PAST DISTRIBUTION OF *TILIA*-FEEDING *PHYLLONORYCTER* MICROMOTH (LEPIDOPTERA: GRACILLARIIDAE) IN THE RUSSIAN FAR EAST BASED ON SURVEY OF HISTORICAL HERBARIUM

Kirichenko N.I.[1,2*], Akulov E.N.[3], Babichev N.S.[1], Mikhailova I.A.[1], Ponomarenko M.G.[4,5], Lopez-Vaamonde C.[6,7]

*1) Sukachev Institute of Forest, Sukachev Institute of Forest SB RAS, Federal Research Center «Krasnoyarsk Science Center SB RAS», Akademgorodok, 50/28, Krasnoyarsk, 660036, Russia. E-mail: miia@mail.ru. *Corresponding author, E-mail: nkirichenko@yahoo.com*

2) Siberian Federal University, Krasnoyarsk, Svobodny Prospect, 79, Krasnoyarsk, 660041, Russia,

3) All-Russian Plant Quarantine Center, Krasnoyarsk branch, Maerchaka str., 31a, Krasnoyarsk, 660075, Russia. E-mail: akulich80@ya.ru

4) Federal Scientific Center of the East Asia Terrestrial Biodiversity FEB RAS, prospect 100-letiya Vladivostoka, 159, Vladivostok, 690022, Russia. E-mail: margp@ibss.dvo.ru

5) Far Eastern Federal University, Russky Island, Vladivostok, 690922, Russia.

6) INRA, UR0633 Zoologie Forestière, Orléans, F-45075, France. E-mail: carlos.lopezvaamonde@inra.fr

6) Institut de Recherche sur la Biologie de l'Insecte (IRBI), UMR 7261, CNRS/Université de Tours, UFR Sciences et Techniques, Tours, 37200, France.

Summary. Distribution data of *Tilia*-feeding *Phyllonorycter* in the Russian Far East have been retrieved from a century-old *Tilia* herbarium stored in Vladivostok. Overall, 280 typical mines of *Phyllonorycter*, some with larvae and pupae, were found on 61 out of 799 herbarized specimens of *Tilia* spp. collected in Khabarovskii krai and Primorskii krai. For the first time, the presence of *Tilia*-feeding *Phyllonorycter* has been documented more West – in Amurskaya oblast and Jewish Autonomous oblast. High densities of the leafminer have been recorded on *Tilia amurensis* sampled in Khabarovskii krai and Primorskii krai between 1937 and 2005 suggesting a population dynamics with recurrent outbreaks. Our results confirm the importance of historical herbarium collections in studying trophic interactions and invasion ecology of folivore organisms.

Key words: Biogeography, leafminer, distribution range, Easternmost Russia, lime trees, herbarium, new records.

Н. И. Кириченко, Е. Н. Акулов, Н. С. Бабичев, И. А. Михайлова, М. Г. Пономаренко, К. Лопез-Ваамонде. Распространение липовой моли-пестрянки *Phyllonorycter* (Lepidoptera: Gracillariidae) на Российском Дальнем Востоке в прошлом, основанное на изучении исторических гербариев // Дальневосточный энтомолог. 2019. N . С. .

Резюме. Получены данные о распространении минирующей липовой моли из рода *Phyllonorycter* на Дальнем Востоке России на основе анализа вековой гербарной коллекции, хранящейся во Владивостоке. В совокупности было обнаружено 280 типичных мин, нередко с личинками и куколками моли, на 61 из 799 гербарных образцах липы, *Tilia* spp. из Хабаровского и Приморского краев. Находки мин моли на липе западнее – в Амурской и Еврейской Автономной областях – приводятся впервые. Частая встречаемость листовых мин на гербарных образцах *Tilia amurensis* из Хабаровского и Приморского краев, датируемых 1937–2005 гг., свидетельствует о повышении численности популяций минера в прошлом. Результаты работы актуализируют значение исторических гербарных коллекций в исследованиях трофических связей и процессов инвазий фитотрофных организмов.

INTRODUCTION

Historical herbarium collections are important sources of data for entomologists, phytophatologists and ecologists to study past extinctions, diversity, abundance, trophic relations and range expansions of various folivore organisms – arthropods and phytopathogenic fungi, and to assess their responses to global changes (Lees et al., 2011; Hembry, 2013; Drenkhan et al., 2017; Meineke et al., 2018).

Recent study of herbaria specimens allowed ascertaining time when the invasive pathogenic fungus *Hymenoscyphus fraxineus,* causing ash dieback, a chronic and severe fungal disease of European ashes, could arrive in Europe (Drenkhan et al., 2016). The fungus was discovered and formally described in

2006 (under the name *Chalara fraxinea*), whereas herbarium examination dates *H. fraxineus* appearance in Estonia back to 1997 and apparently represents the oldest record of the species in Europe (Drenkhan et al., 2016). Survey of historical herbaria allowed detection of *H. fraxineus* on the herbarized leaves in the Russian Far East (RFE) dated by 1962 confirming its long-term presence in Northeast Asia (Drenkhan et al., 2017).

Besides phytopathogenic organisms, endophagous insects (i.e. leaf-mininig and leaf-galling insects), whose larvae live inside leaf tissues can still be found in leaves sampled and preserved in herbarium collections centuries ago. These archival specimens can be effectively utilized in invasion ecology studies (Lees at al., 2011; Staats et al., 2013).

The lime leafminer, *Phyllonorycter issikii* (Kumata) is a micromoth from the family Gracillariidae (Lepidoptera) attacking lime trees, *Tilia* spp. (Malvales: Malvaceae). It is originally known from Japan, from where it was described in 1963 (Kumata, 1963), from the Republic of Korea (Kumata et al., 1978) and the Russian Far East (Ermolaev, 1977). Since the end of 20th century, this micromoth colonized most of Europe and became a pest of newly colonized lime trees in Western Palearctic (Šefrová, 2002; Kirichenko et al., 2017).

The main aim of our study is to reconstruct the past distribution of the moth and its population dynamics by examining historical herbaria samples of *Tilia* collected in its native range in the Russian Far East.

MATERIAL AND METHODS

The largest herbarium collections of *Tilia* spp. (Malvaceae) sampled in RFE and stored in two depositaries – in the herbarium of the Botanical Garden-Institute of the Far Eastern Branch of the Russian Academy of Sciences (international herbarium code – VBGI, see Index Herbariorum, 2019) and in the herbarium of Federal Scientific Center of the East Asia Terrestrial Biodiversity (VLA), Vladivostok, Russia, were involved in the study.

Herbarized lime leaves were carefully examined for the presence of typical whitish (with the time getting brownish) parenchymal blotch mines of *Phyllonorycter*. Leaves were inspected on both sides, with much attention paid to the lower side of the leaves, where *Tilia*-feeding *Phyllonorycter* females usually oviposit and where larvae make their mines. In the early stages, these are tiny spots with or without preceding tunnels in epidermis; soon they widen to blotch mines (with the tunnel incorporated in the blotch and so that it becomes indistinguishable) located in spongy parenchyma; in the later stage mine gets volumetric (so called tentiform mine), with much spongy parenchyma and partly palisade parenchyma eaten out giving the mine a whitish colour (Kirichenko, 2014). Whenever possible, herbarized specimens – twigs with leaves were neatly detached from herbarium sheets in order to get an access to both leaf sides. After examination, plant specimens were re-attached to the sheets respecting their original placement.

The absence/ presence of mines, number of mines, number of leaves with mines and total number of leaves per herbarium sheet was recorded together with the host plant, the location (continental part or island, district and/ or settlement), the plantation type (forest, national parks, botanical gardens, parks and settlement plantations), and the collection date in order to clarify past distribution of the moth in RFE. Host plants names are given as they were originally identified and written on the herbarium labels.

With the permission of the herbaria curators, mines that showed some sign of having larvae or pupae inside were carefully opened to collect the inhabitants. A thin syringe was used to make gentle dissection of the mines: epidermis covering mines was cut along the contact zone with undamaged leaf tissue providing an access into the mine. Cut epidermis was bent up and fine entomological forceps were utilized to pick up pressed insect individuals from the mines. After this procedure, the epidermis was pressed down to cover the mine; where needed, it was attached to the mine using a tiny drop of polyvinyl acetate glue. Presence of larva or pupa in the mines as well as presence pupal exuvia protruding the mines after imago emergence was documented. Additionally, occurrence of parasitoid pupae or adult wasps was noted. Lime leafminer individuals (larvae and pupae) and their remnant (molting cuticles) as well as parasitoid specimens found in the leaf mines were collected and placed individually into 1.5 ml tubes with hermetic lids, labeled and stored for further genetic analysis.

Archival pupae and pupal exuvia of the leafminer were examined under magnification (x 40) and by their characteristic cremaster, having one pair of rather slender spines curved outwards (Gregor & Patočka, 2001), the studied individuals were tentatively assigned to *Phyllonorycter issikii*. The mines, where no *Phyllonorycter* larvae or pupae were found (i.e. in cracked mines with lost inhabitants, parasitized mines, or abundant mines) were also assigned to the lime leafminer, *Ph. issikii*, as so far it is the only described species known to attack limes in the Russian Far East (Baryshnikova, 2016). However, in this paper we utilize the neutral name “the lime leafminer” or “*Tilia*-feeding *Phyllonorycter*” until more detailed analyses (i.e. DNA barcoding) is done to prove the taxonomic possession of the archival specimens sampled from the herbarium in RFE.

Data retrieved from herbarium specimens were used to compute average number of mines per infested leaves and relative number of infested leaves per herbarium sheet (expressed in %). Data on sampling localities were translated to the coordinates for mapping the historical occurrence of *Tilia*-feeding leafminer in the Russian Far East using ArcGis 9.3 software. The distribution of *Tilia* spp. was extracted from various sources (Pigott, 2012; Koropachinskiy, Vstovskaya, 2012; Zhuravlev, 2019)

Archival specimens of *Phyllonorycter* immature individuals and their parasitoids have been deposited at Sukachev Institute of Forest, Federal Research Center «Krasnoyarsk Science Center SB RAS», Krasnoyarsk.

RESULTS AND DISCUSSION

Herbarium analyses

Overall, 799 herbarium sheets with *Tilia* specimens collected in RFE and stored in about equal proportions in VBGI (404 herbarium sheets) and VLA (395) were examined (Fig. 1A). *Tilia* specimens were sampled in the period from 1920 to 2017 (Fig. 1A). The collection of VLA holded earliest records of sampling, whereas VBGI storeed *Tilia* herbarium collected in RFE only in the last 60 years (Fig. 1A). About 49% of *Tilia* specimens (i.e. 390 out of 799 herbarium sheets) were obtained during 1970–1989.

In total, 61 out of 799 (7.6%) herbarium sheets with *Tilia* specimens collected in RFE carried typical mines of *Phyllonorycter* (Fig. 1B). Altogether, 280 mines were found on 170 out of 1052 (16%) leaves of those 61 herbarium sheets (Table, columns 1, 5–7). Thus one damaged leaf, on average, carried about two *Phyllonorycter* mines. Leaf mines were documented on the pressed lime leaves in the period from 1936 up to 2015 (Fig. 1B). The majority of mined *Tilia* specimens dated from the period of 1970–1990s (i.e. 38 mined *Tilia* herbarium samples out of all 61 herbarium sheets with *Phyllonorycter* damage).

Nearly 80 % of mines were found in advanced developmental stage. By mine size and morphology (oval parenchymal blotches occupying up to 1.2 cm^2 of leaf surface) they could be assigned to IV or V larval instars, or to pupation stage of the leafminer. Other mines were small irregular spots (up to 0.06 cm^2), with or without preceding epidermal tunnel. They were either detected on lime leaves sampled in May corresponding to the first generation of *Tilia*-feeding *Phyllonorycter,* or they were found on pressed leaves collected in August–September representing the second generation of the moth.

Phyllonorycter mines on *T. amurensis* specimen collected in V.L. Komarov Mountain-Taiga Station, Primorskii krai in July 1936 represented the earliest record of the moth damage (Table, columns 2, 3, 5). No much data was provided on the label of that specimen (collector was not indicated). Since the mine was broken with partly loose epidermis, no larva or pupae of *Phyllonorycter* was found in it. Collected in August of the next year (1937), from Primorskii krai, Khorolsky district, from fir forest near the River Pompeevka (D. Vorobiev leg.), the specimen of *T. amurensis* (in 1984 reidentified by V. Nedoluzhko as *T. taquetii*) carried 19 mines on 12 leaves (i.e. about 2 mines per a leaf) in one herbarium sheet (Table, columns 2, 3, 5; Fig. 2 A–B). Interestingly, 58% of mines (11 out of 19 mines) were heavily parasitized, with 2-6 pupae of a greragious parasitic wasp found per a mine. Other mines had broken epidermis, with no *Phyllonorycter* larvae or pupae present within the mines. These two earliest findings dated back to 1936 and 1937 confirm presence of the lime leafminer in Primorskii krai, at least 28 years before the insect was formally described from the Japanese island of Hokkaido (Kumata, 1963).

In total, 17 larvae and pupae of *Phyllonorycter* were sampled from the mines on 17 out of 61 herbarium sheets. Additionally, 2 parasitoid pupae and one adult of parasitic wasp were collected from *Tilia* herbarium from Primorskii krai dated back to 1937 and 1997 (Table, column 10).

We preliminary identified the immature *Phyllonorycter* specimens found within the archival mines as *Ph. issikii*. So far, it is the only *Phyllonorycter* species has been known on *Tilia* in RFE (Baryshnikova, 2016). However, in our recent study the presence of a putative cryptic species of *Phyllonorycter* on limes in the Russian Far East was suggested, that was found in the sympatry and on the same hosts with *Ph. issikii* in the remote localities in Sikhote-Alin Mts and delimited by three sequenced genes (COI, Histone 3 and 28S) (Kirichenko et al., 2017). Further in-depth morphological and genetic analyses are needed to test the validity of this putative cryptic species.

The majority of herbarium specimens carrying typical *Phyllonortycter* mines were represented by *Tilia amurensis* (54 % of herbarium sheet with mines). Other host species on which the mines were found on the pressed leaves were *T. taquetii* (23% of herbarium sheets with the mines), *T. mandshurica* (18%), *T. maximowicziana*, *T. pekinensis*, *T. divaricata*, and *T. koreana* (altogether 5%) (Table, column 4).

Tilia pekinensis, *T. divaricata* and *T. koreana* are recorded for the first time as hosts for the lime leafminer. However, the taxonomy of these lime species remains dubious. In Russia, *T. divaricata, T. koreana* as well as *T. taquetii* are considered as junior synonyms of *T. amurensis* (Koropachinskiy, Vstovskaya, 2012), whereas *T. pekinensis* is treated as a junior synonym of *T. mandshurica* (Qian et al., 2003).

Four herbarium specimens of *Tilia amurensis* were exceptionally significantly damaged by *Phyllonorycter* species. Three of them originated from Primorskii krai – from Khorolsky District collected in 1937, and Vladivostok suburban forest collected in 1992 (Fig. 2 C–D) and 2005, and one herbarium specimen was collected in Khabarovskii krai, in Komsomolsk-on-Amur district in 1961 (Table, column 6). Nearly all leaves on these herbariums specimens were covered by *Phyllonorycter* mines, accounting altogether 141 mines, which makes 50% of all mines found in *Tilia* herbarium in VBGI and VLA.

Historical distribution of *Tilia*-feeding *Phyllonorycter* in RFE

We discovered *Phyllonorycter* mines in herbarized *Tilia* specimens collected in four administrative regions of RFE: Amurskaya oblast, Jewish Autonomous oblast, Khabarovskii krai and Primorskii krai, and in 61 localities within these four regions (Fig. 3, Table, columns 1, 2). According to most recent faunistic reviews, *Tilia*-feeding *Phyllonorycter* has been known only from Khabarovskii krai and Primorskii krai (Baryshnikova et al., 2016; Kirichenko et al., 2019). Historical herbarium data confirm the distribution of the lime leafminer in these regions and provide additional evidence for the lime leafminer occurrence in Amurskaya oblast and Jewish Autonomous oblast (Table, columns 2, 5). According to herbarium data, the location in Amurskaya oblast, i.e. the ridge Tukuringra in Zeya Nature Reserve (54°09'N, 126°09'E) is the most western point of *Tilia*-feeding *Phyllonorycter* distribution within its natural range in RFE (Fig. 3). The presence of the lime leaf-mining moth in Amurskaya oblast and Jewish Autonomous oblast is not surprising, as it well corresponds to the range of its common East Asian hosts, *Tilia amurensis* and *T. mandshurica* (Koropachinskiy, Vstovskaya, 2012; Fig. 3). Thus, according to our herbarium survey, the lime leafminer is present in all administrative regions of the Russian Far East where its host plants occur. In Primorskii krai, the mines of *Phyllonorycter* were found on herbarium specimens not only from the continental part of the region, but also from the neighboring insular territories, i.e. the Islands Askold, Russkiy and Popov (Table, columns 2, 5; Fig. 3, № 32, 33, 46–55), from where no distribution records of *Tilia*-feeding *Phyllonorycter* are known from literature sources.

Presence of *Phyllonorycter* mines on the pressed leaves of *Tilia* sampled in 1974–1987 in Primorskii krai along the border with China (i.e. the locations № 16 – Khasansky District, Lake Khanka and № 17 – Pogranichny Distict, Kedrovaya Mt., Fig. 3) and collected in 1975 at around 20 km from the border with North Korea (the location № 61, Khasansky District, Lake Talmi, Fig. 3) suggest occurrence of the lime leafminer in North-East China and in northern part of North Korea. *Phyllonorycter issikii* presence in China refers to its single record in Tianjin, Baxian Mountain Nature Reserve (40˚09'N, 117˚43'E) (Kirichenko et al., 2017), whereas no data on *Ph. issikii* distribution is available from North Korea. The reference on its occurrence in the Republic of Korea concerns only the southern part of the Korean Peninsula (Kumata et at al., 1983).

Overall, data retrieved from the historical herbarium collections deposited in Vladivostok provide evidence for wider distribution range of *Tilia*-feeding *Phyllonorycter* in the Russian Far East, at least in the past. Besides Khabarovskii and Primosky krais, the typical mines of *Phyllonorycter* were recorded more West – in Jewish Autonomous oblast and Amurskaya oblast meaning that the moth was distributed (and probably remains so) across the whole range of its primary *Tilia* hosts in the Russian Far East.

High densities of *Phyllonorycter* mines on archival *Tilia* specimens dated back to 1937, 1961, 1992, and 2005 in Khabarovskii krai and Primorskii krai suggest the existence of outbreaks, a fact never reported in the literature from these regions. Keeping in mind that botanists tend to select undamaged plant leaves for herbarium collections (Verkholat: pers. communication, 2019), the presence of such high densities of mined leaves in herbarium samples indicate the presence of pronounced foci of the moth in its primary range in the past.

CONCLUSION

Our study of a one century-old historical herbarium specified past distribution of an insect which has rapidly expanded its range across the Palearctic. Future genetic analysis of larvae and pupae collected from the archival leaf mines found in the herbarized specimens will help to clarify the invasion history of this pestiferous leaf-mining moth species and point the source populations in East Asia that contributed the pest expansion westwards.

Our study highlights the importance of keeping plant vouchers in botanical and entomological research and assuring the preservation of historical herbaria as treasure troves of data reflecting processes happening in a fast changing world. With this, we would like to encourage botanists and herbalists to sample not only intact plant specimens for herbarium collections but also those having any kind of damage, and advise ecologists, entomologists and phytopahologists to consider involving historical herbarium collections in their studies as they may store important data on past distribution and diversity of organisms, including pestiferous and invasive species.

AKNOWLEDGMENTS

We thank the curators of the herbarium collections – Valentina P. Verkholat (VBGI, Vladivostok), Zoya V. Kozhevnikova (VLA, Vladivostok), Valentin V. Yakubov (VLA, Vladivostok) for their cooperation and hospitality. We also thank Yuri N. Baranchikov (SIF SB RAS, Krasnoyarsk) for fruitful discussions. This work was supported by the Russian Foundation for Basic Research (project no.19-04-01029-A).

REFERENCES

Baryshnikova, S.V. 2016. Gracillariidae. P. 50–59. In: Lelej, A.S. (Ed.). *Annotated catalogue of the insects of Russian Far East*. Vol. II, Lepidoptera. Dalnauka, Vladivostok. 812 p.

Drenkhan, R., Riit, T., Adamson, K. & Hanso, M. The earliest samples of *Hymenoscyphus albidus* vs. *H. Fraxineus* in Estonian mycological herbaria. *Mycological Progress*, 15: 835–844. DOI 10.1007/s11557-016-1209-5

Drenkhan, R., Solheim, H., Bogacheva, A., Riit, T., Adamson, K., Drenkhan T., Maaten, T. & Hietala, A.M. 2017. *Hymenoscyphus fraxineus* is a leaf pathogen of local *Fraxinus* species in the Russian Far East. *Plant Pathology*, 66: 490–500. Doi: 10.1111/ppa.12588

Gregor, F. & Patočka, J. 2001. *Die Puppen der mitteleuropäischen Lithocolletinae*. Mitteilungen des internationalen entomologischen Vereins. Supplement 8: 1–186.

Hembry, D. 2013. Putative insect extinction on the deforested Island of Mangareva (Gambier Archipelago, FrenchPolynesia). *Pacific Science*, 67(4): 553–560.

Index Herbariorum. 2019. The New York Botanical Garden. http://sweetgum.nybg.org/science/ih/ Accessed 9th of July 2019.

Johns, C.A., Tangalin N., Bustamente K. & Kawahara A.Y. 2014. Evidence of an undescribed, extinct *Philodoria* species (Lepidoptera: Gracillariidae) from Hawaiian *Hesperomannia* herbarium specimens. *Proceedings of the Hawaiian Entomological Society*, 46: 55–57.

Kirichenko, N. 2014. The Lime Leafminer *Phyllonorycter issikii* in Western Siberia: some ecological characteristics of the population of the recent invader. *Contemporary Problems of Ecology*, 7: 114–121.

Kirichenko, N., Triberti, P., Ohshima, I., Haran, J., Byun, B.-K., Li, H., Augustin, S., Roques, A. & Lopez-Vaamonde, C. 2017. From east to west across the Palearctic: Phylogeography of the invasive lime leaf miner *Phyllonorycter issikii* (Lepidoptera: Gracillariidae) and discovery of a putative new cryptic species in East Asia. *PLoS ONE*, 12 (2): e0171104. DOI:10.1371/journal.pone.017110

Koropachinskiy, I.Yu. & Vstovskaya, T.N. 2012. Woody plants of the Asian part of Russia. Academic Publishing House “Geo”, Novosibirsk. 707 p.

Kumata, T. 1963. Taxonomic studies on the Lithocolletinae of Japan (Lepidoptera: Gracillariidae) Part I. *Insecta Matsumurana*, 25: 53–90.

Kumata, T., Kuroko, H. & Park, K. 1983. Some Korean species of the subfamily Lithocolletinae Gracillariidae, Lepidoptera. *Korean Journal of Plant Protection*, 22: 213–227.

Lees, D.C., Lack, H.W., Rougerie, R., Hernandez, A., Raus, T., Avtzis, N.D., Augustin, S. & Lopez-Vaamonde, C. 2011. Tracking origins of invasive herbivores using herbaria and archival DNA: the case of the horse-chestnut leafminer. *Frontiers in Ecology and the Environment*, 9: 322–328.

Meineke, E.K., Classen, A.T., Sanders, N.J. & Davies, T.D. 2018. Herbarium specimens reveal increasing herbivory over the past century. *Journal of Ecology*, 107: 105–117. DOI: 10.1111/1365-2745.13057

Pigott, D. 2012. *Lime-trees and Basswoods. A Biological Monograph of the Genus Tilia*. Cambridge University Press, Cambridge, New York. 395 p.

Qian, H., Krestov, P., Fu, PY., Wang, QL., Song, J.S. & Chourmouzis, C. 2003. Phytogeography of Northeast Asia. P. 51–91. In: Kolbek, J., Šrůtek, M., Box, E.O. (Eds). *Forest Vegetation of Northeast Asia*. *Geobotany*, Vol. 28. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-0143-3_4

Šefrová, H. 2002. *Phyllonorycter issikii* (Kumata, 1963) – bionomics, ecological impact and spread in Europe (Lepidoptera, Gracillariidae). *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* 50: 99–104.

Staats, M., Erkens, R.H.J., van de Vossenberg, B., Wieringa, J.J., Kraaijeveld, K., Stielow, B., Geml, J., Richardson, J.E. & Bakker, F.T. 2013. Genomic treasure troves: complete genome sequencing of herbarium and insect museum specimens. *PLoS ONE* 8(7): e69189. doi:10.1371/journal.pone.0069189

Zhuravlev, B.B. 2019. Map of areas the main types of limes in the USSR [map]. Available: https://upload. wikimedia.org/wikipedia/ru/5/5a/Tilia_USSR.png Accessed 9th of July 2019.

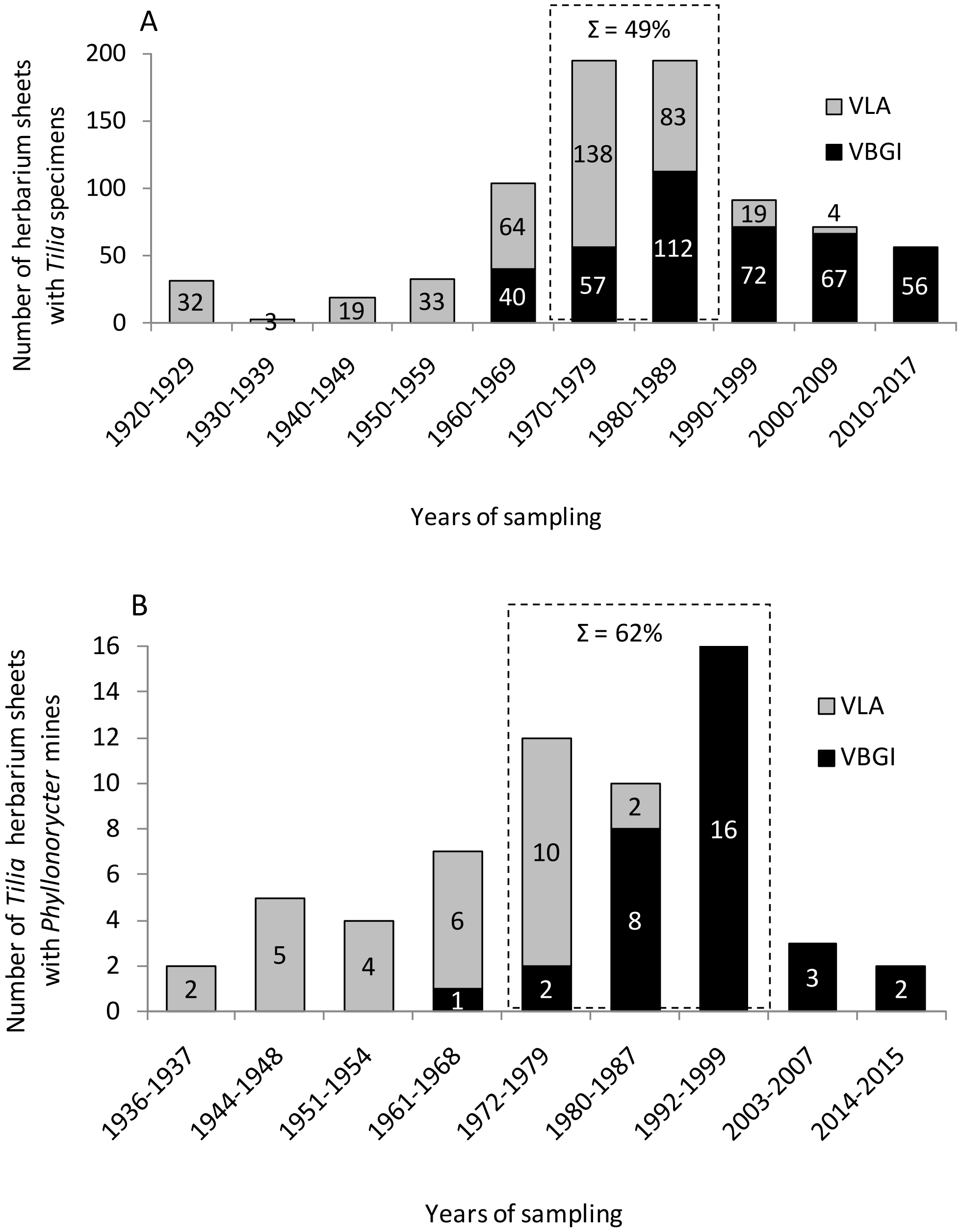

Fig. 1. Accumulation of *Tilia* herbarium during one century period in the Russian Far East (A) and number of herbarized *Tilia* specimens with *Phyllonorycter* mines (B). VLA – herbarium of the Federal Scientific Center of the East Asia Terrestrial Biodiversity of the Far Eastern Branch RAS, VBGI – herbarium of the Botanical Garden-Institute of the Far Eastern Branch RAS, Vladivostok, Russia.

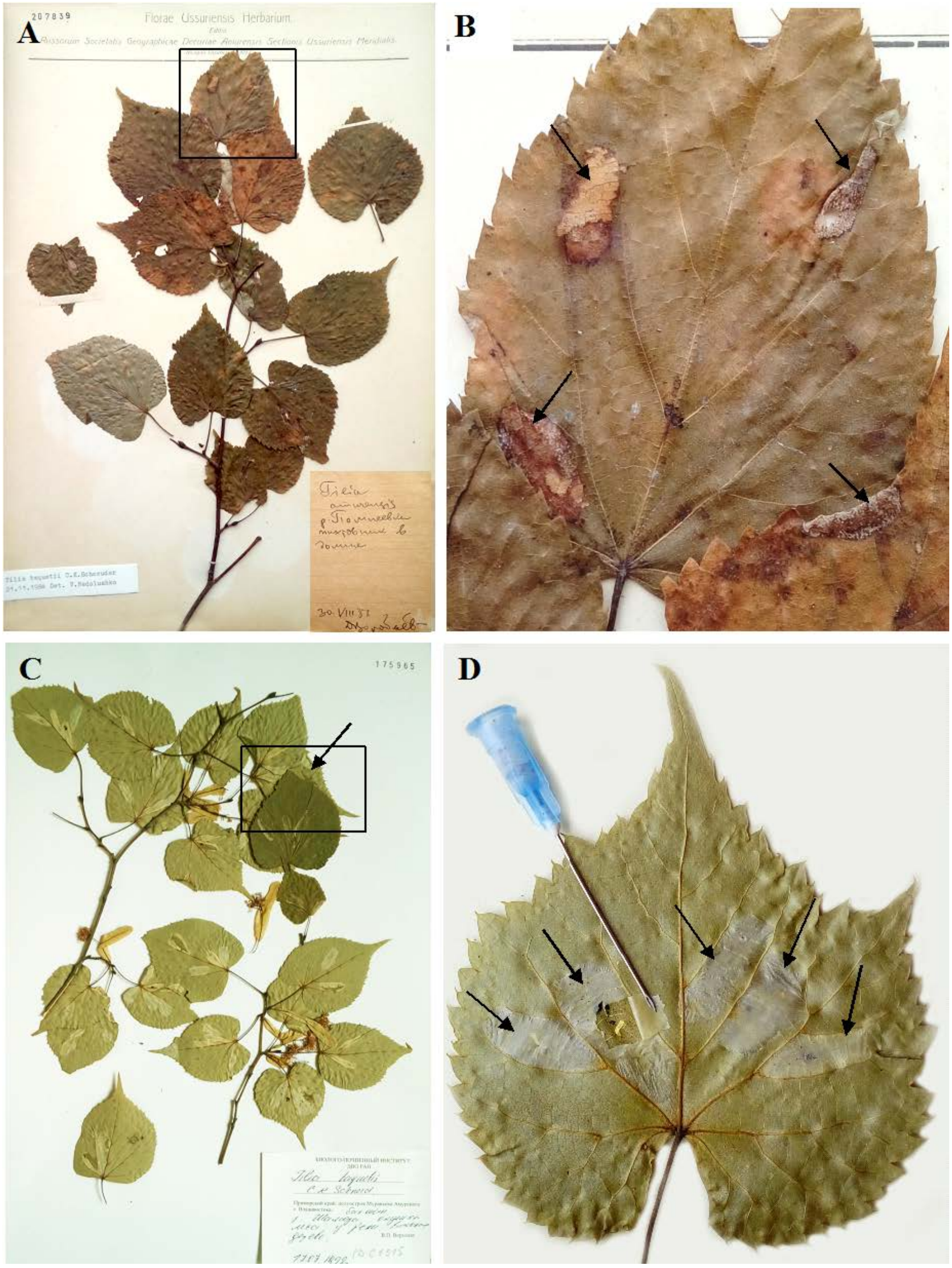

Fig. 2. Herbarium specimens of *Tilia amurensis* with *Phyllonorycter* mines, originating from the Russian Far East. A–B – one of the oldest specimens with leaf mines, Primorskii krai, Khorolskiy district, near the river Pompeevka, fir forest, *Tilia amurensis*, 30.VIII.1937, D. Vorobiev leg, ID 207839, stored in VLA; C–D – Muravyov-Amurskii Peninsula, Vladivostok, basin of the River Shamora, forest, *T. amurensis*, 17.VII.1992, V.P. Verkholat leg., ID 61515, stored in VBGI. A, C – black rectangle indicated sampled leaf (on the figure C, the leaf is additionally pointed by an arrow); B, D – black arrows show *Phyllonorycter* mines; one mine is opened showing the larva in the center of the mine.

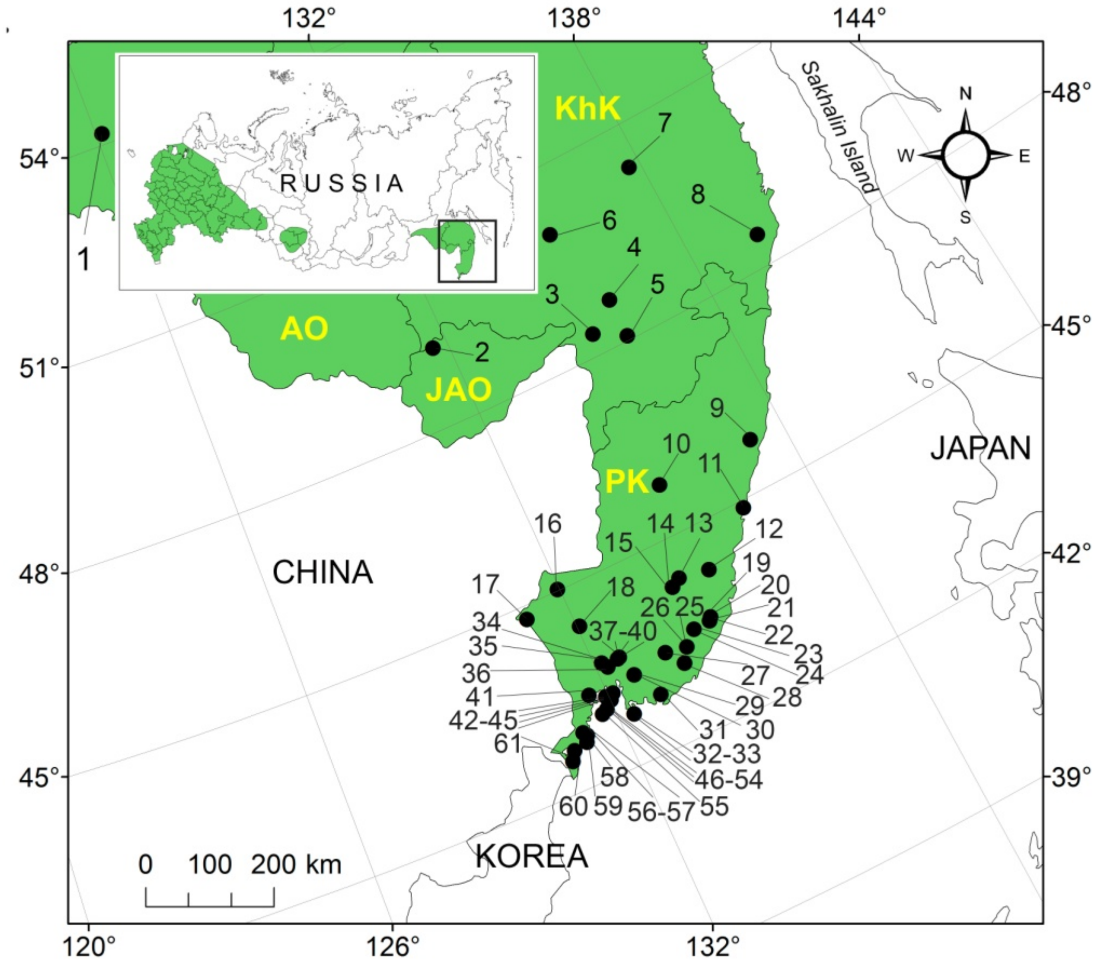

Fig. 3. Historical records of *Tilia*-feeding *Phyllonorycter* occurrence in the Russian Far East retrieved from on one century-old herbarium. For locations 1–61 see Table 1. In the left upper corner, a map of Russia is provided with indicated *Tilia* distribution range (shaded in green); the region of study is shown by black rectangle. AO – Amurskaya oblast, JAO – Jewish Autonomous oblast, KhK – Khabarovskii krai, PK – Primorskii krai.

Table – *Tilia* herbarium specimens with typical *Phyllonorycter* leaf mines and sampling locations in the Russian Far East.

1	2	3	4	5	6	7	8	9	10	11
№ h.s.[1]	**Location in RFE[2]**	**Collection date**	***Tilia* species[3]**	**Number of**					**Presence of larva or pupa in the mines[4]**	**Depository**
				mines	**leaves with mines**	**leaves in the herb. sheet**	**mines per damaged leaf**	**mined leaves per h.s.[1], (%)**		
				AMURSKAYA OBLAST						
1	ZNR	VIII.1977	*T.a.*	1	1	24	1	4	+	VLA
				JEWISH AUTONOMOUS OBLAST						
2	v. Kuldur	VII.1974	*T.a.*	3	2	13	1,5	15	—	VBGI
				KHABAROVSKII KRAI						
3	BNR	1965	*T.m.*	1	1	9	1	11	—	VLA
4	KhabD, v. Elabuga	1975	*T.a.*	2	2	8	1	25	—	VLA
5	R. Durmin	1954	*T.t.*	1	1	53	1	2	—	VLA
6	KAMD, ridge Dzhaki-Unakhta-IAkbyiana	1961	*T.a.*	31	12	12	2,6	100	+	VLA
7	KAM, KNR	VIII.1985	*T.a.*	1	1	11	1	9	+	VLA
8	SGD, R.Tyumnin	VIII.1972	*T a.*	1	1	26	1	4	—	VLA
				PRIMORSKII KRAI						
9	TD	VII.1982	*T.a.*	1	1	15	1	7	—	VBGI
10	KrD, v. Vostretsovo	VIII.1978	*T.p.*	3	2	6	1,5	33	—	VLA
11	TD, SANR	VIII.1980	*T.a.*	1	1	29	1	3	—	VLA
12	KovD, R. Dorozhnaya	1979	*T.d.*	1	1	25	1	4	+	VLA
13	CD	IX.1974	*T.a.*	1	1	8	1	13	+	VLA
14	CD	1978	*T.t.*	1	1	20	1	5	—	VBGI
15	CD	1980	*T.t.*	2	2	20	1	10	—	VBGI
16	KhD, Lake Khanka	1974	*T.m.*	1	1	4	1	25	—	VLA
17	PoD, Kedrovaya Mt.	1987	*T.a.*	2	1	22	2	5	—	VBGI
18	KhoD, R. Pompeevka	VIII.1937	*T.a.*	19	12	12	1,6	100	+†	VLA
19	Sikhote-Alin Mts.	X.1944	*T.a.*	1	1	5	1	20	—	VLA

1	2	3	4	5	6	7	8	9	10	11
20	Sikhote-Alin Mts.	X.1944	*T.a.*	4	4	19	1	21	—	VLA
21	Sikhote-Alin Mts.	X.1946	*T.a.*	10	4	9	2,5	44	—	VLA
22	Sikhote-Alin Mts.	VIII.1946	*T.a.*	5	2	9	2,5	22	—	VLA
23	ChD, ZTNP	VIII.2014	*T.a.*	2	2	41	1	5	—	VBGI
24	LD, LNR	X.1964	*T.m.*	1	1	7	1	14	—	VLA
25	LD, v. Benevskoe	VIII.1952	*T.a.*‡	1	1	15	1	7	+	VLA
26	LD, v. Benevskoe	VIII.1952	*T.a.*‡	3	3	16	1	19	—	VLA
27	ShD	VI.1987	*T.t.*	1	1	12	1	8	+	VBGI
28	ShD	VI.1987	*T.t.*	1	1	12	1	8	—	VBGI
29	ShD	IX.1999	*T.t.*	3	3	23	1	13	—	VBGI
30	ShD	VIII.1968	*T.m.*	1	1	11	1	9	+	VBGI
31	PaD	1948	*T.t.*	2	2	22	1	9	—	VLA
32	Askold Isl.	VIII.1995	*T.a.*	1	1	16	1	6	—	VBGI
33	Askold Isl.	VIII.1995	*T.a.*	1	1	27	1	4	+	VBGI
34	UD, MTS	VII.1998	*T.a.*	1	1	7	1	14	+	VBGI
35	UD, MTS	VII.1936	*T.a.*	1	1	27	1	4	—	VLA
36	UD, v. Kamenushka	IX.1986	*T.m.*	1	1	6	1	17	+	VBGI
37	UD, UNR	VIII.2007	*T.m.*	2	2	5	1	40	—	VBGI
38	UD, USR	1975	*T.m.*	2	2	3	1	67	—	VLA
39	UD, USR	VII.1965	*T.a.*	1	1	31	1	3	—	VLA
40	UD, USR	VII.1965	*T.a.*	3	3	52	1	6	—	VLA
41	KhD, v. Kravtsovka	VIII.1985	*T.t.*	3	3	12	1	25	—	VBGI
42	MAP, Vlad., forest	VII.1997	*T.a.*	1	1	24	1	4	—	VBGI
43	MAP, Vlad., forest	IX.2005	*T.a.*	26	10	12	2,6	83	+	VBGI
44	MAP, Vlad., forest	1997	*T.a.*	3	1	20	3	5	—	VBGI
45	MAP, Vlad., forest	VII.1992	*T.a.*	65	20	20	3,3	100	+	VBGI
46	Russky Isl.	VII.1998	*T.a.*	2	2	23	1	9	—	VBGI
47	Russky Isl.	X.1997	*T.m.*	1	1	3	1	33	—	VBGI
48	Russky Isl.	X.1997	*T.m.*	3	3	4	1	75	—	VBGI

1	2	3	4	5	6	7	8	9	10	11
49	Russky Isl.	X.1997	*T.t.*	16	9	27	1,8	33	+†	VBGI
50	Russky Isl.	VIII.1998	*T.t.*	3	3	24	1	13	—	VBGI
51	Russky Isl.	VIII.1998	*T.t.*	5	5	33	1	15	—	VBGI
52	Russky Isl.	VIII.1998	*T.t.*	10	8	15	1,3	53	—	VBGI
53	Russky Isl.	VIII.1998	*T.t.*	5	5	15	1	33	—	VBGI
54	Russky Isl.	VIII.1998	*T.t.*	5	5	7	1	71	—	VBGI
55	Popov Isl.	VI.1973	*T.a.*	2	2	28	1	7	—	VLA
56	KhD, R. Ryazanovka	X.1951	*T.k.*	1	1	15	1	7	+	VLA
57	KhD, v. Ryaszanovka	1981	*T.max.*	1	1	17	1	6	—	VBGI
58	KhD, v. Vityaz	VIII.2015	*T.a.*	1	1	21	1	5	—	VBGI
59	KhD, v. Vityaz	1968	*T.a.*	2	2	20	1	10	—	VLA
60	KhD, Krabbe Semi-Isl.	VIII.2003	*T.a.*	3	3	17	1	18	—	VBGI
61	KhD, Lake Talmi	VIII.1975	*T.m.*	1	1	3	1	33	+	VLA
Total / [Average]		*T.a. – 33; T.t. – 14; T.m. – 10; T.max. – 1; T.d. – 1; T.k. – 1; T.p. – 1*		280	170	1052	[1,2±0,1]	[22,7±8,2]	— 44 + 17	VBGI – 32 VLA – 29

[1]№ h.s. – herbarium sheet number. [2]Administrative districts: CD – Chuguyevskii, KhabD – Khabarovskii, KhD – Khasanskii, KhoD – Khorolskii, KovD – Kovalerovskii, KrD – Krasnoarmeyskii, LD – Lazovskii, PaD – Partizanskii, PoD – Pogranichnyi, ShD – Shkotovskii, TD – Terneiskii, UD – Ussurijskii, KAMD – Komsomolsk-na-Amure, SGD – Sovetsko-Gavanskii districts. Nature reserves and stations: BNR – Bolshekhekhtsirskii Nature Reserve, KNR – Komsomolskii Nature Reserve, LNR – Lazovskii Nature Reserve, SANR – Sikhote-Alin Nature Reserve, TMS – Mountain-Taiga Station, UNR – Ussurijskii Nature Reserve, ZNR – Zeya Nature Reserve, ZTNP – "Zov Tigra" National Park. Other conjunctions: MAP – Muravyov-Amurskii Peninsula, Vlad. – Vladivostok, v. – village; R. – River, Mts – mountains, Isl. – Island. [3]*Tilia* species: *T.a. – T. amurensis*, *T.d. – T. divaricata, T.k. – T. koreana, T.m. – T. mandshurica, T.max. – T. maximowicziana; T.p. – T. pekinensis, T.t. – T. taquetii.* [4]Presence of insects in the mines: — no insect in the mine, + present. ‡ – reidentified as *T. taquetii* by V. Nedoluzhko in 1984; †Larvae were heavily attacked by parasitoids.