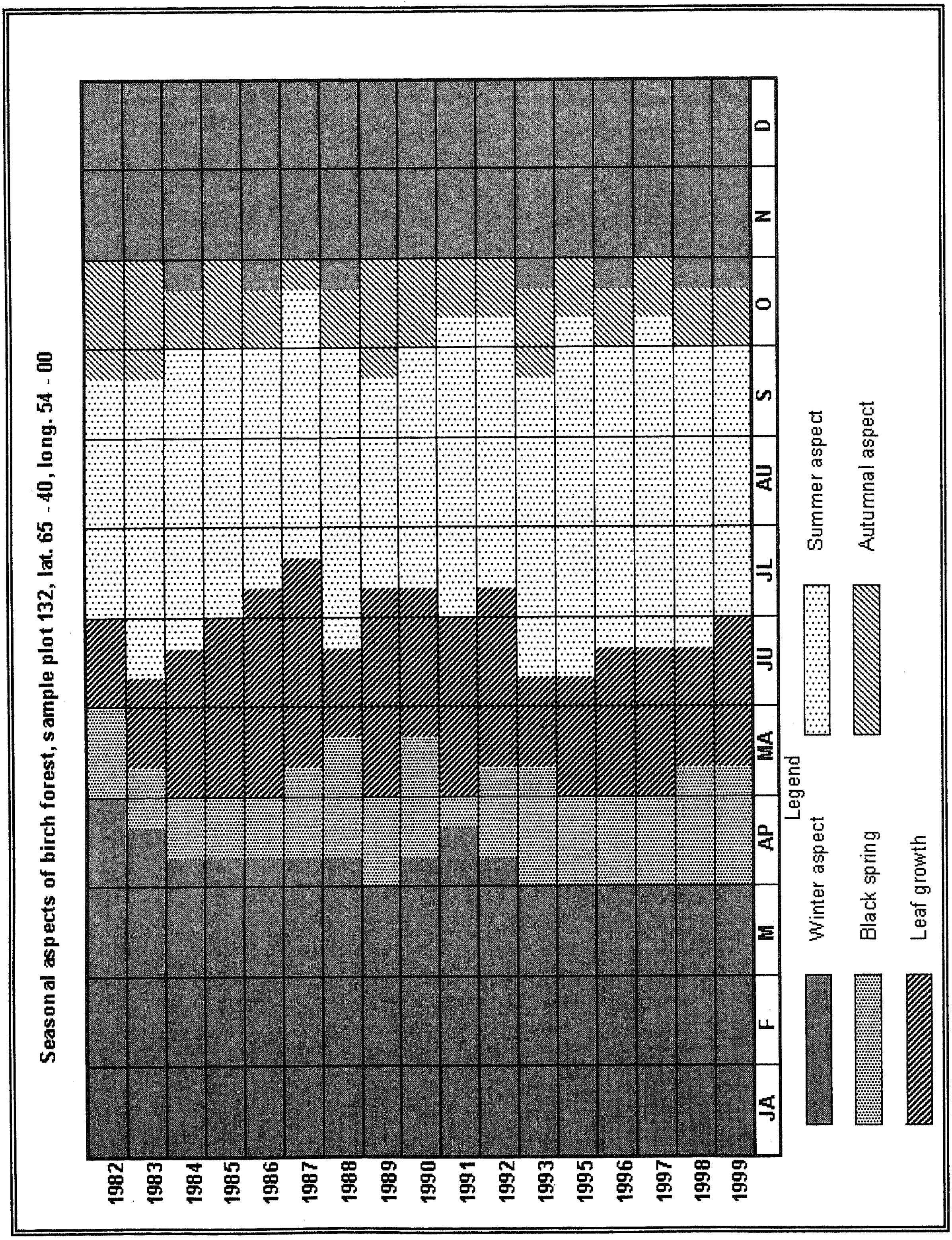

Middle East (Yemen – Hadromouth) Standard Deviation
E3
W2
V2
W1
standard deviation
time [year]
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99

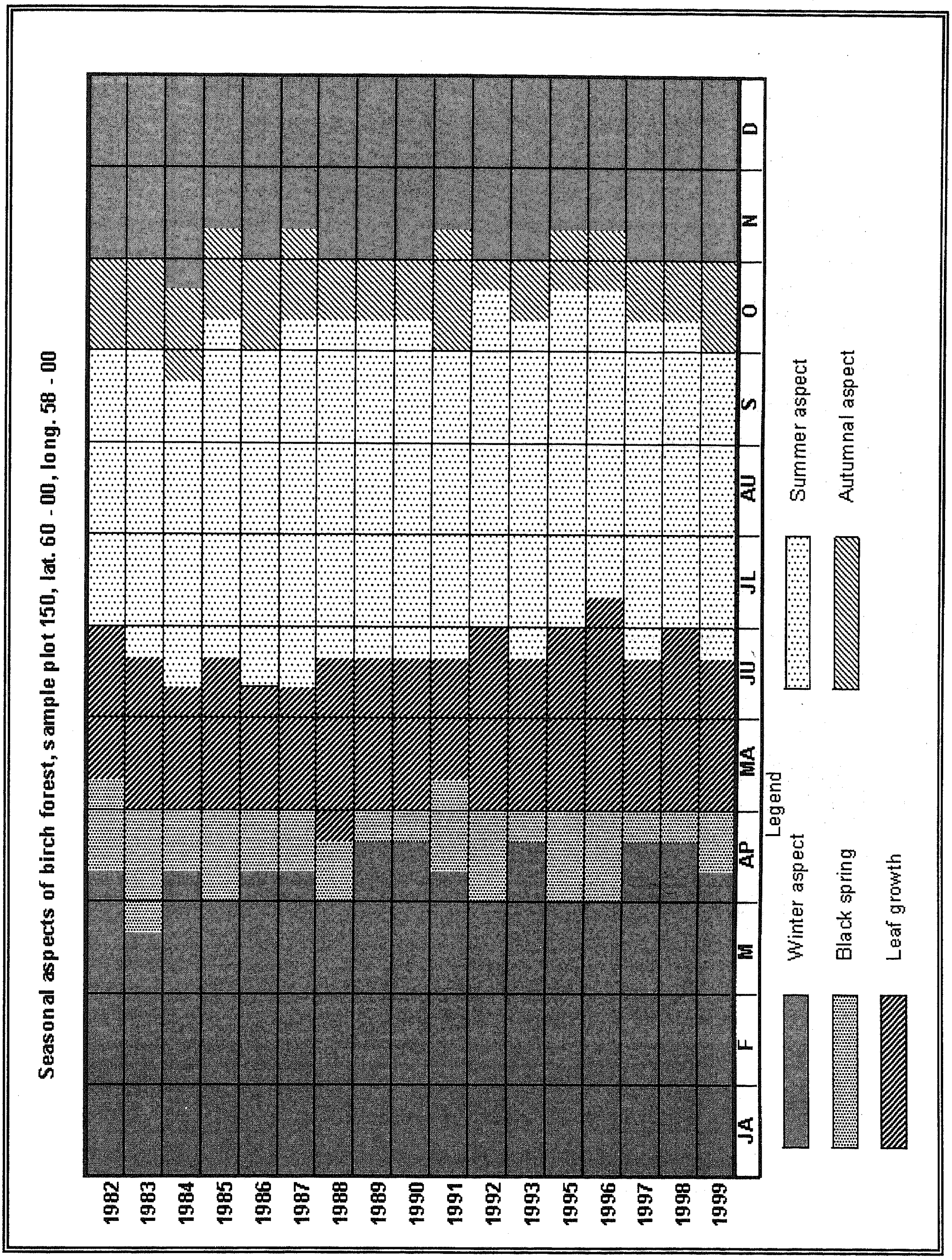
Appendix III

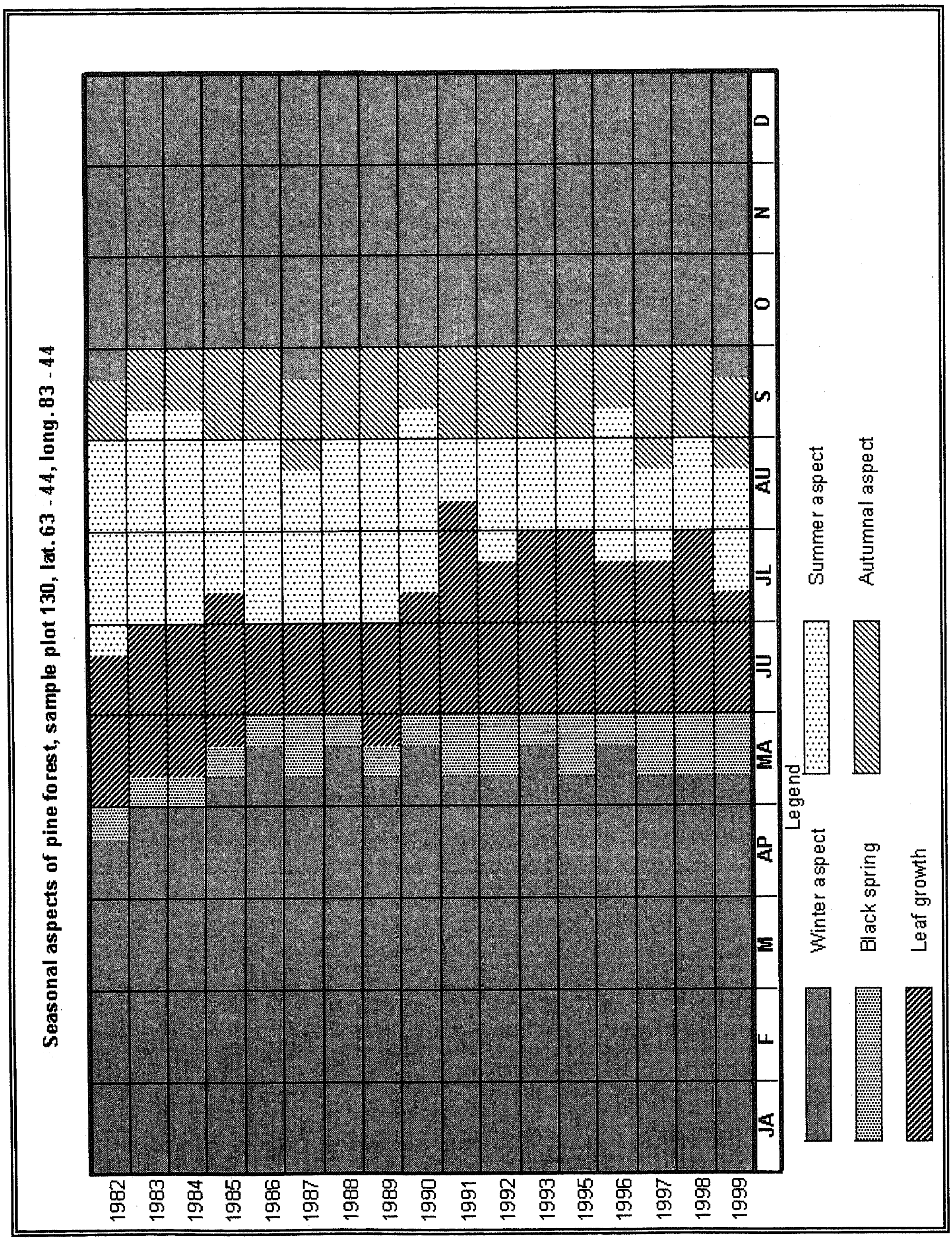
MEAN ANNUAL (1982-1999) SEASONAL ASPECTS OF RUSSIAN FORESTS

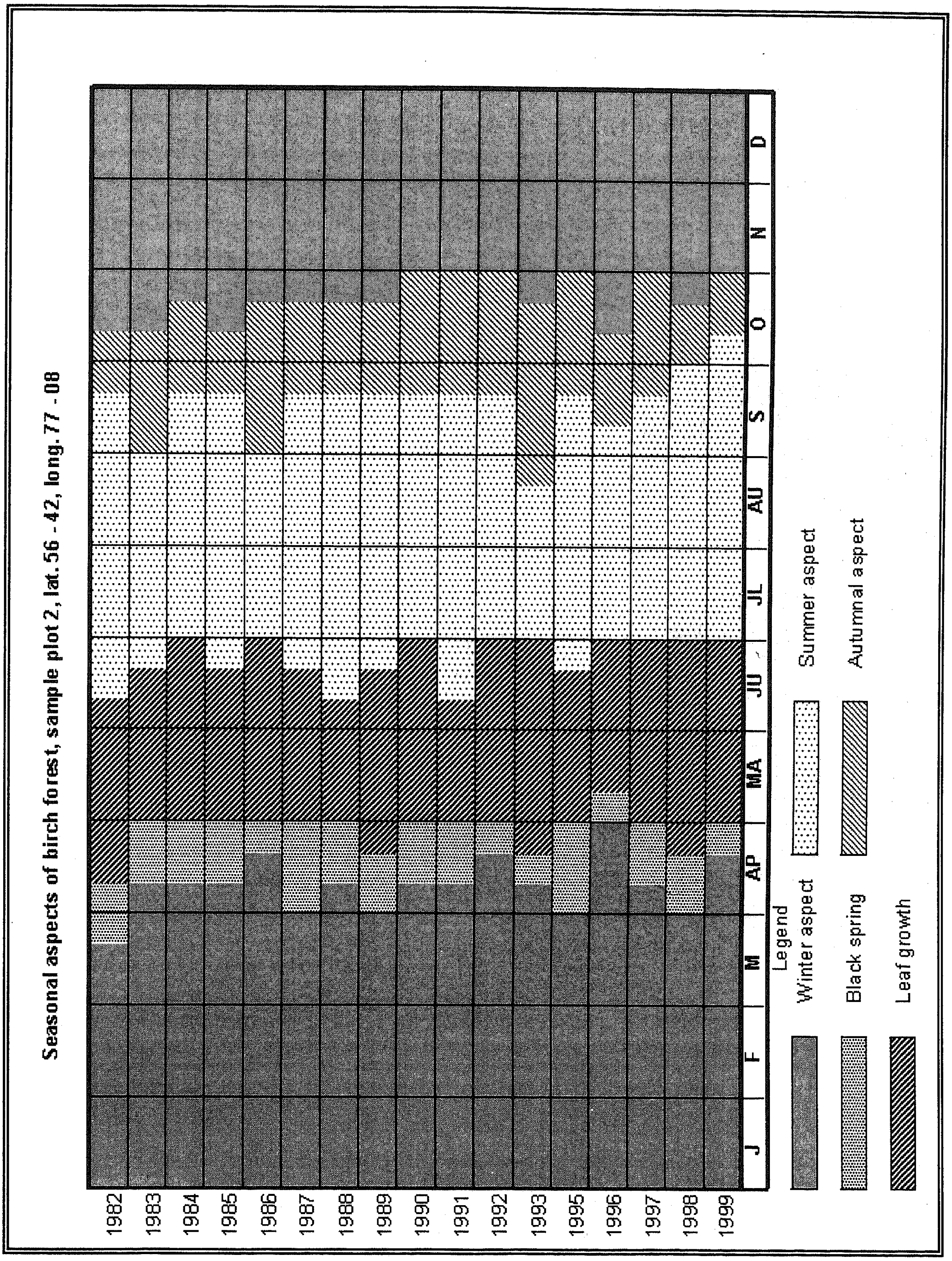
Note: Characteristics of sample plots are given in **Table 2.3.2**

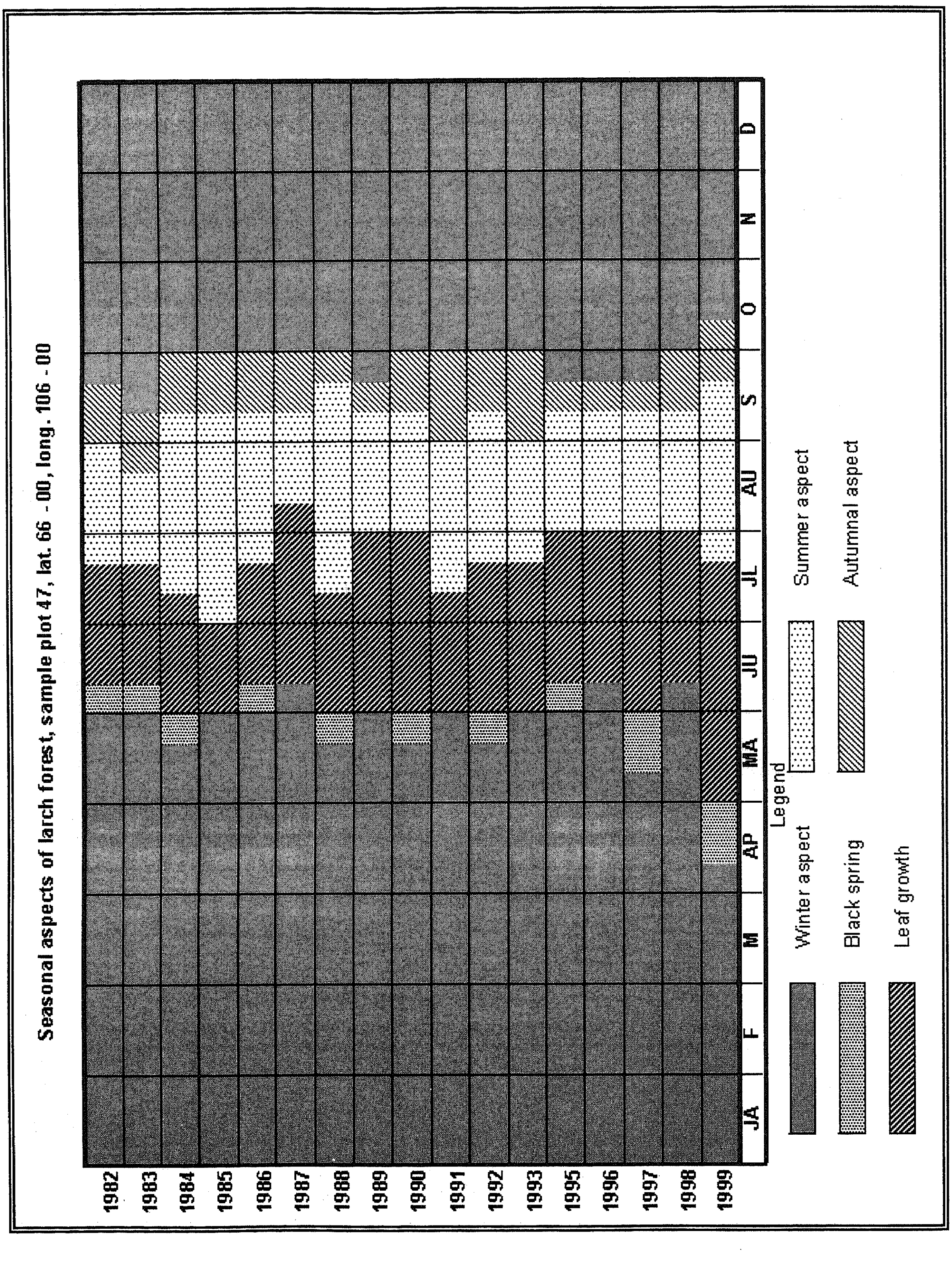


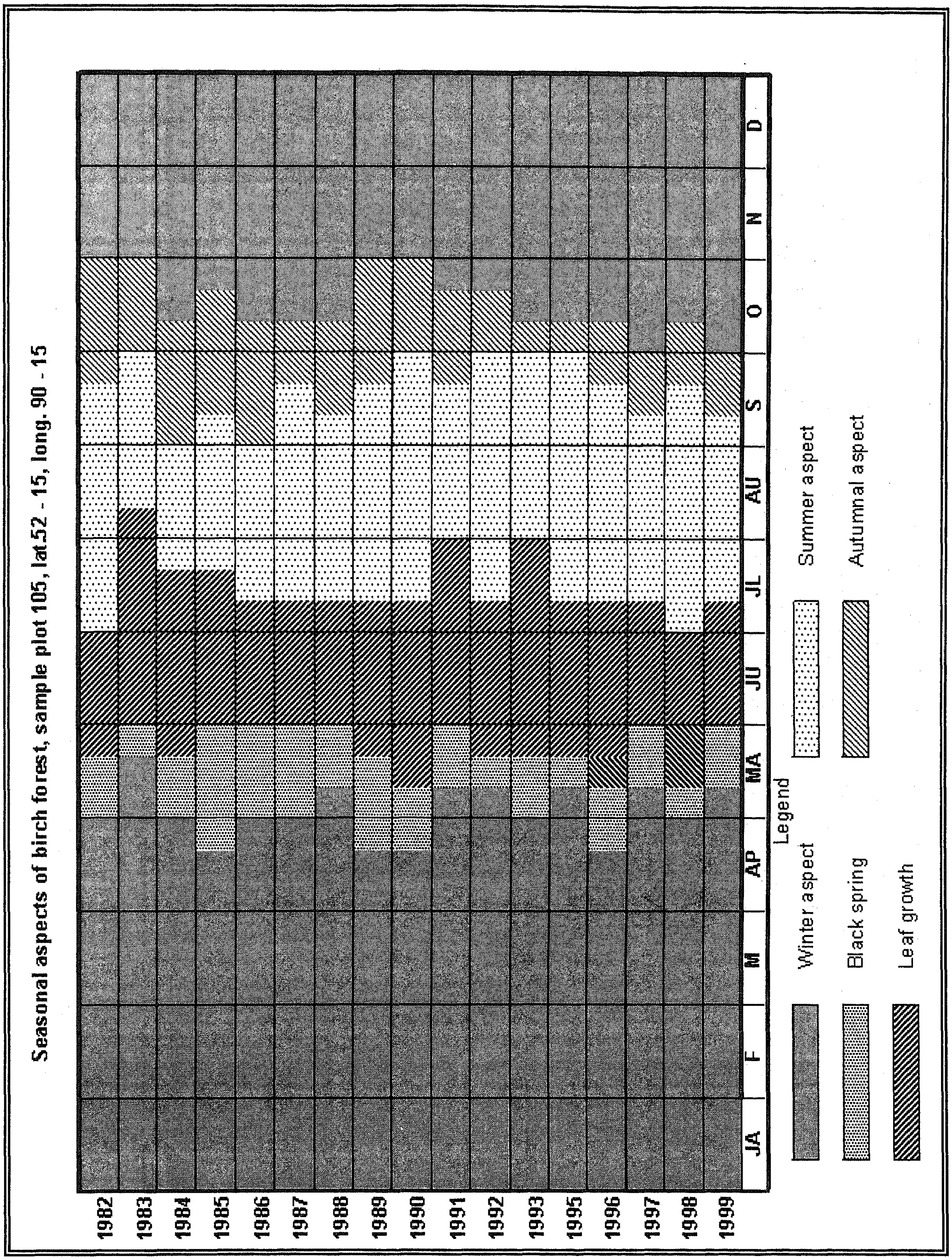

Seasonal aspects of birch forest, sample plot 132, lat. 65 - 40, long. 54 - 00
JA
F
M
AP
MA
JU
JL
AU
S
O
N
D
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
Legend
Winter aspect
Black spring
Leaf growth
Summer aspect
Autumnal aspect

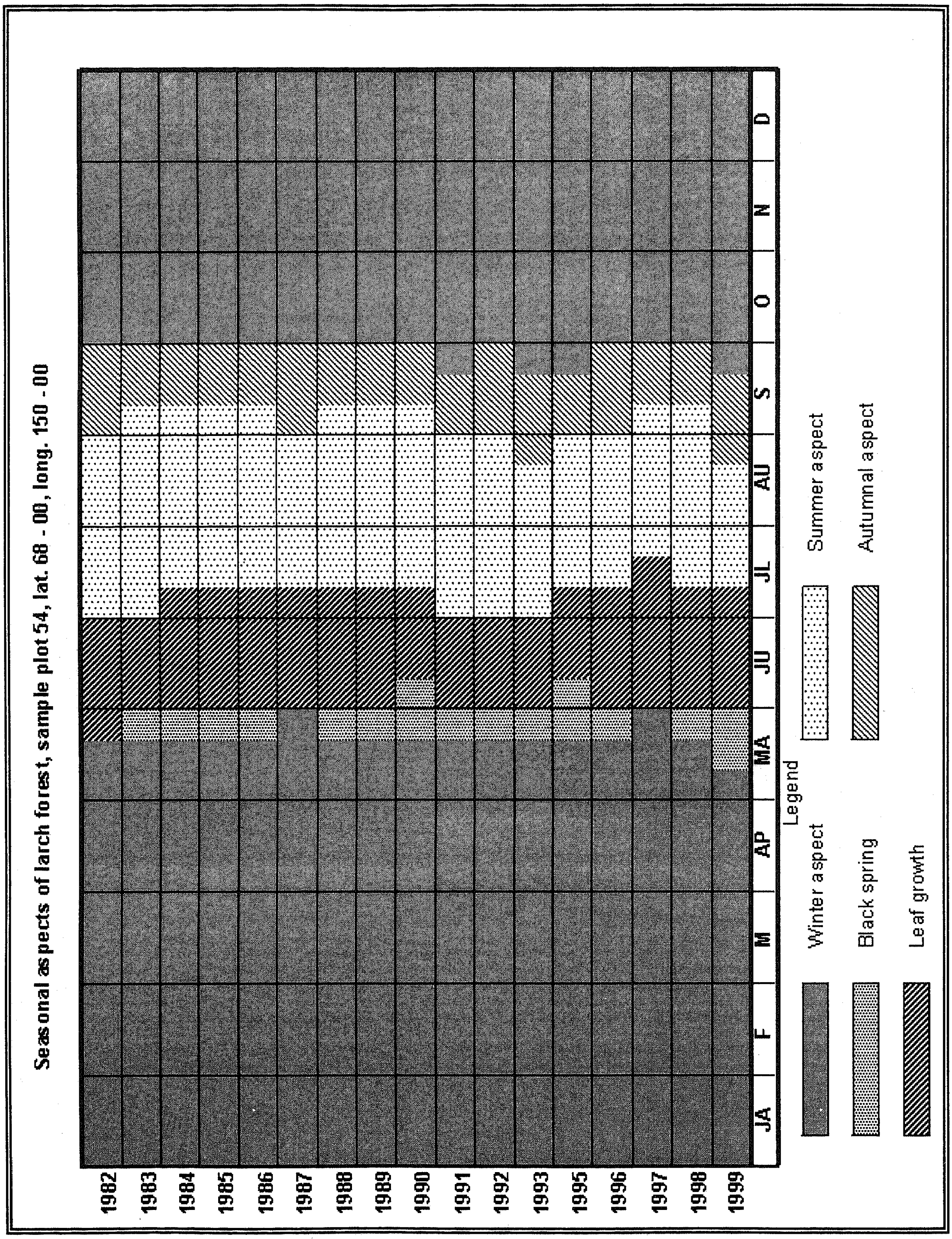

Seasonal aspects of birch forest, sample plot 150, lat. 60 - 00, long. 58 - 00
JA
F
M
AP
MA
JU
JL
AU
S
O
N
D
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
Legend
Winter aspect
Black spring
Leaf growth
Summer aspect
Autumnal aspect

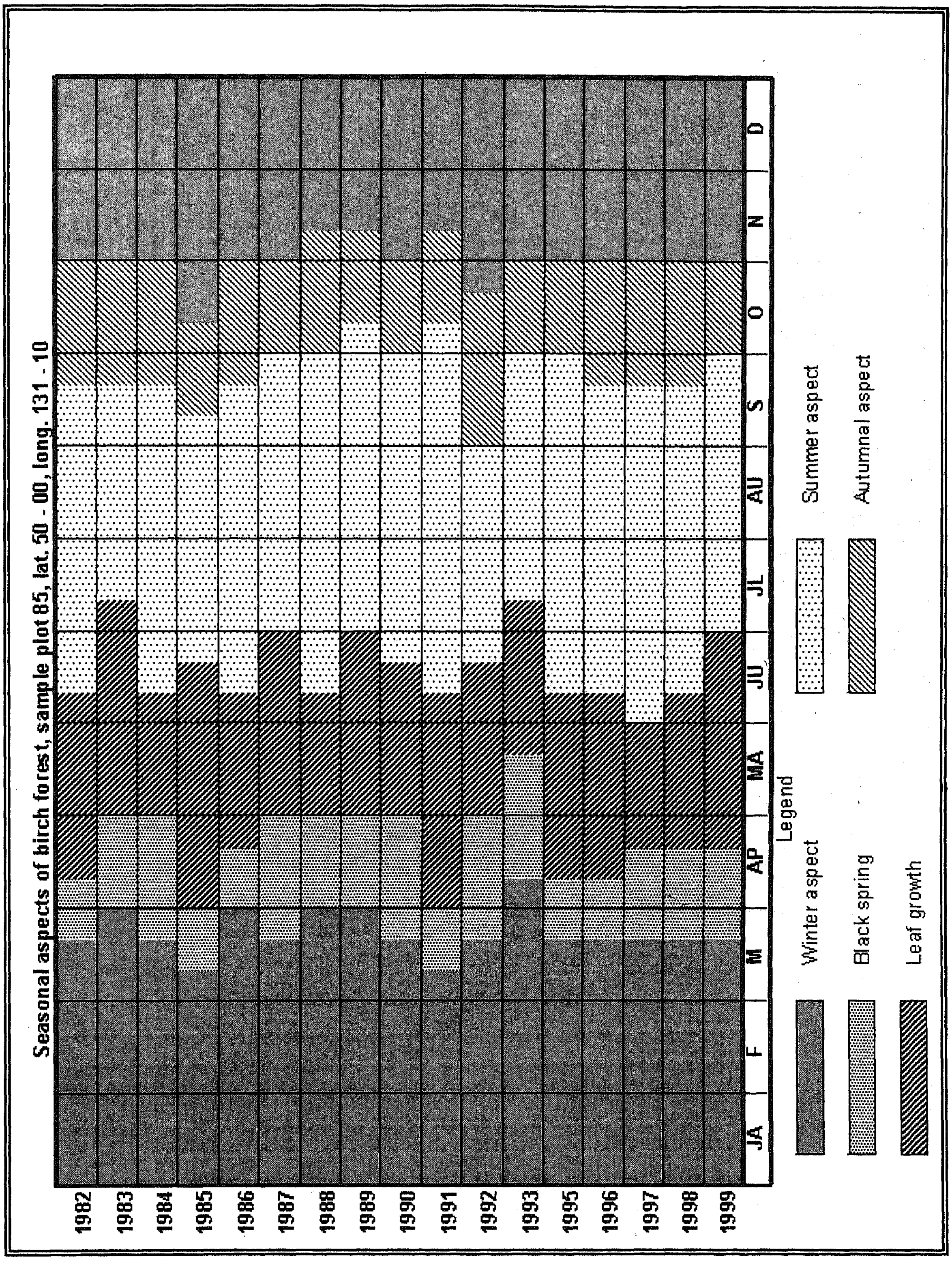

Seasonal aspects of pine forest, sample plot 130, lat. 63 - 44, long. 83 - 44
JA
F
M
AP
MA
JU
JL
AU
S
O
N
D
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
Legend
Winter aspect
Black spring
Leaf growth
Summer aspect
Autumnal aspect

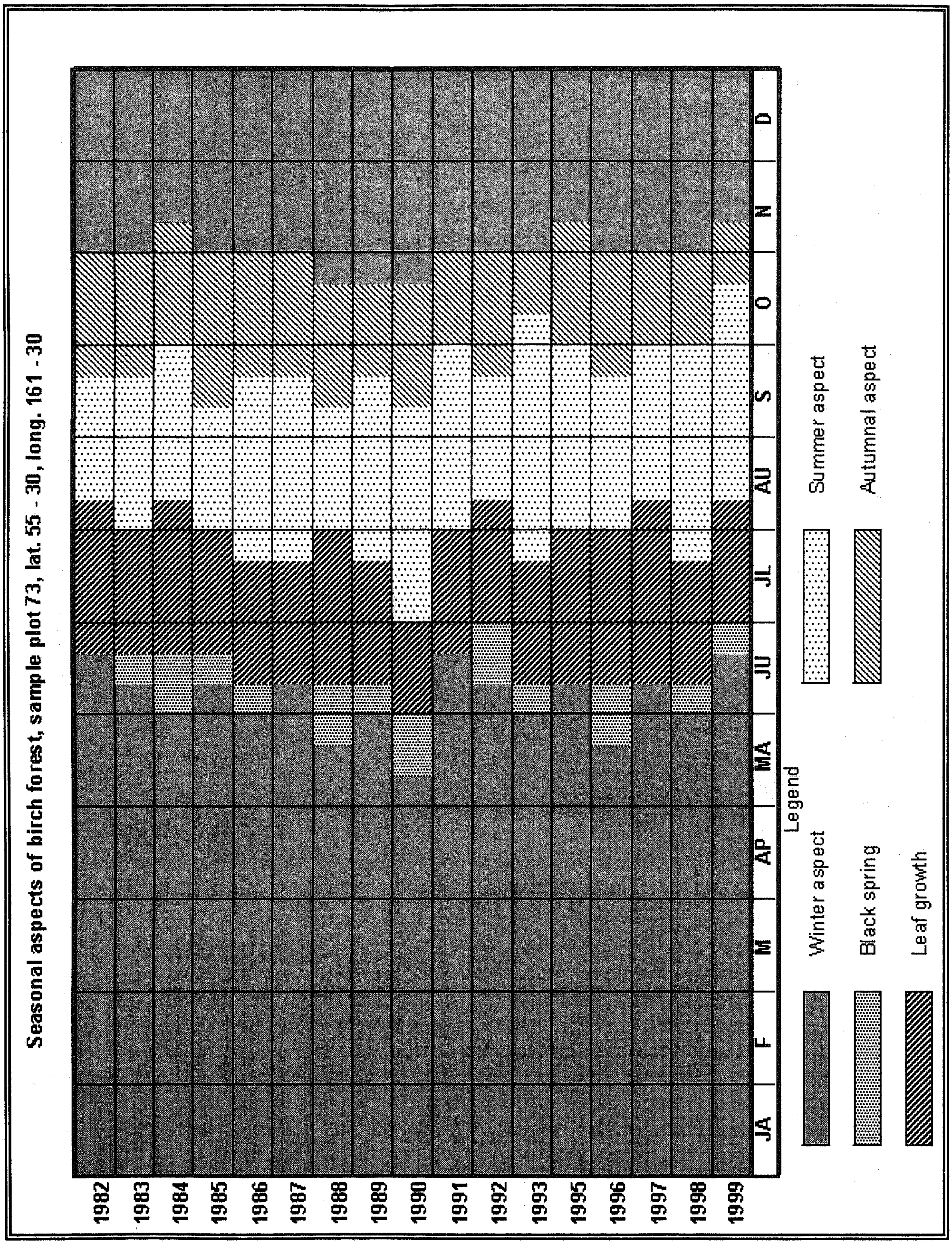

Seasonal aspects of birch forest, sample plot 2, lat. 56 - 42, long. 77 - 08
J
F
M
AP
MA
JU
JL
AU
S
O
N
D
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
Legend
Winter aspect
Black spring
Leaf growth
Summer aspect
Autumnal aspect


Seasonal aspects of larch forest, sample plot 47, lat. 66 - 00, long. 106 - 00
JA
F
M
AP
MA
JU
JL
AU
S
O
N
D
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
Legend
Winter aspect
Black spring
Leaf growth
Summer aspect
Autumnal aspect


Seasonal aspects of birch forest, sample plot 105, lat.52 - 15, long. 90 - 15
JA
F
M
AP
MA
JU
JL
AU
S
O
N
D
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
Legend
Winter aspect
Black spring
Leaf growth
Summer aspect
Autumnal aspect


Seasonal aspects of larch forest, sample plot 54, lat. 68 - 00, long. 150 - 00
JA
F
M
AP
MA
JU
JL
AU
S
O
N
D
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
Legend
Winter aspect
Black spring
Leaf growth
Summer aspect
Autumnal aspect


Seasonal aspects of birch forest, sample plot 85, lat. 50 - 00, long. 131 - 10
JA
F
M
AP
MA
JU
JL
AU
S
O
N
D
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
Legend
Winter aspect
Black spring
Leaf growth
Summer aspect
Autumnal aspect


Seasonal aspects of birch forest, sample plot 73, lat. 55 - 30, long. 161 - 30
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1995
1996
1997
1998
1999
JA
F
M
AP
MA
JU
JL
AU
S
O
N
D
Legend
Winter aspect
Black spring
Leaf growth
Summer aspect
Autumnal aspect

Appendix IV

Center for Environmental Remote Sensing (CEReS), Chiba University, Japan

International Forest Institute, Russian Academy of Physical Sciences, Moscow, Russia

Nikolai Kharin and Ryutaro Tateishi

PHENOTAIGA
METHODOLOGY FOR ESTIMATION OF THE OPTIMAL SEASONS OF AERIAL (SPACE) PHOTOGRAPHIC MISSIONS OF FORESTS IN RUSSIA

The methodology is based on phenological maps (maps of seasonal aspects) of forests compiled by NOAA/AVHRR low resolution data and on existing phenological maps, thematic maps, climatic data and other sources of information. The status of phenological development of forest tracts was evaluated by 10 days NDVI imagery within 1 pixel, 1 min. in size. But we recommend to use the maps for estimation of a seasonal status of forests of larger tracts, at least 3x3 pixels (24x 24 km) because of possible phenological variability and errors in estimation of coordinates. The phenological maps characterize a seasonal status of forests on the basis of long term data (1982 – 1999). Phenological zoning of the forests of Russia is given in **Figure 1**.

This map was compiled on the basis of phenological maps and climatic data (N. G. Kharin, 1972, Atlas of the USSR Forests, 1973). Characteristics of all phenological regions of Russia are given in **Table 1**.They include :

- The main length of the growing season in days,
- Latitudinal gradient (the number of days on later seasonal development per 1° of the latitude),
- Altitudinal gradient (the number of days on later seasonal development per 100 m of altitude),
- Longitudinal gradient (the number of days in later seasonal development per 1° of longitude).

Table 2 illustrates the concept of calculation of the optimal seasons of aerial photography. The optimal season of aerial photography for forest inventory and mapping begins after starting period of full leaf season. During the summer period tree species have the highest spectral reflectance in visible and near infrared regions of spectrum. So, aerial (space) photos can give a standard uniform information about the composition of forest species, crown density and status of forest stands, even if photos are used in vast areas. During this period the recognition features for identification of ground objects are more or less stable. Phenological maps are given in **Figures 2.7.6 (a), 2.7.6 (b), 2.7.6 (c), 2.7.6 (d), 2.7.6 (e)**.

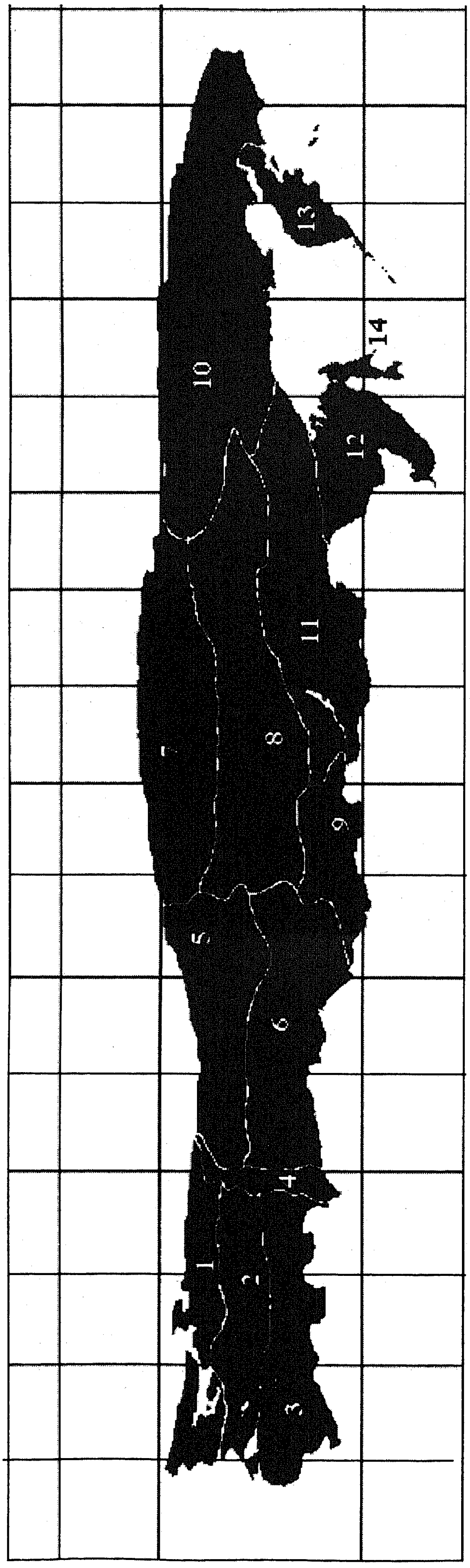


Figure 1

Table 1

Phenological zoning of the forests of Russia

Number	Names of regions	Growing season			Gradients		
		Beginning	End	Length, days	Latitudinal	Altitudinal	Longitudinal
1	North Taiga of Feno-Scandia and East European Plain	5.06	24.08	80	+3.2	+2.1	+0.2
2	Middle Taiga of East European Plain	15.05	28.08	105	+2.3	+2.2	+0.3
3	South Taiga and Mixed Forests of East European Plain	3.05	6.09	126	+2.1	+2.4	+0.1
4	Taiga Forests of the Ural	5.05-5.06	5.09 – 20.08	75-86	+2.3	+2.4	+0.2
5	North Taiga of West Siberia	6.06	20.08	75	+2.2	+2.3	+0.3
6	Middle and South Taiga of West Siberia	15.05	25.08	102	-1.9	+2.3	+0.3
7	North Forests of Middle Siberian Plateau	15.06	20.08	76	+2.3	+2.4	+0.3
8	Middle Taiga of Middle Siberian Plateau	31.05	20.08	81	+2.3	+2.3	+0.3
9	Taiga of the Altai and the Sayan Mountains	31.05	20.08	81	+2.4	+2.4	+0.3
10	Woodland of North East Siberia	10.06	10.08	59	+2.3	+2.4	-0.4
11	Forests of the Baikal Region	5.06	20.08	75	+2.3	+2.3	+0.3
12	Forests of the Far East	31.05	3.09	95	+1.8	+2.6	+0.2
13	Woodland of Dwarf Cedar and Dwarf Birch of Kamchatka	5.06	20.08	75	+2.4	+2.3	0.0
14	Forests of the Sakhalin	3.06	28.08	83	+2.2	+2.0	0.0

Table 2
Optimal seasons of aerial (space) photography

June			July			August			September		
1	2	3	1	2	3	1	2	3	1	2	3
		F				**P**					**B**
			X	**X**	**X**	**X**	**X**	**X**	**X**		
						T	**T**				

Phenological maps

F Starting period of full leaf season (filename F_FULL.JPG in attached diskette)
P Peak period (filename P_PEAK.JPG in attached diskette)
B Staring period of leaf coloration (filename B_COLOR.JPG in attached diskette)

Estimation of the optimal seasons of aerial (space) photography

X Optimal season of aerial (space) photography for forest inventory and mapping
T Optimal season of aerial (space) photography for special biological investigations (assessment of biological productivity, growth and phytomass of plant communities)

But in the end of growing season, when the green chlorophyll pigments are lost, the leaves increase markedly their reflectance in green region of spectrum (0.55 mkm), and decrease it in near infrared region (0.75 – 1.35 mkm). Autumnal aspect begins later. But the end of the optimal season terminates 10 days earlier before the beginning of leaf coloration (brown wave).

The second optimal season for special biological investigations is indicated by the map of peak period of leaf growth, and it lasts about 20 days. The highest values of NDVI are registered during this period, maximum growth of trees in height is also a characteristic feature of this period.

Our recommendations concern all types of remote sensors functioning in visible and near-infrared regions of spectrum. Let's consider 2 examples of calculation of the optimal seasons of aerial (space) photography.

1.__Estimation of the optimal season of aerial (space) photographic missions for forest__

A. Inventory and Mapping.

First of all, the users of this methodology estimate the coordinates of forest tracts to be photographed, by existing forest maps. The minimal size of these tracts must have 9 pixels.

They input the coordinates in computer and make the following calculation.
The phenological data include (for 9 pixels):

a. *Data on starting period of full leaf season*

7B	6E	6E
6E	6E	6E
6E	6E	6E

b. *Data on starting period of leaf coloration*

9M	9B	9M
9M	9M	9M
9M	9M	9M

The sequence of calculation :

1. To estimate the latest 10 days period of full leaf season : **7B**
2. To calculate the beginning of the optimal season of aerial photography:
   7B + 1 (ten days period) = 7M
3. To estimate the earlier 10 days period of leaf coloration : **9B**
4. To calculate the end of the optimal season of aerial photography:
   9B – 1 (ten days period) = 8E
5. To calculate the total length (L) of the optimal season of aerial photography:
   L = 7M + 7E + 8B + 8M + 8E = 5 ten days periods.

Note : In the southern part of the forest zone several pixels belong to agricultural lands.

"Brown wave" appears in these pixels in August when agricultural crops are ripening. That fact should be taken into consideration by planning photographic missions. The area of agricultural lands should be excluded from assessment of the optimal season of aerial (space) photographic missions.

2. *The estimation of the optimal season of aerial (space) photographic missions for special biological investigations.*

The optimal season of aerial photography for assessment of phytomass is calculated in the following way (for 9 pixels) :

c. *Data on peak periods*

8B	8B	8M
8B	8B	8B
8B	8B	8B

The sequence of calculation:

1. To estimate the latest 10 days period of the peak season : **8M**
2. To calculate the length of the optimal season:
   8M + 1 ten days period = 8M + 8E = 2 ten days periods

Other seasons of the year are not suitable or less suitable for aerial photography, except special cases when users of remote sensing data need a specific information about forest stands or about processes occurred in forest ecosystems. In these cases, the given phenological maps, including the map of the starting period of growing season, can be used.

We also want to emphasize that four phenological maps characterize seasonal development of forests during the growing season. Many practical works in forestry (measures on fire control, planting trees, collection of seeds of forest species, collection of mushrooms and berries, hunting and protection of wildlife, etc.) are carried out according to the seasonal rhythms of forests. Seasonal indicators of these practical measures vary from region to region. So, the authors of the maps hope that many foresters and ecologists will find in these maps new indicators for their activities on forest management and nature conservation.

Note : Phenological maps are given in the attached diskette.