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# Climatic controls of forest vegetation distribution in Northeast Asia

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## Abstract

This study focusses at the problem of indication of climatic gradients by vegetation complexes at local and regional scales and aims to quantify the local and regional scale relations of vegetation units, their complexes and climatic parameters within subarctic, boreal and temperate vegetation zones in Northeast Asia. The problem is approached by analysis of extensive phytosociological (over 5000 releves) and climatic (1802 climatic stations) databases. Identification of bioclimates was made in accordance with S. RIVAS-MARTÍNEZ et al. (1999) approach using different climatic parameters that include Kira's warmth and coldness indices, continentality index, ombro-evapotranspirational index and winter precipitation. Because of numerous compensational effects of edaphic or local climatic factors on community development the finding of relationships between community types and a regional climate is possible by comparison of communities on the sites, which are equal in environmental characteristics. A link between regional climate and vegetation units was found with an aid of a concept of zonal site formulated by POJAR et al (1991). Combined analysis of geographic distribution of associations and their bioclimatic ranges provide a powerful tool to indication of phytogeographical zonation in the mountainous regions, where zonal association indicates a particular bioclimatic belt that is characterized by certain amount of heat, moisture and by their distribution throughout seasons of year.

## 1. Introduction

Large-scale vegetation studies are one of the fundamental aspects of ecology and biogeography and a key to the clarification of modern as well as past processes in vegetation cover. The understanding of vegetation changes that follow the climatic fluctuation in different time scales has became the one of the most important question for the simulation and prediction of biota development in conditions of global climatic fluctuations. One of the critical methodological points in the climate-vegetation relationships is the concept of phytogeographical zones. The problem of zonality is approached from the assumption that a leading role in zonal differentiation belongs to climatic factors that may by indicated by different peculiarities of vegetation.

Vegetation of Northeast Asia is developed under the influence of two basic climatic gradients. A wide latitudinal range causes the climate to change from temperate in the south to the polar in the north. The differentiation in climate causes a change in vegetation expressed from north to south as a sequence of phytogeographical zones of polar deserts, tundra, subarctic dwarf-pine woodlands, boreal forests and temperate hardwood-conifer and summergreen broadleaved forests. The location on the coast of Pacific Ocean causes a continentality gra-dient towards the interior. The climate on the oceanic islands is oceanic with cold summers and mild winters. In the inner regions it changes to ultra-continental with very cold winters and warm summers. The territory of the Far East Asia is subdivided commonly into five continentality sectors: oceanic, suboceanic, maritime, continental and ultra-continental (BOX 1995, KRESTOV 2003, NAKAMURA & KRESTOV 2005). The vegetation in each sector reflects a change in climate from dump and relatively seasonally even oceanic climate to dry and seasonally contrasting climate in the inner regions.

Although the principal regularities in plant cover of the vast area of North Asia have been comprehensively discussed in Russian, Japanese and Chinese literature, we need a tool that could emphasize the major environmental factors driving the development of vegetation at different spatial scales under the changing climate. Among the numerous approaches to this problem, special attention must be paid to the recent achievements of S. Rivas-Martinez' research group (RIVAS-MARTÍNEZ et al. 1999). This elegant integration of phytosociological, floristic and bioclimatological knowledge is seen as a right way to the assessment of bio-environmental relationships at global and regional scales.

Despite of numerous local studies on each of mentioned zonal subdivisions have been carried on in different regions of Northeast Asia, until now we have a few to say about general regularities of biota for whole region because of the following: (1) insufficient to be used directly climatic data; (2) uneven involvement in vegetation-environment studies of bioclimatic indices in Japan, Korea, China (very high) and Russia (very poor); (3) if the phytosociological unit is used as a reference criterion of vegetation, then the problem is the unevenness of phytosociological information available for different parts of a region; (4) at regional and local spatial scales the vegetation units, beside regional climate, reflect edaphic gradients along toposequences, stages on natural and anthropogenic chronosequences, local climatic anomalies such as temperature inversion, overinsolation, cold air drainage, frost pokkets, snow accumulations and many others, and it is not always clear, which vegetation units do reflect climatic factors at a landscape scale.

In the last decades the amount of phytosociological information for Asia rapidly increases due to the recent research in Mongolia, China, Korea, Japan and Russia. The minuteness of syntaxonomical systems still remains very uneven in different countries. If in Japan and Korea most of vegetation types have been integrated in well developed phytosociological systems, so in Chinese and Russian parts of the Eastern Asia the systems covering major zonal vegetation types appeared recently.

This study focuses at the problem of indication of climatic gradients by vegetation complexes at local and regional scales. The objectives of this study were to quantify the local and regional scale relations of vegetation units, their complexes and climatic parameters within subarctic, boreal and temperate vegetation zones in Northeast Asia.

## 2. Material and methods

### 2.1 Study area

The Russian Far East, northeast China, Japanese archipelago and Korean peninsula represent the northeast edge of the Asian continent. The whole area covers approximately 5,000,000 km$^2$, ranging from 35°N to 73°N latitude and from 100°E to 169°W longitude. Elevations range between the sea level and 4885 m a.s.l. (Klyuchevskaya Sopka, Kamchatka). Northeast Asia is a mountainous area composed of massive folded structures, plutonic mountains, extensive volcano plateaus, interrupted by accumulative plains especially extensive in the extreme north, along the big river on the Arctic Ocean coast. Peculiar feature of the area is a position on the zone of contact of oceanic and continental geological platforms that caused a formation of long island arcs along the coast and very high volcanic activity. Most active volcanoes are concentrated in Kamchatka peninsula, Kuril Islands and Japanese archipelago.

## 2.2 Phytosociological data

Phytosociological database was formed as a result of numerous field researches in different regions of the Eastern Asia and includes over 5000 releves of *Pinus pumila* and *Alnus fruticosa* krummholzs, *Larix cajanderi*, *L. gmelinii*, *Picea jezoensis* and *Abies sachalinensis* forests, deciduous broadleaved forests and many others. Releves are made in accordance with standard phytosociological technique described by MULLER-DOMBOIS & ELLENBERG (1974) and include full species lists, a number of environmental data and exact geographical position. The classification systems were produced according BRAUN-BLANQUET (1964) method and published (KRESTOV & NAKAMURA 2002, NAKAMURA & KRESTOV 2005, KRESTOV et al. 2006, KRESTOV et al. 2007). The most important phytosociological systems for Eastern Asia made by MIYAWAKI (1980-1989), KIM (1992), SONG (1992), ERMAKOV et al. (2000) and ERMAKOV (2003) were involved into analysis.

## 2.3 Climatic data

The climatic database currently includes records from 1802 climatic stations in Russia, Korea, Japan and China. Identification of bioclimates was made in accordance with S. RIVAS-MARTÍNEZ et al. (1999) approach using the following climatic parameters: annual temperatures (T, °C), average temperature of the coldest (Tmin, °C) and warmest (Tmax, °C) months, annual precipitation (P, mm), summer (Ps, mm) and winter (Pw, mm) precipitation, total average precipitation of those months whose average temperature is higher than 0°C (Pp, mm), sum of the monthly average temperature of those months whose average temperature is higher than 0°C (Tp, °C), Continentality Index (Ic = Tmax – Tmin), Ombrothermic Index (Io = (Pp/Tp) x 10), Thermicity Index It = (T + m + M) x 10). For the assessment of critical for plants amount of heat we employed Kira's warmth index (WK) that was calculated as WK = Smax {0, (Ti – 5)} and coldness index was calculated as CK = -Smin {0, (5 –Ti)}, where Ti is the mean temperature in ºC of the *i*-th month (Kira, 1945, 1977). To reflect the importance of snow cover especially in continental regions with water deficit and oceanic regions a precipitation in months with average temperatures less than 0ºC (Tn) was also calculated. The isopleths of each estimated parameter are shown on figure 1.

General multiple slope linear regression models were developed to predict bioclimatic indices on the basis of geographical variables: latitude, longitude and elevation. Bioclimatic parameters were examined for linearity and homogenous variance on continuous variables including latitude, longitude and elevation. Residuals from model fittings were examined for precision and bias. The precision was examined using mean squared prediction error (NETER et al. 1996).

## 2.4 Vegetation-climate relationships

Because of numerous compensational effects of edaphic or local climatic factors on community development (over-moisture, over-droughts, high insolation, temperature inversions) the finding of relationships between community types and a regional climate is possible by comparison of communities on the sites, which are equal in environmental characters. A link between regional climate (MAJOR 1963) and vegetation units can be found with an aid of a concept of zonal site suggested by KRAJINA (1960) on the basis of term 'plakor' (VYSOTSKY 1909) and formulated by POJAR et al (1991). The site is considered zonal if it can be characterized by the following features: „1) middle slope position on the meso-slope in mountainous terrain (meso-slope is the slope segment that directly affects site water movement); upper slope position in subdued terrain; 2) slope position, gradient, aspect, and location that does not result in a strong modification of climate (e.g., frost pocket, snow drift area, steep

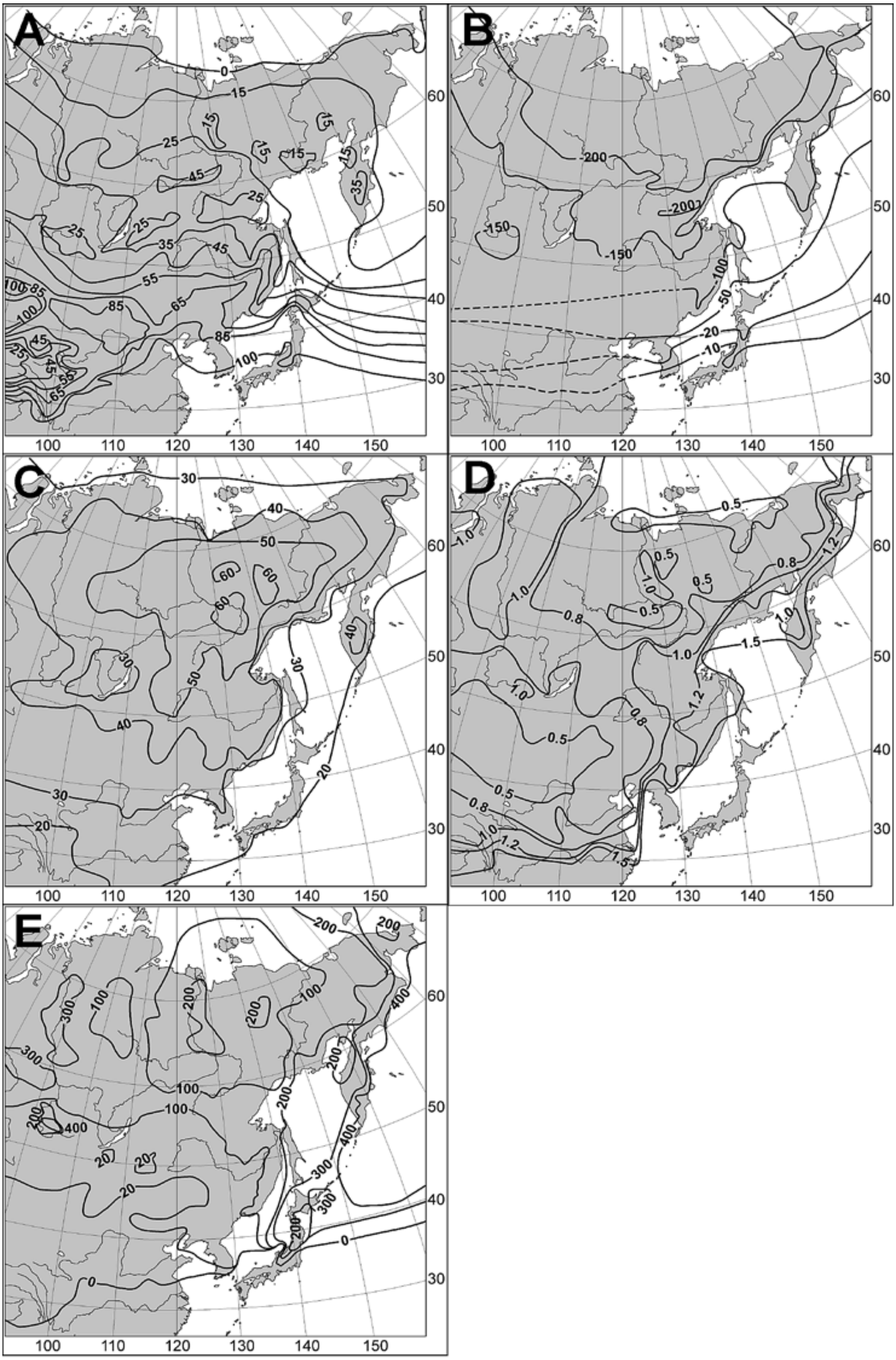

Figure 1. Isopleths of bioclimatic indices in the northeast Asia. A - Kira's warmth index, B - Kira's coldness index, C - continentality index, D - ombro-evapotranspirational index, E - precipitation in month with negative month temperatures.

south or north aspect); 3) gentle to moderate (5-30%) slope; in dry or cold climates, on slopes to less than 5%; in wet climates, on slopes up to 50%; and 4) soils that have: (a) a moderately deep to deep (50-100+ cm) rooting zone, (b) no restricting horizon within the rooting zone, (c) loamy texture with coarse fragment content less than 50% by volume, and (d) free drainage“ (POJAR et al. 1991: 12). Other sites influenced more strongly by local environmental factors, such as physical and chemical properties of soil parent materials, frost pokkets, cold air drainage, strong wind, high insolation and the others can be drier, wetter, richer, or poorer than zonal sites; and overall they do not provide as clear a reflection of the regional climate. To avoid strong effect of edaphic factors we involved into analysis only the releves occurring on the zonal sites.

## 3. Results

### 3.1 Relationships between bioclimatic indices and geographical variables

Distribution of major climatic parameters in northern Asia is very uneven that reflect complicated relationships between the major climate-controlling factors on this extensive territory. In addition to the latitude and elevation both thermal and humidity indices are controlled by longitude that represents the influence of Pacific and Atlantic oceans on climate formation in the interior regions of Asian continent.

Distribution of Kira’s warmth index in Northern Asia is strongly correlated with latitude and elevation in the interior areas, however, with proximity of Pacific Ocean a contribution of longitude in WK prediction becomes more valuable. On the northern Kuril Islands located at latitude 48-52°N the values of WK is similar to those of latitudes of 70°N in the interior. Generally WK on the Pacific coast has much lower values comparing with regions with corresponding elevation and latitude in the interior (Fig. 1A). The decreasing of WK in southern regions is caused by increasing elevation. The increasing of index in northern regions becomes possible due to the orientation of major mountain systems protecting sometimes very extensive areas from the influence of cold air currents in summer time. Most valuable WK peaks can be observed in the central part of Kamchatka peninsula (also known as ‘conifer island’) and in the middle part of Lena river basin.

Distribution of Kira’s coldness index (Fig. 1B) shows that lowest temperatures are characteristic to the interior regions of North Asia, north of 60°N. The coldest place with lowest ever recorded absolute temperature -71.2°C in Oimyakon area is considered as the pole of cold of Northern hemisphere. From this point winter temperatures sharply increase towards the Pacific coast and gradually increase along the latitudinal gradient and towards Europe. Distribution pattern of coldness suggest that the cold cannot be considered as limiting factor for vegetation distribution (forest vegetation is common around Oimyakon). From the other hand, mild winters in coastal Pacific regions cause a lack of frozen soils in winter time that provide opportunities for frost-intolerant species to invade communities of tundra or subarctic scrub types.

Distribution of continentality index has a concentric character (Fig. 1C) showing a maximum in Oimyakon (over 100 degrees difference between summer maximum and winter minimum temperatures and 65 degrees between averages of coldest and warmest months) and gradual decreasing in all directions. Lowest values of IC are characteristic to oceanic coast and island arcs. Climate of oceanic regions between the latitudes 40 and 60°N is characterized by mild winters with coldest month averages ranging between -5 and 0°C and cool summers with warmest month averages ranging between +5 and +15°C. Vegetation cover in these areas is formed in conditions of heat deficit and unfrozen soils.

Humidity is one of the critical factors for vegetation distribution. Since IOE shows the ratio between precipitation in months with positive temperatures and potential evapotranspiration, the value of IOE critical for vegetation is 1,0. Values below 1.0 show possibility of humidity deficit in months with temperatures above zero. Normally, IOE lower than 0.8 is prohibitive for forest vegetation if some factors do not compensate the climatic moisture deficit. Fig. 1D shows that lower values of this index occur in the interior regions with sharp increase towards Pacific coast and very gradual increase to Europe. If in temperate zone the moisture deficit appears to be very important limiting factor restricting distribution of forests, the climatic moisture deficit within boreal zone does not stop forests due to the well expressed compensative effect from the extensive permafrost that provide melting water for tree development.

Due to the depth of snow cover depends on secondary horizontal moving by wind and gravity, the winter precipitation measured in climatic stations is considered as more consistent measure of amount of snow. The pattern of snow distribution in many features repeats the distribution of continentality index: less in the interior and increasing towards the coast (Fig. 1E). We assume that snow cover is not stable in regions where average temperatures are not below zero. The influence of snow cover on vegetation distribution is in transforming of other factors. In condition of North Asia there are minimum two kinds of significant snow effects on vegetation. In the areas with relatively low summer temperatures and snow cover exceeding a depth of 10 m (eastern Kamchatka, Aleutian and Kuril Arcs) the release of ground from snow happens 2-3 weeks after establishing of vegetative temperatures. The late snow melting cause the significant shortening of the growing season limiting development of many tree species. From the other hand, very small or lack of snow cover in condition of temperate monsoon climate cause well expressed period of spring and early-summer drought even in regions, where ombro-evapotranspirational index exceeds value 1.0 that limits the distribution of humidity-dependant species. In areas, where the winter temperatures fall below zero, snow cover provides protection of soils against freezing.

### 3.2 Vegetation

A preliminary prodromus of forest vegetation of Northeast Asia comprises 99 syntaxa of the association, 27 of alliance, 13 of order and 6 of class ranks (KRESTOV 2006). The application of a ‘zonal site filter’ allowed to select for further analysis only 35 listed below associations of forest communities that occur on zonal sites.

Class
  Order
    Alliance
      Association

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Betuletea glanduloso-divaricatae prov. (BET-BET)
  Larici cajanderi-Betuletalia divaricatae prov. (Lar-Bet)
    Larici gmelinii-Betulion divaricatae prov.
      1. Flavocetrario cuculatae-Betuletum divaricatae Krestov 2007
      2. Salici krylovii-Laricetum gmelinii Krestov 2007
  Vaccinio-Pinetalia pumilae Suzuki-Tokio 1964 (VAC-PIN)
    Vaccinio-Pinion pumilae Suzuki-Tokio 1964 (Vac-Pin)
      3. Vaccinio-Pinetum pumilae Maeda et Shimazaki 1951
      4. Ledo decumbentis-Pinetum pumilae Kobayashi 1971
Vaccinio-Piceetea Br.-Bl. in Br.-Bl. et al. 1939 (VAC-PIC)

Lathyro humilis-Laricetalia cajanderi Ermakov et al. 2002 (Lat-Lar)
Lathyro humilis-Laricion cajanderi Ermakov et al. 2002
5. Lathyro humilis-Laricetum cajanderi Ermakov et al. 2002
Ledo palustris-Laricetalia cajanderi Ermakov 2004 (Led-Lar)
Ledo palustris-Laricion cajanderi Ermakov 2004
6. Ledo palustris-Laricetum cajanderi Ermakov et al. 2002
Rhododendro aurei-Laricion dahuricae Krestov et al. 2006
7. Sanguisorbo-Laricetum dahuricae Krestov et Osipov 2007
Abieti-Piceetalia jesoensis Miyawaki, Ohba et Okuda 1968 (Abi-Pic)
Pino pumilae-Piceion jezoensis Krestov et Nakamura 2002
8. Vaccinio-Piceetum jezoensis Krestov et Nakamura 2002
Abieti nephrolepidis-Piceion jezoensis Song 1991
9. Oplopanaco elati-Piceetum jezoensis Krestov et Nakamura 2002
10. Philadelpho-Piceetum jezoensis Krestov et Nakamura 2002
11. Thujo koraiensis-Abietetum sachalinensis Song 1995
Piceion jezoensis Suzuki-Tokio ex Jinno et Suzuki 1973
12. Piceo jezoensis-Abietetum sachalinensis Ohba ex Nakamura 1988
13. Asaro-Abietetum sachalinensis Krestov et Nakamura 2002
14. Maiantho-Tsugetum diversifoliae
Abietion mariesii Suzuki-Tokio 1954
15. Abietetum veitchio-mariesii Maeda et Shimazaki 1951
16. Abietetum mariesii Horikawa ex Suzuki-Tokio 1954
Betulo ermanii-Ranunculetea acris Suzuki-Tokio 1964 (BET-RAN)
Betuletalia ermanii Krestov et al. prov. (Bet)
Pino pumilae-Betulion ermanii Krestov et al. prov
17. Salici arcticae-Betuletum ermanii Krestov et al. prov
18. Geranio erianthi-Betuletum ermanii Krestov et al. prov
Artemisio opulentae-Betulion ermanii Krestov et al. prov
19. Artemisio opulentae-Betuletum ermanii Krestov et al. prov
Streptopo-Alnetalia maximowiczii Ohba 1973 (Str-Aln)
Athyrio brevifrontis-Weigelion middendorffianae Ohba 1973
20. Weigelo middendorffii-Betuletum ermanii Nakamura 1988
21. Dryopterido-Alnetum fruticosae prov.
22. Glycerio alnastereti-Alnetum fruticosae prov.
Querco mongolicae-Betuletea davuricae Ermakov et Petelin 1997 (QUE-BET)
Querco mongolicae-Betuletalia davuricae Ermakov 1997 (Que-Bet)
Kitagawio terebinthaceae-Betulion davuricae Ermakov 1997
23. Geranio davuricae-Betuletum davuricae Ermakov 1997
Lespedezo bicoloris-Quercetalia mongolicae Krestov et al. 2006 (Les-Que)
Corylo heterophyllae-Quercion mongolicae Krestov et al. 2006
24. Meehani urticifoliae-Quercetum mongolicae Ban et al. 2006
25. Sophoro flavescentis-Quercetum mongolicae Krestov et al. 2006
26. Lycopi lucidi-Quercetum mongolicae Krestov et al. 2006
Quercetea mongolicae Song ex Krestov et al. 2006 (QUE)
Tilio amurensis-Pinetalia koraiensis Kim ex Krestov et al. 2006 (Til-Pin)
Phrymo asiaticae-Pinion koraiensis Krestov et al. 2006
27. Ribesi maximowicziani-Pinetum koraiensis Krestov et al. 2006
Jeffersonio dubiae-Quercion mongolicae Kim ex Krestov et al. 2006
28. Polysticho-Pinetum koraiensis Gumarova et al. ex Krestov et al. 2006
Aceri pseudosieboldiani-Quercetalia mongolicae Takeda et al. 1994 (Ace-Que)

Rhododendro-Quercion mongolicae Song ex Takeda et al. 1994
29. Dryopterido-Quercetum mongolicae Kim ex Krestov et al. 2006
Lindero obtusilobae-Quercion mongolicae Kim 1990
30. Lindero obtusilobae-Quercetum mongolicae Song et al. 1995
Fagetea crenatae Miyawaki, Ohba et Murase 1964 (FAG)
Saso-Fagetalia crenatae Suzuki-Tokio 1966 (Sas-Fag)
Saso-Fagion crenatae Miyawaki, Ohba et Murase 1964
31. Saso kurilensis-Fagetum crenatae Suzuki-Tokio 1949
32. Aucubo-Fagetum crenatae
33. Sapio japonici-Fagetum crenatae
Quercetalia serrato-grosseserratae Miyawaki et al. 1971 (Que-Que)
Carpino-Quercion grosseserratae Takeda, Uematsu et Nakanishi 1983
34. Abieti-sachalinensis-Quercetum grosseserratae
35. Dryopterido crassirhizomae-Abietetum sachalinensts

### 3.3 Relationships between vegetation units and bioclimatic indices

Analysis of indices calculated with an aid of developed models showed the significant differences of vegetation units of the order rank in bioclimatic ranges.

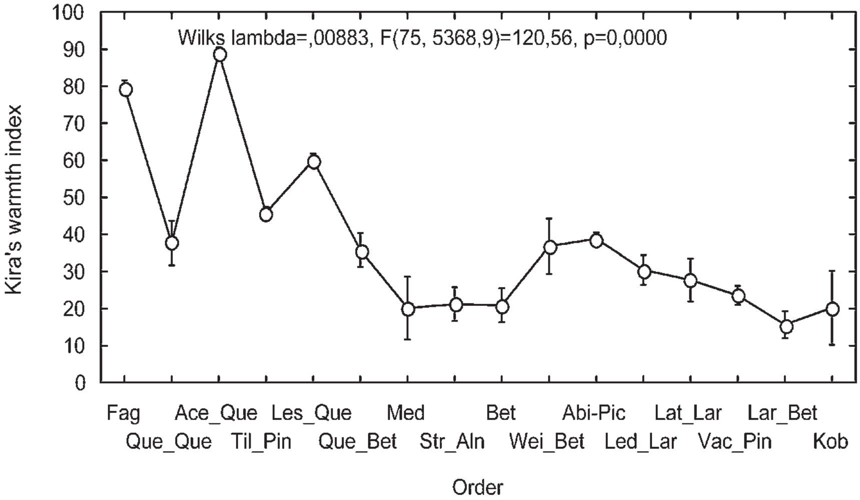


Figure 2. Means (circles) and standard deviations (vertical bars) of Kira's warmth index values for vegetation orders. Abbreviations for orders as in syntaxa list on page 136.

Kira's warmth index decreases from values over 75 in the middle temperate zone (Saso-Fagetalia, Aceri-Quercetalia) to the values less than 20 in subarctic zone (Fig. 2). Among boreal vegetation units the orders of Betulo-Ranunculetea have the lowest warmth index that can be explained by cool summer in conditions of oceanic climate. Kira's coldness index (Fig. 3) varies between values of -25 and -150 within boreal and temperate zones with prevalence of deciduous broadleaved, mixed and evergreen broadleaved forests. The boreal orders Lathyro-Laricetalia and Ledo-Laricetalia representing boreal deciduous coniferous forests are characterized by very low values of coldness index that, in this case, is comparable to that of subarctic orders.

The ranges of orders along the continentality gradient (Fig. 4) are reflected by changes of vegetation types within a zone with proximity to the ocean. In temperate zone the continen-

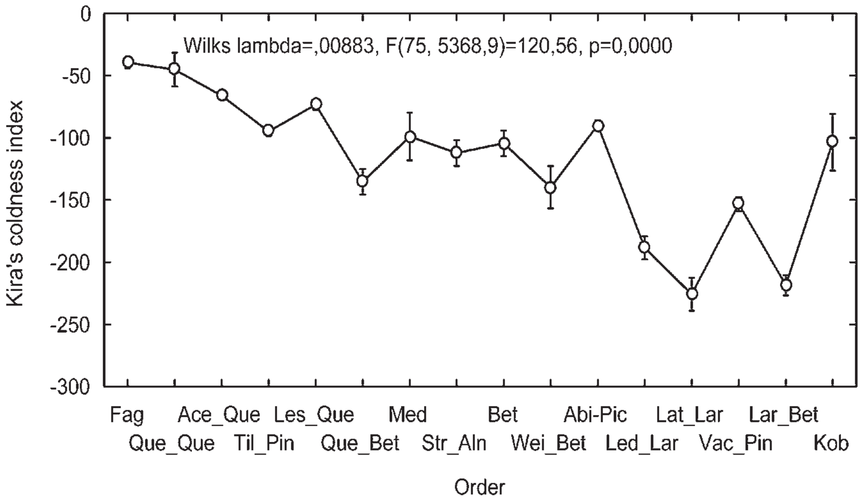


Figure 3. Means (circles) and standard deviations (vertical bars) of Kira's coldness index values for vegetation orders. Abbreviations for orders as in syntaxa list on page 136.

tality index increased from Japanese order Saso-Fagetalia trough the maritime orders of class Quercetea mongolicae to the continental orders of class Querco-Betuletea, the extreme representatives of which occur in the forest-steppe ecotone. In boreal zone the lowest values of continentality index are characteristic to the class Betulo-Ranunculetea, and deciduous coniferous orders Lathyro-Laricetalia and Ledo-Laricetalia are developed in conditions of maximum for the whole North Asia continentality. Vegetation of subarctic zone is characterized by moderate values of continentality index due to the influence of Arctic Ocean.

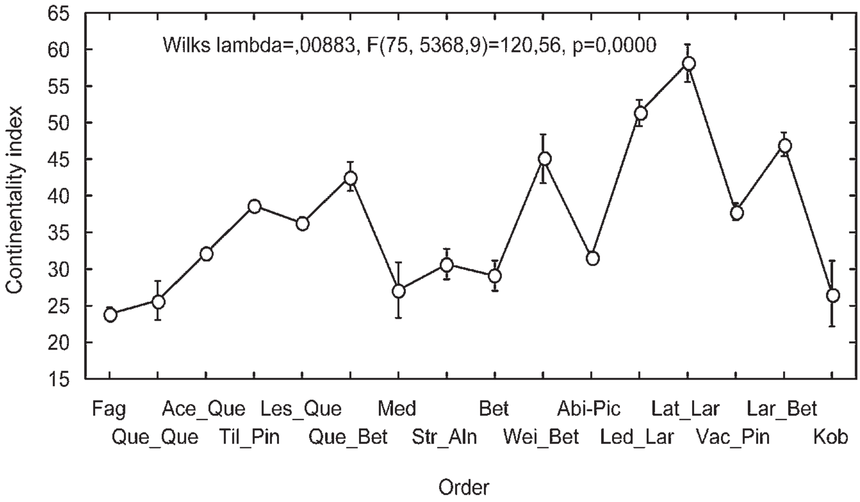


Figure 4. Means (circles) and standard deviations (vertical bars) of continentality index values for vegetation orders. Abbreviations for orders as in syntaxa list on page 136.

The distribution of ombro-evapotranspirational index (Fig. 5) among vegetation orders shows that nemoral Querco-Betuletalia, boreal Lathyro-Laricetalia and Ledo-Laricetalia and partly subarctic order Larici-Betuletalia are developed in critical conditions of significant

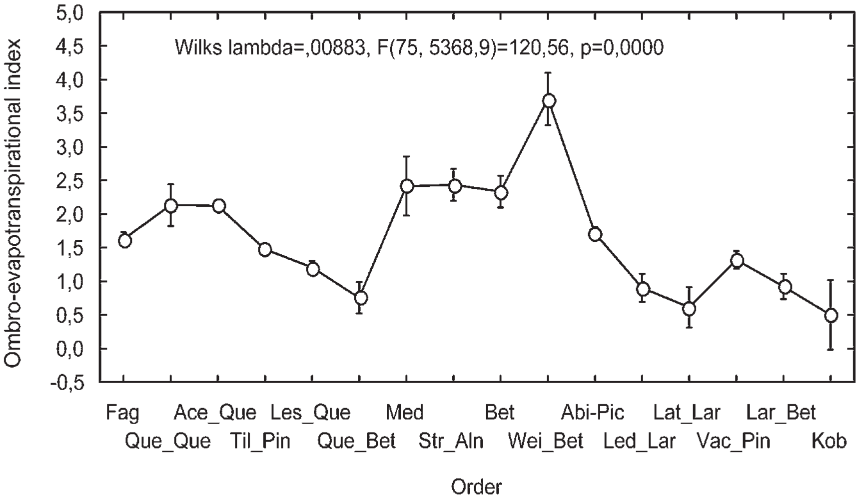


Figure 5. Means (circles) and standard deviations (vertical bars) of ombro-evapotranspirational index values for vegetation orders. Abbreviations for orders as in syntaxa list on page 136.

moisture deficit that normally does not support forest vegetation. The existence of forests in dry areas of temperate zone is supported by the edaphic moisture accumulating on the north-faced mountain slopes. Most important source of water in dry areas of boreal zone is melting permafrost. A significant peak of IOE for the subalpine order Weigelo-Betuletalia is caused by monsoon character of precipitation in the mountainous areas of Hokkaido and Sikhote-Alin, where the high summer precipitation is enforced by low evapotranspiration due to the low temperatures in subalpine belt.

The relationships of vegetation units with snow cover become significant in the conditions of continental climate in the northern subzone of temperate zone, where lack of snow in winter causes a shortage of moisture in spring and early summer, and in oceanic regions of boreal zone, where the strong accumulation of snow causes 2-3 week delay of its melting and a con-

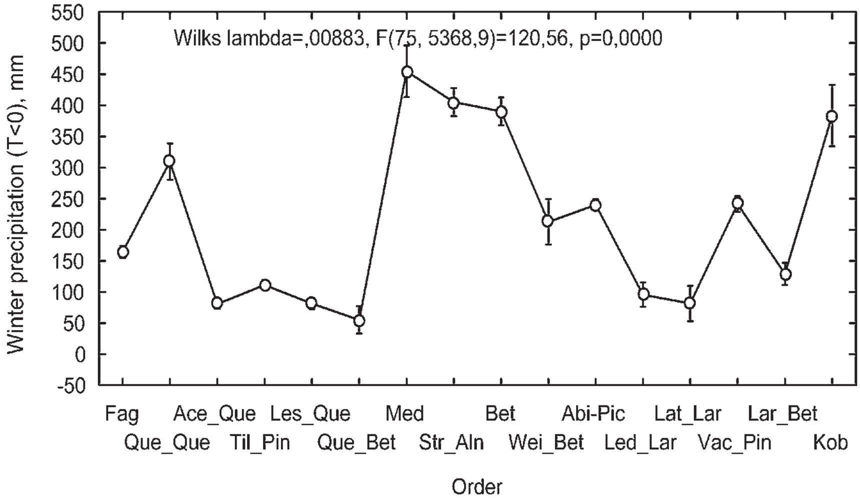


Figure 6. Means (circles) and standard deviations (vertical bars) of winter precipitation values for vegetation orders. Abbreviations for orders as in syntaxa list on page 136.

siderable shortening of growing season (Fig. 6). The communities of Querco-Betuletea enriched with drought tolerant species are developed in climates with spring-early summer droughts. Communities of *Betula ermanii, Alnus fruticosa* and tall-forb meadows are characteristic to the regions with slower-melting heavy snow deposits.

### 3.4 Climatic ranges of associations and Rivas-Martínez's worldwide bioclimatic framework

All described up to now zonal associations of North Asia was differentiated by combination of 5 bioclimatic indices (Table 1). The use of the world-wide bioclimatic classification (RIVAS-MARTÍNEZ et al. 1999) allowed to order zonal associations by their bioclimatic ranges in the 3-dimensional space determined by a zone, a continentality sector and an elevation belt (Table 2).

Table 1. Standard deviations of bioclimatic indices for zonal associations.

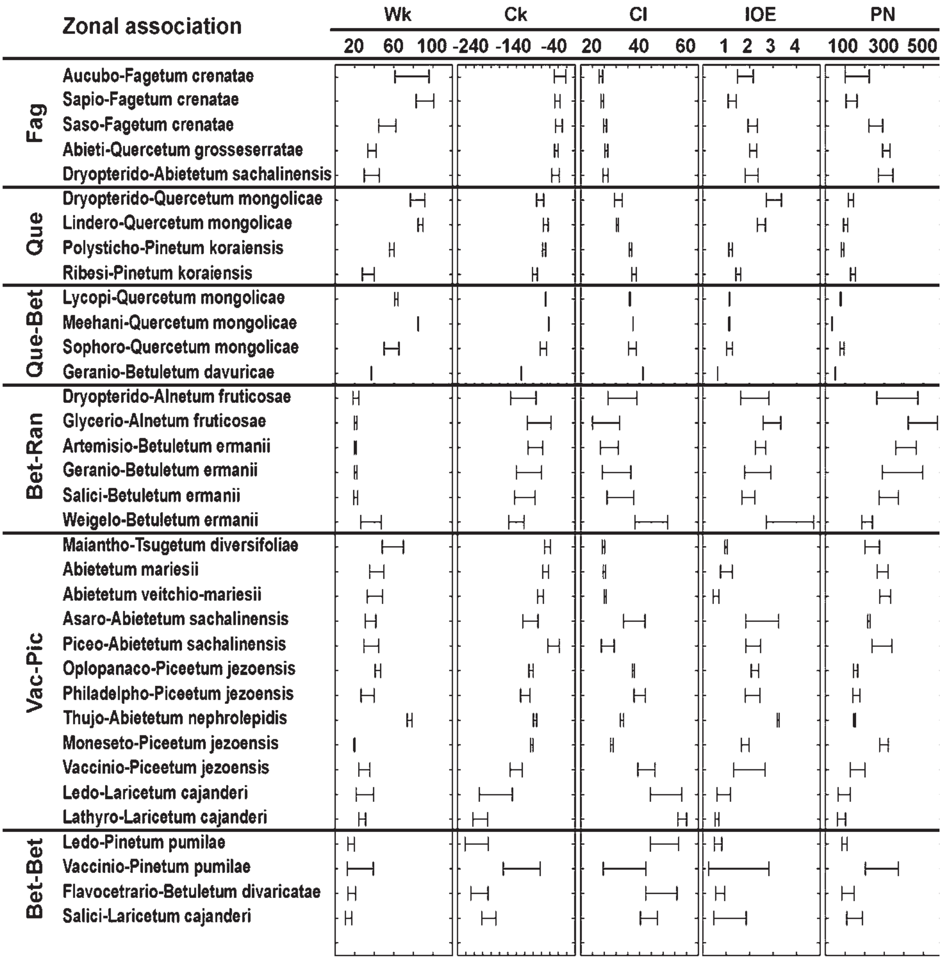

Table 2. Zonal associations / community types characteristic to bioclimate regions and vertical belts of Northeat Asia.

| **Macrobioclimate / altitudinal thermopype** | | **Continentality sectors** | | | | |
|---|---|---|---|---|---|---|
| | | **Ultracontinental** | **Continental** | **Maritime** | **Suboceanic** | **Oceanic** |
| **Polar** | Suprapolar | -- | -- | *Cryptogam comm.* | *Carex comm.* | *Cassiope comm.* |
| | Mesopolar | -- | *Betula exilis comm.* | *Eriophorum vaginatum comm.* | *Vaccinio-Empetretum nigrae* | *Vaccinio-Empetretum nigrae* |
| | Thermopolar | *Flavocetrario-Betuletum divaricatae* | *Salici krylovii-Laricetum gmelinii* | *Ledo-Pinetum pumilae* | *Dryopterido-Alnetum fruticosae* | *Artemisio-Arnicetum unalascensis* |
| **Northern Boreal** | Crioroboreal | *Kobresia* spp. *comm.* | *Dryas comm.* | *Dryas comm.* | *Carex comm.* | *Cassiope comm.* |
| | Oroboreal | *Flavocetrario-Betuletum divaricatae* | *Ledo-Pinetum pumilae* | *Vaccinio-Pinetum pumilae* | *Dryopterido-Alnetum fruticosae* | *Dryopterido-Alnetum fruticosae* |
| | Supraboreal | *Flavocetrario-Betuletum divaricatae* | *Flavocetrario-Betuletum divaricatae* | *Salici krylovii-Laricetum gmelinii* | *Salici arcticae-Betuletum ermanii* | *Dryopterido-Alnetum fruticosae* |
| | Mesoboreal | *Ledo-Laricetum cajanderi* | *Ledo-Laricetum cajanderi* | *Saussureo-Laricetum gmelinii* | *Geranio erianthi-Betuletum ermanii* | *Dryopterido-Alnetum fruticosae* |
| | Thermoboreal | *Lathyro-Laricetum cajanderi* | *Ledo-Laricetum cajanderi* | *Moneco-Piceetum jezoensis* | *Artemisio opulentae-Betuletum ermanii* | *Glycerio-Alnetum fruticosae* |
| **Southern Boreal** | Crioroboreal | *Kobresia* spp. *comm.* | *Dryas comm.* | *Dryas comm.* | *comm.of Loiseleurio-Vaccinetea* | -- |
| | Oroboreal | *Betula rotundifolia comm.* | *Vaccinio-Pinetum pumilae* | *Vaccinio-Pinetum pumilae* | *Vaccinio-Pinetum pumilae* | |
| | Supraboreal | *Larici-Pinetum pumilae* | *Larici-Pinetum pumilae* | *Sanguisorbo-Laricetum gmelinii* | *Weigelo-Betuletum ermanii* | -- |
| | Mesoboreal | *Ledo-Laricetum cajanderi* | *Ledo-Laricetum cajanderi* | *Philadelpho-Piceetum jezoensis* | *Asaro-Abietetum sachalinensis* | -- |
| | Thermoboreal | *Lathyro-Laricetum cajanderi* | *Vaccinio-Piceetum jezoensis* | *Oplopanaco-Piceetum jezoensis* | *Piceo-Abietetum sachalinensis* | -- |

| Macrobioclimate / altitudinal thermotype | | Continentality sectors | | | | |
|---|---|---|---|---|---|---|
| | | **Ultracontinental** | **Continental** | **Maritime** | **Suboceanic** | **Oceanic** |
| **Northern Temperate** | Criorotemperate | *Kobresia* spp. *comm.* | *Dryas comm.* | *Dryas comm.* | *Salici-Oxytropidetum yesoensis* | -- |
| | Orotemperate | ***No data*** | *Vaccinio-Pinetum pumilae* | *Vaccinio-Pinetum pumilae* | *Vaccinio-Pinetum pumilae* | -- |
| | Supratemperate | ***No data*** | *Larici-Pinetum pumilae* | *Philadelpho-Piceetum jezoensis* | *Piceo jezoensis-Abietetum sachalinensis* | -- |
| | Mesotemperate | *Geranio-Betuletum davuricae* | *Licopi-Quercetum mongolicae* | *Ribesi-Pinetum koraiensis* | *Dryopterido-Abietetum sachalinensis* | -- |
| | Thermotemperate | *Leibnitzio-Filifolietum sibirici* | *Sophoro-Quercetum mongolicae* | *Polysticho-Pinetum koraiensis* | *Abieti sachalinensis-Quercet. grosesserratae* | -- |
| **Middle Temperate** | Criorotemperate | *Kobresia spp. comm.* | *Dryas comm.* | *Dryas comm.* | *Leontopodietum fauriei* | -- |
| | Orotemperate | ***No data*** | ***No data*** | *Vaccinio-Pinetum pumilae* | *Vaccinio-Pinetum pumilae* | -- |
| | Supratemperate | *Caragano-Cleistog-enetum squarrosae* | *Picea wilsonii & Pinus tabulaeformis comm.* | *Thujo-Abietetum nephrolepidis* | *Abietetum mariesii* | -- |
| | Mesotemperate | *Caragano-Cleistogen-etum squarrosae* | *Meehani-Quercetum mongolicae* | *Dryopterido-Quercetum mongolicae* | *Saso-Fagetum crenatae* | -- |
| | Thermotemperate | *Stipo-Convolvuletum ammanii* | ***No data*** | *Lindero-Quercetum mongolicae* | *Aucubo-Fagetum crenatae* | -- |
| **Southern Temperate** | Crioro-temperate | ***No data*** | ***No data*** | ***No data*** | *Kobresio-Oxytropide-tum japonicae* | *Kobresio-Oxytropide-tum japonicae* |
| | Orotemperate | ***No data*** | ***No data*** | ***No data*** | *Vaccinio-Pinetum pumilae* | *Vaccinio-Pinetum pumilae* |
| | Supratemperate | ***No data*** | ***No data*** | ***No data*** | *Abietetum mariesii* | *Abietetum veitchio-mariesii* |
| | Mesotemperate | ***No data*** | ***No data*** | ***No data*** | *Maiantho-Tsugetum diversifoliae* | *Maiantho-Tsugetum diversifoliae* |
| | Thermotemperate | ***No data*** | ***No data*** | ***No data*** | *Aucubo-Fagetum crenatae* | *Sapio japonici-Fagetum crenatae* |

## 4. Discussion and conclusion

In the mainland East Asia, the problem of vegetation zonation was approached from the point of view of dominant vegetation types (LAVRENKO & SOCHAVA 1954, CHUNG & LEE 1965, SOCHAVA 1969, OKUMURA 1974 and YIM 1977). In Japan, vegetation zonation was interpreted from the viewpoint of syntaxonomical approach (MIYAWAKI et al. 1994). Despite of methodological difference, all vegetation maps agree in differentiating of evergreen broadleaved, deciduous broadleaved and mixed broadleaved-coniferous and coniferous forests zones. The differences between the maps mentioned are subdivision of a zone of deciduous broadleaved and mixed broadleaved-coniferous forests into subzones and in the position of boundaries. HÄMET-AHTI et al. (1974), YIM & KIRA (1975), KIRA (1977), FANG & YODA (1990) and GRISHIN (1995) examined the existing vegetation maps with the warmth and coldness indices and confirmed the major biotemperature limits for the phytogeographical zones: warmth indices 15°, 45°, 55° and 85° correspond respectively to the southern borders of subarctic, boreal and northern temperate and middle temperate subzones of temperate zone. The use of global bioclimatic classification of RIVAS-MARTÍNEZ (1999) in combination with phytosociological knowledge and a concept of zonal sites (POJAR et al. 1987) provides a powerful tool for three dimensional arrangement of vegetation along the latitudinal, longitudinal and altitudinal gradients and for distinguishing the particular climatic factors limiting the development of each zonal vegetation type.

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