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The potential of the pinewood nematode *Bursaphelenchus xylophilus* to become estabished in countries of the former USSR

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Summary. The potential for establishment of the pinewood nematode *Bursaphelenchus xylophilus* in countries of the former USSR and their possible threat to conifers in these areas are discussed. *Bursaphelenchus mucronatus* is wide-spread, however *B. xylophilus* has not been found in the former USSR territories. Conditions exist which are suitable for the colonization by *B. xylophilus*, and the resultant occurrence of pine wilt disease, in both the European and Asian parts of the former USSR: vectors (*Monochamus*), susceptible plants, and favorable climatic factors. Based on an analysis of the potential distribution of *B. xylophilus* it may be concluded that a threat exists to conifer forests in several areas and territories of the former USSR. This threat is mainly from *B. xylophilus*, which has the potential to develop as a major factor to the detriment of Russian forestry due to both disease establishment and problems presented with international export of timber product.

Key words: *Bursaphelenchus xylophilus*, *B. mucronatus*, pinewood nematode, *Monochamus*, vector, former USSR, distribution, coniferous forest, climate.

During the past 15-20 years, the pinewood nematode *Bursaphelenchus xylophilus* (Steiner & Buhrer, 1934) Nickle, 1970 has received considerable attention from forest and quarantine services in many countries. It has been suggested that this pest was introduced to East Asia from North America at the beginning of the 20th century. It causes extensive damage (pine wilt disease) to native pine species in southern Japan and eastern China (Mamiya, 1983, 1984; Malek & Appleby, 1984). The nematode lives as a parasite in wood tissues where it feeds on, and destroys, cambium (Myers, 1986; Kuroda et al., 1988). In warm climates, as in southern Japan, *B. xylophilus* can cause girdling on trees, resulting in pine wilt disease.

Outside Japan, *B. xylophilus* is wide-spread in eastern China and has been recorded in Taiwan (Chun, 1982; Shong & Tang, 1985; Yang & Wang, 1989) and the Korean Republic (Choi & Moon, 1989). The European and Mediterranean Plant Protection Organization (EPPO) placed *B. xylophilus* on its A1 list of quarantine pests (Anonymous, 1986a, 1990; Rautapaa, 1986), as a result of forest devastation in Japan and the potential threat to conifer forests in Europe. Since 1984 several Scandinavian countries (Finland, Norway, Sweden) and Korea have introduced embargoes against conifer wood from regions of the world known to be infested with *B. xylophilus*. This action has caused difficulties in forestry exports causing an estimated tens of millions of dollars loss of revenue to the North American forest industry (Bergdahl, 1988).

Russia has extensive forest resources and is a major exporter of raw softwood. The potential problem associated with the introduction and spread of *B. xylophilus* is the important concern for ecological stability and economic success of the forest industry of Russia. This paper provides an analysis of data on *B. xylophilus* and the pine wilt problem and examines the distribution patterns of this nematode species and pine wilt disease in Russia and neighboring countries of the former USSR .

MATERIALS AND METHODS

Data used for analysis, the results of which are presented in this paper, were obtained from publications, unpublished records received from colleagues and from our own research (Kulinich, 1993; Kulinich & Kolossova, 1993; Kulinich et al., 1994).

Climate data used in the analyses was obtained from «The Atlas of the USSR» (Anonymous, 1986b). Mean daily temperatures for former USSR territories are presented in the atlas as isotherms of 4° C intervals for January and July. Information of the family *Cerambycidae* was obtained from «Fauna of the USSR, Coleoptera» (Plavilstshikov, 1958) and the distributions of conifer species were obtained from «The trees and bushes» (Katchalov, 1970) and from «The Atlas of the USSR» (Anonymous, 1986b).

RESULTS AND DISCUSSION

The primary factors influencing the occurrence and distribution of pine wilt disease caused by *B. xylophilus*, are climatic, pathogenicity of the *B. xylophilus* population, plant resistance and presence of a suitable *B. xylophilus* vector.

Distribution of pinewood nematode *Bursaphelenchus xylophilus* and closely related species

The genus *Bursaphelenchus* includes the group of closely related species *B. fraudulentus* Ruhm, 1956, *B. xylophilus*, *B. mucronatus* Mamiya & Enda, 1979, *B. kolymensis* Korentchenko, 1980, all of which overlap in their principal morphological characteristics (Nickle et al., 1981; Yin et al., 1988) The species *B. fraudulentus* is associated with deciduous trees and has been reported from West Germany and Austria (Schauer-Blume, 1989; Schauer-Blume & Sturhan, 1989). The other three species are associated with conifers and have similar life-cycles. The level of affinity and morphological differentiation of these species have been the subject of investigations in several laboratories (Nickle et al.,1981; De Guiran et al., 1985; Abad et al., 1990; Webster et al., 1990). Based on reproductive strategies, morphology, pathogenicity and DNA analyses it may be concluded that *B. xylophilus* and *B. mucronatus* are members of a species complex, which includes intermediate forms. Rutherford et al. (1990) refer to this group of similar populations associated with conifers, as «the pinewood nematode species complex (PWNSC)».

Two forms of *B. xylophilus* are recognized in North America: the «M» form which have females with a mucro on the tail and the «R» form whose females have a rounded tail tip. Only the «R» form of *B. xylophilus* has been introduced and become established in Japan and China (Mamiya & Kiyohara, 1972).

Bursaphelenchus mucronatus is widely distributed in Europe and Asia, including the former USSR area. In Europe it is present in France (De Guiran & Boulbria, 1986), Norway (McNamara & Stoen, 1988), Sweden (Magnusson & Schroeder, 1989), Finland (Tomminen et al., 1989) and Italy (Palmisano et al., 1992). *B. mucronatus* is also present in Japan (Mamyia & Enda, 1979), China (Cheng et al., 1986) and the Korean Republic (Choi & Moon, 1989). The affinity between European and Japanese populations has not been determined. On the basis of enzyme, DNA analysis and crossing experiments it was supposed that populations from Japan and France are separate species (Bolla & Boschert, 1992; Riga et al., 1992).

Distribution of the members of «pinewood nematode species complex» in the former USSR territories

Most information on the occurrence of PWNSC in USSR territories is provided by the Plant Quarantine Services in countries which have imported timber from the former USSR. *B. mucronatus* has been recovered from timber products imported from the European part of the former USSR (Dr. J. Rautapaa in litt.) and from several different regions of Siberia (Braash, 1991; Dr. C. Magnusson and Dr. J. Rautapaa, in litt.). A survey in the Russian Far East revealed B.mucronatus to be wide-spread in the area (Kulinich et al. 1994).

Recently, *B. xylophilus* was recovered by the Chinese Quarantine Service from logs imported from the former USSR (Anonymous, 1991). We consider that this report requires confirmation therefore this record is not used in the distribution map of PWNSC present in the former USSR territories (Fig. 1). Another record of *B. xylophilus*, occurring in Siberia, was reported by W.R. Nickle in Rutherford & Webster, (1987), but Dr.Nickle (in litt.) now believes this record to be incorrect.

Bursaphelenchus kolymensis is a member of the PWNSC and has been recovered from *Monochamus sutor* beetles found attacking *Larix daurica* in the Magadan district of Russia (Korentchenko, 1980). The morphological characteristics of this species overlap with those of *B.mucronatus* from Russia and Europe (Magnusson & Kulinich, unpubl. data). The affinity between *B. kolymensis* and *B. mucronatus* and the taxonomic status of these species are not analyzed in the present paper.

Vector

The biology of members of the PWNSC, including *B. xylophilus,* is closely associated with that of Cerambycid beetles, primarily of the genus *Monochamus*, as the beetles serve as transport vectors to transmit the nematodes from tree to tree during of feeding or oviposition (Wingfield & Blanchette, 1983). The principal vector of *B. xylophilus* in Japan is *Monochamus alternatus* and in North America is *M. carolinensis* (Wingfield et al., 1982; Linit, 1988). A survey of conifer forest in several European countries (Sweden, Finland) revealed that the beetles *Monochamus* sutor and *M. galloprovincialis* are vectors of *B. mucronatus* (Anonymous, 1989; Magnusson & Schroeder, 1989; Tomminen et al., 1989). Additionally, *M. urussovi* and *M. sartor* may be regarded as potential vectors of *B. xylophilus*. Except for *M. sartor*, all these species are distributed throughout the European and Asian parts of the former USSR. They attack larch, pine and spruce and *M. sartor* also attacks conifer species but it is found only in West Ukraine (Plavilstshikov, 1958).

Climate

Important factors influencing pine wilt disease expression are temperature and humidity (Mamiya, 1984; Rutherford & Webster , 1987). Two variants of the influence of temperature on the expression and distribution of pine wilt disease have been investigated.

One variant was the mean annual air temperature, which has been suggested as a limiting factor of pine wilt distribution. An example of this factor occurs in Japan where pine wilt disease is wide-spread and damaging only in areas with a mean annual temperature greater than 14° C (Mamyia, 1988). The disease caused by *B.xylophilus,* does not develop in the cooler areas with annual mean temperatures below 10 - 12° C.

Territories in the former USSR located south of the 10° C mean annual temperature isotherm include the southern parts of Moldavia and Ukraine, Caucasus, the Middle Asia republics and southern Kazakhstan (Fig 1). In the former USSR the mean annual temperature as a limiting factor for the occurrence of pine wilt disease, caused by *B. xylophilus* species, is not entirely compatible with the distribution of the disease in the forest areas in the continental climate zone which has cold winters and warm or hot summers.

A second, more useful, variant for forecasting the spread and occurrence of pine wilt disease is the mean air temperature of the hottest summer month. Takeshita et al. (1975) reported that the greatest damage from *B. xylophilus* was correlated with drought-stressed trees and mean air temperatures in excess of 25° C for 55 days. Pine wilt is widespread in areas of Japan where the mean August temperature is greater than 25° C (Mamiya, 1984). In these areas at least 90% of infected trees die during one year (Mamiya, 1983). In the cooler areas, with average August temperatures below 24° C, the pathogenicity of pine wilt disease is delayed, and, fewer than 50% of trees die within the year of infection (Zinno et al., 1987). Pine wilt apparently does not occur in areas of Japan where *B. xylophilus* is present and the temperature of the hottest summer month is below 20° C average (Rutherford & Webster, 1987).

The hottest summer month in the former USSR territories is July. Regions with mean July temperatures higher than 20° C are large and include

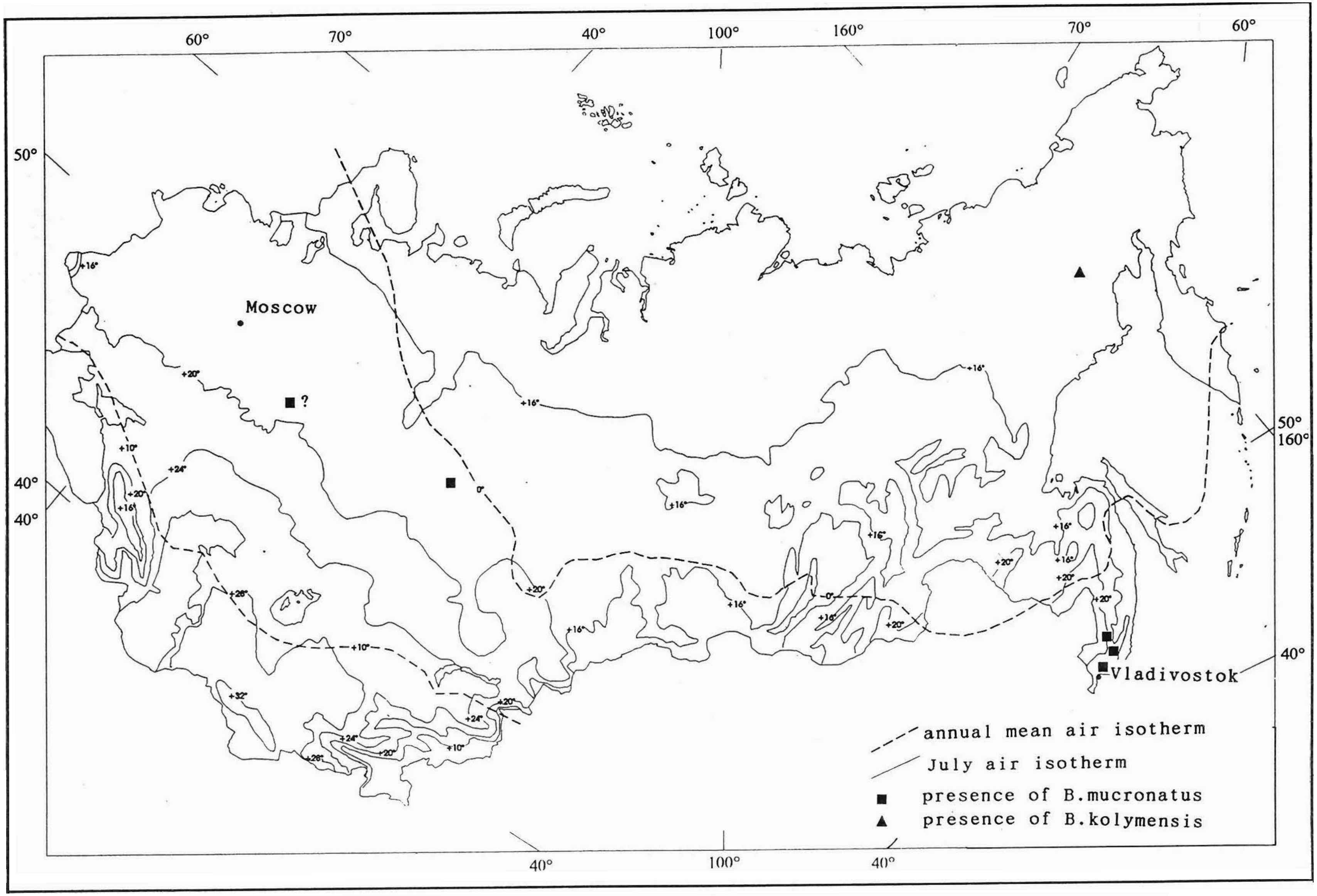

Fig. 1. The occurrence of *Bursaphelenchus mucronatus* and *B. kolymensis* in the former USSR territories and the 0° C and 10° C annual mean air temperature isotherms and the 16, 20, 24, 28 and 32° C July mean air isotherms.

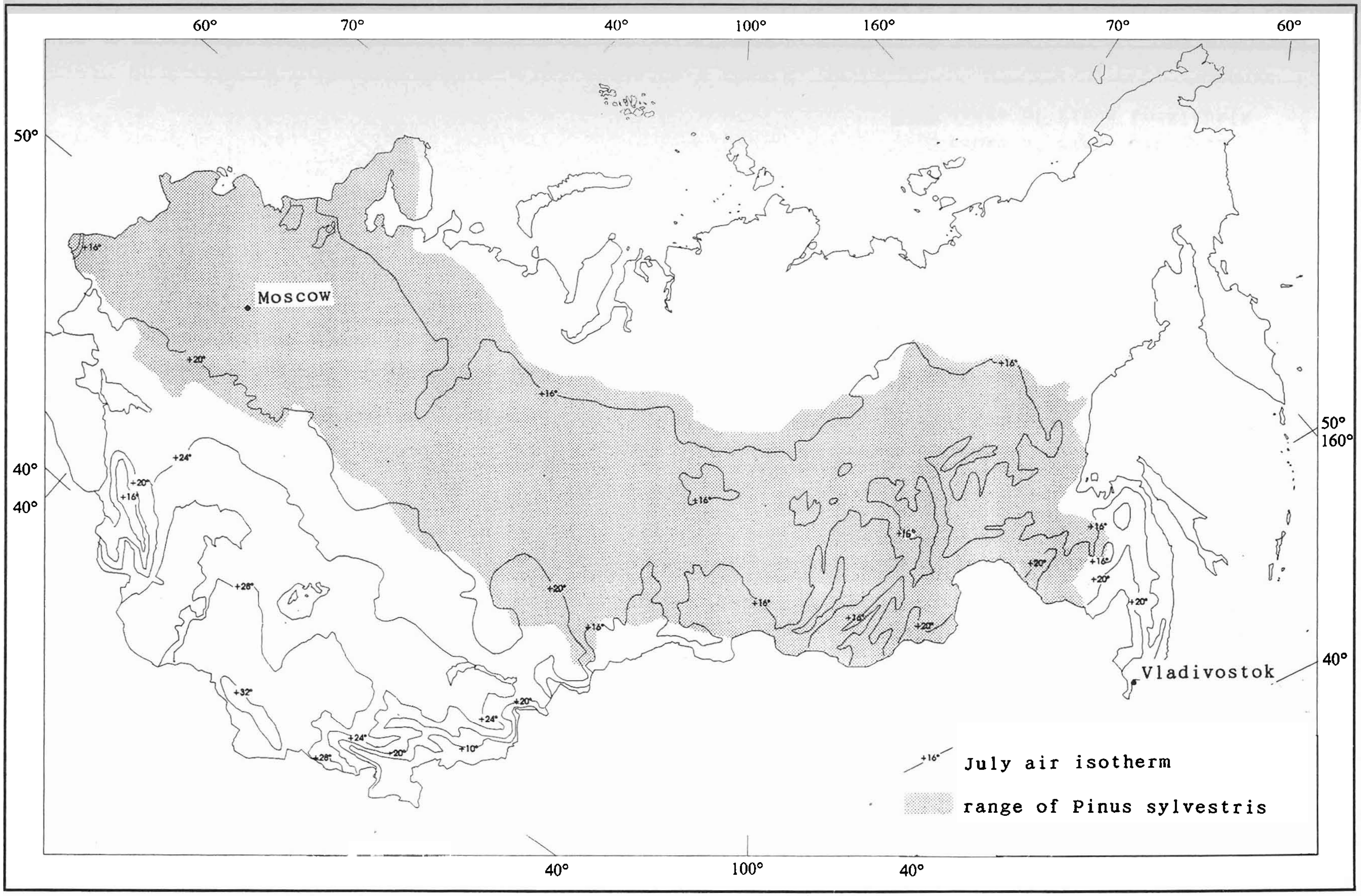

Fig. 2. Distribution of *Pinus sylvestris* and the 16, 20, 24, 28 and 32° C July mean air isotherms.

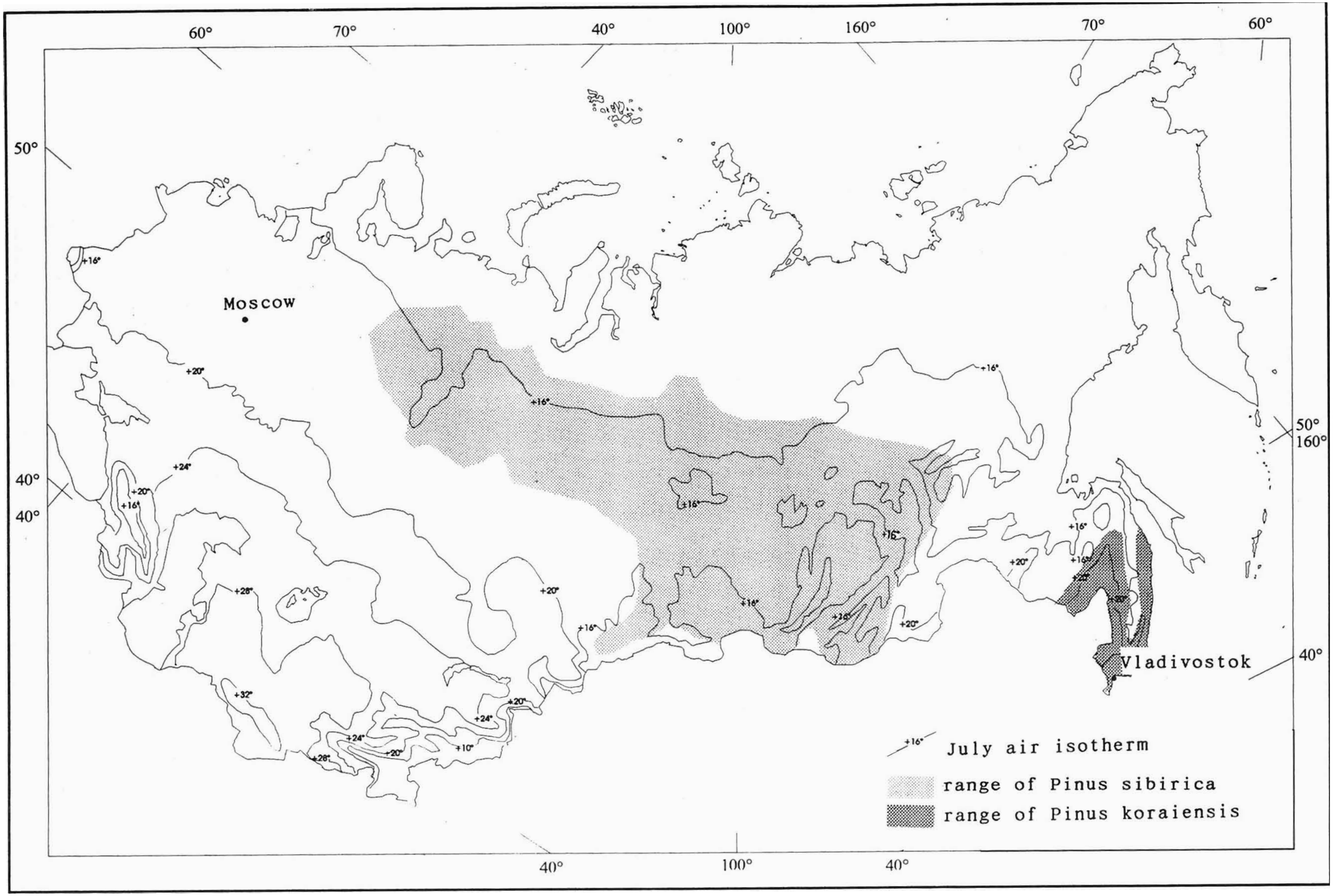

Fig. 3. Distribution of *Pinus sibirica* and *koraiensis* and the 16, 20, 24, 28 and 32° C July mean air isotherms.

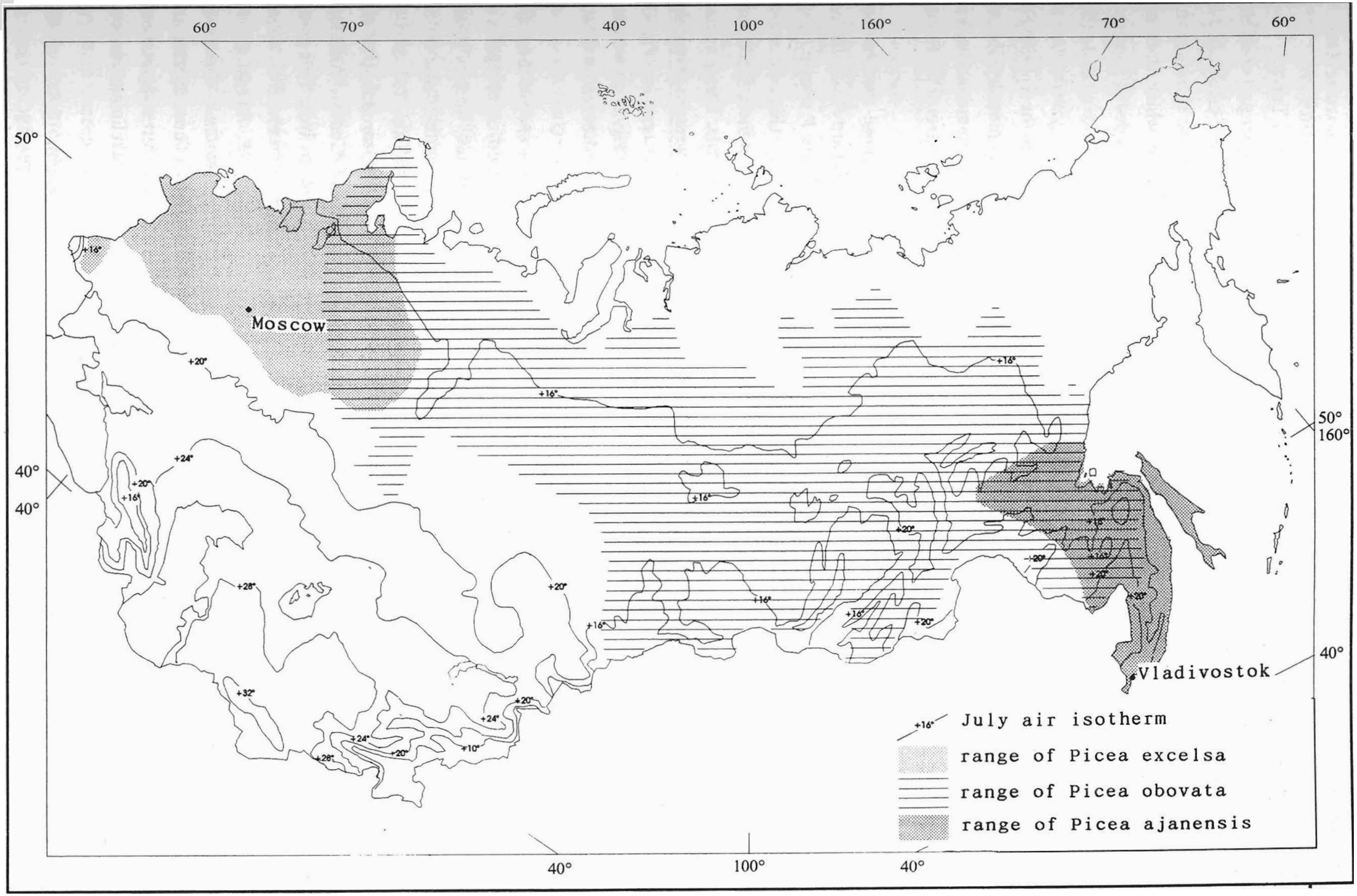

Fig. 4. Distribution of *Picea ajanensis, P. obovata* and *P. excelsa* and the 16, 20, 24, 28 and 32° C July mean air isotherms.

Moldavia, South Ukraine with the Crimea, Caucasus territory, a substantial area of the European part of Russia from the Black Sea to the Voronezh district, republics of Middle Asia, Kazakhstan and the western part of the Russian Far East (Primorsky territory and Khabarovsk district). It may be concluded, that pine wilt disease, caused by Japanese populations of *B. xylophilus*, will be not be damaging to conifers in the Baltic republics which are located to northward from the 20° C July isotherm.

The occurrence of pine wilt disease is influenced by topography, especially by altitude as it affects temperature. Surveys in Japan have shown that the disease does not occur above 700 m, even though *B. xylophilus* and its vector are present as high as 1000 m. In this situation temperature is the limiting factor for the occurrence of pine wilt disease. Average temperatures in this area for July-August at 100, 700 and 1200 m are 28° C, 23° C and 20° C, respectively (Hashimoto et al., 1974). Thus, we may exclude the Caucasus and the Middle Asia mountains, in the former USSR territory where the mean temperature for July-August is below 20° C from potential areas of pine wilt disease occurrence. Furthermore, many the Middle Asia regions with mean July air temperatures above 32° C are occupied by desert areas such as Kara-Kum and Kizil-Kum, and do not have conifer forests.

Conifer distribution and susceptibility to pine wilt disease

Plant resistance is a primary factor influencing the occurrence of pine wilt disease. Some native conifers in North America are resistant to *B. xylophilus*, and, pine wilt disease is relatively uncommon in the Western hemisphere (Mamyia, 1984). Usually, it is conifers from the Eastern hemisphere which are infected by *B. xylophilus*.

Conifers growing in the former USSR territory may be divided into two groups: the native species and species introduced from other regions of the world. The principal native species of conifers in the former USSR are:

Pinus sylvestris L.	*Picea koraiensis* Nakai.
P. sibirica Mayr.	*Abies sibirica* Leder.
P. koraiensis Sieb. et Zucc.	*A. nephrolepis* Maxim.
P. pumila Rgl.	*A. holophylla* Maxim.
Picea excelsa Link.	*A. sachalinensis* Mast.
P. obovata Lab.	*Larix sibirica* Led.
P. ajanensis Fisch.	*L. daurica* Turcz.

These species constitute the major part of conifer resources of the former USSR and are established as extensive forested areas. Each of these species have a southern boundary of distribution which does not cross the 20° C July isotherm. Species distributions are illustrated in Figs. 2-6. Scots pine (*P. sylvestris*) is the most widely distributed species, growing in all territories from the Baltic republics to the Russian Far East. The southern border of Scots pine distribution extends past the 20° C isotherm in numerous regions (Fig. 2) in the European and Asian parts of the former USSR.

Other major conifer spp., whose distributions extend past the 20° C July isotherm are *Pinus sibirica, P. koraiensis* (Fig. 3), *Picea ajanensis, P. obovata* (Fig. 4), *Abies sibirica, A. nephrolepis* (Fig. 5), *Larix sibirica, L. dahurica* (Fig. 6). Most of these species are limited only to the Asian part of Russia. This is a small region in southern Siberia and the western part of the Russian Far East. *Pinus pumila, Picea excelsa* (Fig. 4), *Abies holophylla, A. sachalinensis* (Fig. 5) grow in the cooler regions which lie from the north of the 20° C July isotherm.

Apart from these major conifer species there are many others which form forests in different regions of the former USSR. Indigenous conifer species which also grow in the warmer areas south of the 20° C temperature isotherm, are listed in Table 1.

A second conifer group was introduced to the former USSR from North and Central America, Central Asia and the Mediterranean area. This group includes more than 40 species represented by *Pinus strobus, P. banksiana, P. pinea, P. halepensis, P. montezumae, P. coulteri, P. sabiniana, Cupressus sempervivens, Thuja occidentalis*. These species are widely distributed and are used for forest-plantations and for forest shelter-belts in several climatic zones of the former USSR.

Analysis of the bibliographic data on the resistance and susceptibility to PWNSC isolates of

Table 1. List of the wide-spread indigenous conifer species in the former USSR growing in the warmer areas, south of 20 ° C July mean temperature isotherm.

Conifer species	Region with conifers growing south of 20° C July termperature isotherm
Pinus	
P. sylvestris	numerous along all latitudes of the former USSR
P. pinea	Crimea, Caucasus Black Sea coast
P. pallasiana	Crimea
P. funebris	Primorski Territory
P. kochiana	valleys in Georgia, Armenia, Azerbaijan
P. pithyusa	Caucasus Black Sea coast
P. eldarica	Georgia
P. stankeviezi	Crimea
P. hamata	Caucasus
P. sibirica	several small areas in Kazakhstan
P. koraiensis	southern Primorski Territory
Picea	
P. obovata	valleys along the Amur river and its tributaries
P. schrenkiana	south-east Middle Asia
P. orientalis	north of the Caucasus
P. ajanensis	Primorski Territory, valleys along the Amur river
P. koraiensis	southern Primorski Territory
Abies	
A. sibirica	small areas in valleys along the Amur river
A. nephrolepis	valleys along the middle part of the Amur river
A. holophylla	southern Primorski Territory
Larix	
L. sibirica	southern Ural mountains
L. daurica	small areas in valleys in the middle part of the Amur river

indigenous conifers growing in the former USSR has provided information only for *Pinus sylvestris* and *P. koraiensis* (Futai & Furuno, 1979; Yang & Wang, 1989; Bakke et al., 1991).

Numerous experiments with Scots pine (*Pinus sylvestris*) seedlings have shown the species to have a high susceptibility to PWNSC infection. Mortality ranging from 25-100% has been reported at the relatively low air temperature of 21° C (Futai & Sutherland, 1989; Riga et al., 1991). *Pinus koraiensis* is also susceptible to *B. xylophilus* infection (Futai & Furuno,1979; Mamiya, 1984; Yang & Wang, 1989). Among the wide-spread, introduced tree species in the former USSR, *P. halepensis* and *Thuja occidentalis* show resistance to *B. xylophilus* infection. Reports of *Pinus strobus* and *P. banksiana* susceptibility are contradictory. Thus, *P. banksiana* seedlings show a very high susceptibility to *B. xylophilus*, whereas mature trees are resistant (Linit & Tamura, 1987). This result may be explained by differential resistance of different tree ages, variable experimental conditions (temperature, humidity) or different pathogenicity of the *B. xylophilus* isolates.

CONCLUSIONS

From our analysis of the potential for *B. xylophilus* to pose a threat to conifers in the former USSR it may be concluded that there are two pathways for *B. xylophilus* to become established in Russia: firstly, through introduction with woody material, e.g. nursery stocks, dunnage, and secondly, by association with and importation of its vector beetles. Conditions exist for *B. xylophilus* to become established in both the European and Asian parts of the former USSR as the appropriate vectors and susceptible plants are present in association with favorable climatic factors. From observation of the distribution of *B. xylophilus* world-wide it may be concluded that southern Russia is an area where *B. xylophilus* could become established. *B. xylophilus* is widespread in Japan and east-

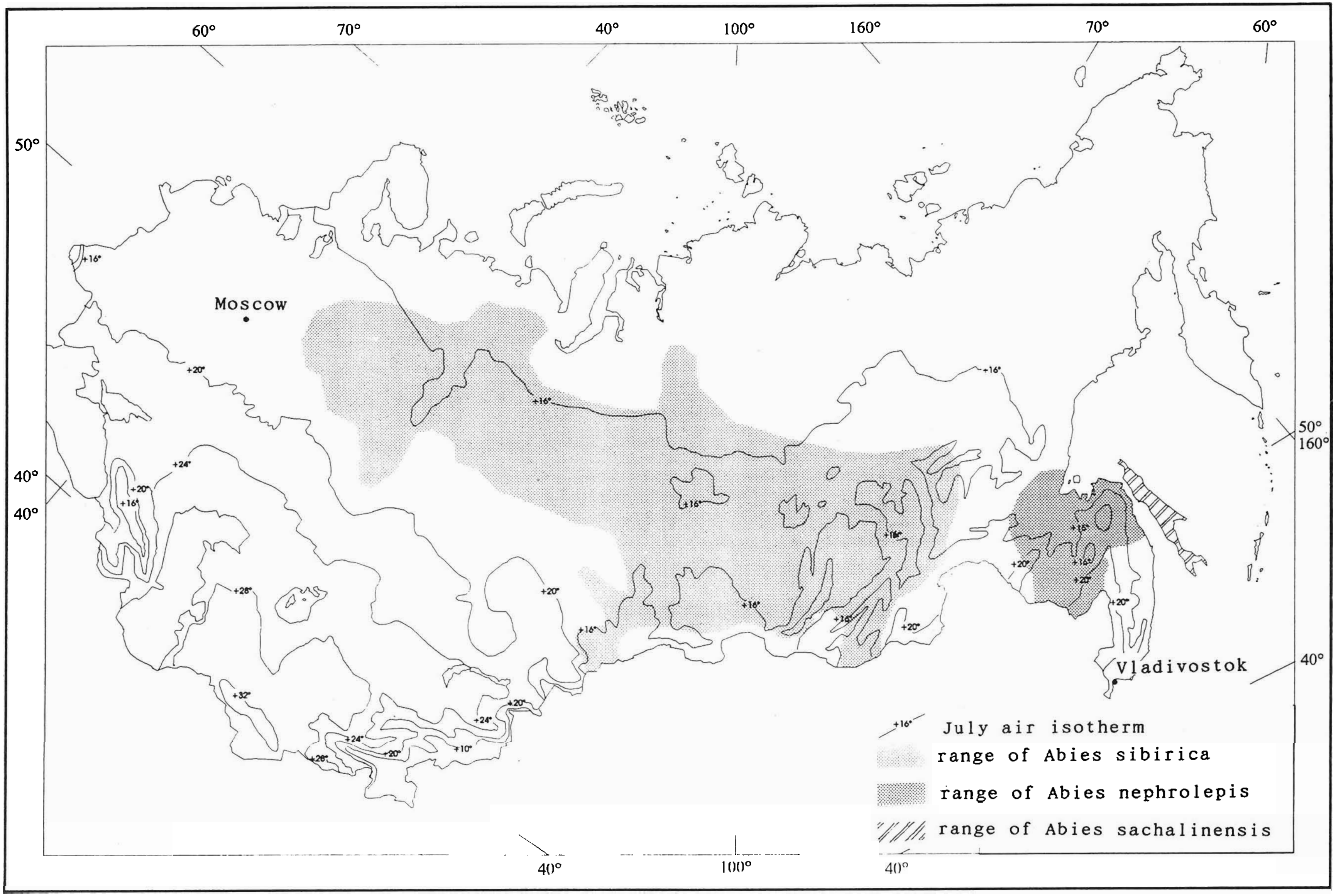

Fig. 5. Distribution of *Abies sibirica, A. nephrolepis* and *A. sachalinensis* and the 16, 20, 24, 28 and 32° C July mean air isotherms.

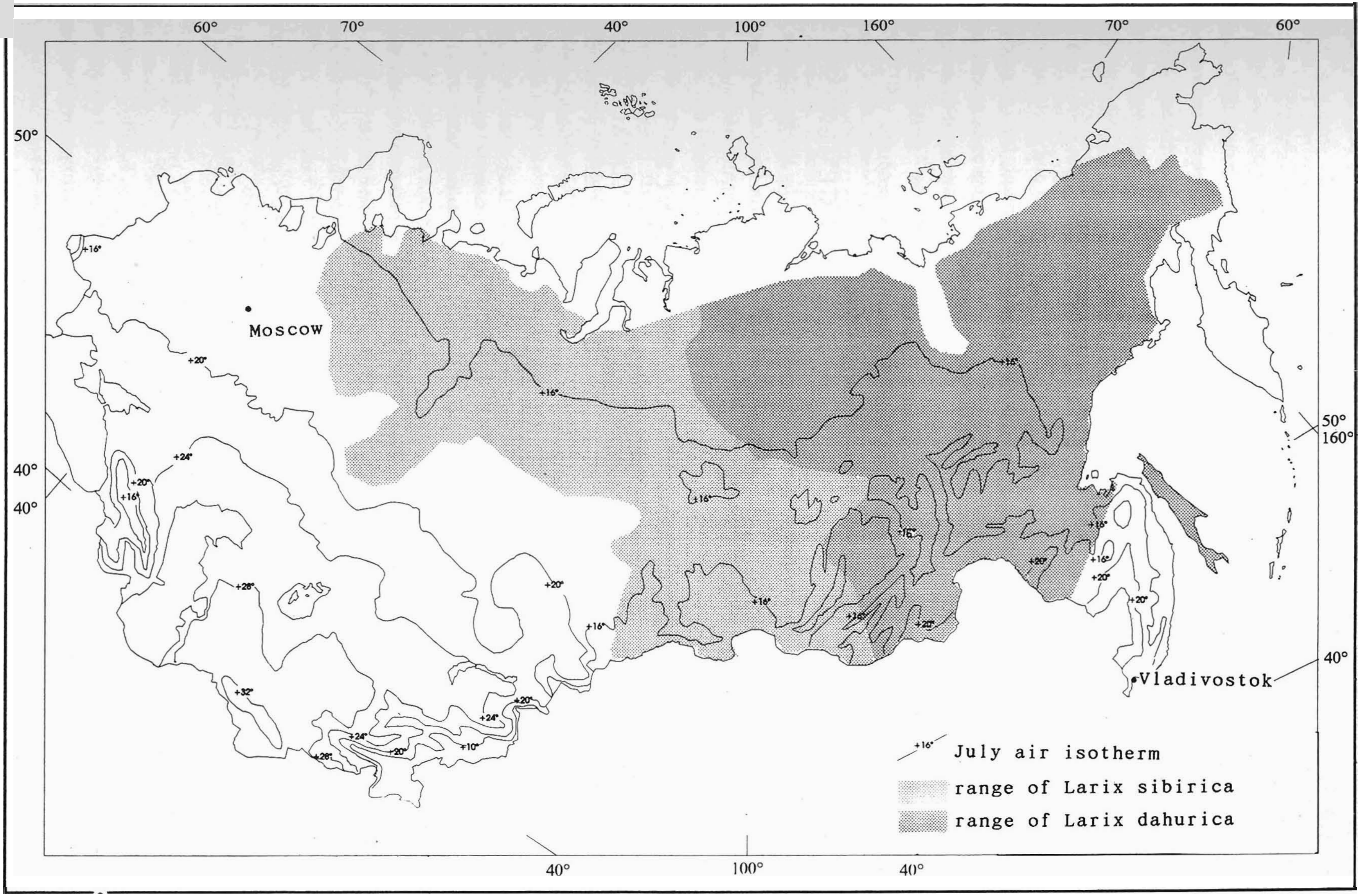

Fig. 6. Distribution of *Larix sibirica* and *L. dahurica* and the 16, 20, 24, 28 and 32° C July mean air isotherms.

ern China and could be transmitted naturally by migration of its vector from China to the Primorsky territory and Khabarovsk district of Russia and thereafter to Siberia.

The distribution of *B. xylophilus* in the former USSR territories is limited by climate which may protect trees from developing pine wilt disease and hence limit rapid distribution of the disease. The territories with mean July temperatures above 25° C include the Middle Asian Republics and Kazakhstan, but conifer forests in these areas are small and are located only at high altitudes. The greatest potential threat from *B. xylophilus* is in the Russian Far East, alone the Black Sea coast, southern Ukraine, Moldavia and an extensive area of the European part of Russia.

There are two aspects to the problem of the distribution and potential threat from *B. xylophilus* to conifers in Russia and neighboring countries. There is a potential mortality from pine wilt disease of conifers infected by *B. xylophilus* and the occurrence of the nematode may present difficulties when arranging international export of wood materials.

A substantial part of the conifer forests of the former USSR are located in the cooler areas with mean July temperatures below 20° C. Nevertheless, it is necessary to consider that temperature has its primary influence on the occurrence and development of pine wilt disease and does not prevent the establishment or distribution of *B. xylophilus* by the vector. Thus, although pine wilt disease may not kill conifers the presence of the nematode may cause problems with international, and even national export of wood materials.

In our analysis statistical data of the mean monthly temperatures were used, but not data for maximum temperatures. Several experiments have shown that pine wilt disease may develop during the hottest summers in Scandinavian countries and Finland, even where the mean July temperature is below 20° C (Magnusson, 1986; Bakke et al., 1991; Tomminen, 1993).

Inter-population mating and development of hybrids of *B. xylophilus* and *B. mucronatus* are possible (De Guiran & Brugier, 1989; Riga et al., 199 Riga et al., 1992). Such hybrids may have alte pathogenicity traits and survival strategies. Nati hybrids between Russian populations of *mucronatus* and *B. xylophilus* also may have hi pathogenicity for conifers in the former USSR, simil to *B. xylophilus* in Japan. Also, *Pinus sylvestris* and *koraiensis* growing throughout the former USSR a excellent plant-hosts for many populations of PWNS

From our analysis of the potential distribution *B. xylophilus* it can be concluded that a threat exists t conifer forests in several areas and territories of th former USSR. This threat is mainly from *B. xylophil* which has the potential to develop as a major factor the detriment of Russian forestry due to both disea establishment and problems presented wi international export of timber products.

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Кулинич О.А., Колосова Н.В. Возможность распространения сосновой древесной нематоды *Bursaphelenchus xylophilus* в странах бывшего СССР.
Резюме. Рассмотрены возможное распространение сосновой древесной нематоды *Bursaphelenchus xylophilus* в странах бывшего СССР и потенциальная угроза хвойным лесам на указанной территории. Анализ оригинальных и литературных данных показал отсутствие достоверных сведений об обнаружении вида *B. xylophilus* на территории бывшего СССР, однако, по мнению авторов, существует реальная угроза проникновения нематоды как естественным путем с помощью жуков-переносчиков, так и искусственным - через упаковочный древесный или посадочный материал. Наиболее вероятным регионом естественного проникновения *B. xylophilus* является территория Дальнего Востока России, куда нематода может быть занесена из Китая и Японии. К числу основных факторов, влияющих на распространение болезни, вызываемой *B. xylophilus*, относятся климатические, наличие жуков-переносчиков и устойчивость хвойных пород. По климатическим условиям развитие болезни возможно на значительной части Европейской части России, на Кавказе, юге Украины, в Молдавии, Средней Азии, Казахстане и частично на Дальнем Востоке. На основании анализа сделано заключение, что распространение *B. xylophilus* может создать серьезную угрозу как лесному хозяйству, так и проблеме экспорта леса и лесопродуктов за рубеж.