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Review of the *Aphrophora salicina* (Goeze, 1778) (Homoptera: Cercopoidea: Aphrophoridae) species group of Russia and adjacent territories with description of a new species

Обзор видов группы *Aphrophora salicina* (Goeze, 1778) (Homoptera: Cercopoidea: Aphrophoridae) России и сопредельных территорий с описанием нового вида

D.Yu. Tishechkin
Д.Ю. Тишечкин

Department of Entomology, Faculty of Biology, M.V. Lomonosov Moscow State University, Vorobyevy Gory, Moscow 119234, Russia. E-mail: macropsis@yandex.ru

Кафедра энтомологии Биологического факультета Московского государственного университета имени М.В. Ломоносова, Воробьёвы горы, Москва 119234, Россия.

KEY WORDS: froghoppers, taxonomy, morphology, vibrational signals, distribution, synonymy, Kazakhstan, Central Asia.

КЛЮЧЕВЫЕ СЛОВА: пенницы, систематика, морфология, вибрационные сигналы, распространение, синонимия, Казахстан, Средняя Азия.

ABSTRACT. A study of the male calling signals of species of the *Aphrophora salicina* group in Russia, Kazakhstan, and Kyrgyzstan showed that three species of this group occur in this territory. *A. salicina* (Goeze, 1778) = *A. pectoralis* Matsumura, 1903 **syn.n.** occurs throughout Russia and in Kazakhstan and Central Asia. *A. willemsi* Lallemand, 1946 previously misidentified by European authors as *A. pectoralis* = *A. costalis* Matsumura, 1903 is distributed in the central regions of European Russia and in Siberia eastwards at least to Buryatia. *A. itiliensis* **sp.n.** so far was found only in the Lower Volga region. All three species distinctly differ in the calling signal temporal patterns and can occur in the same locality. In morphological traits, *A. salicina* and *A. willemsi* differ from each other in the length of the ovipositor and the length of the hairs on the forewings; *A. itiliensis* **sp.n.** differs from these species in the shape of the pygofer processes.

РЕЗЮМЕ. Исследование призывных сигналов самцов видов группы *Aphrophora salicina* в России, Казахстане и Кыргызстане показало, что на данной территории обитает три вида этой группы. *A. salicina* (Goeze, 1778) = *A. pectoralis* Matsumura, 1903 **syn.n.** встречается по всей территории России, а также в Казахстане и в Средней Азии. *A. willemsi* Lallemand, 1946, ранее ошибочно определенный европейскими авторами как *A. pectoralis* = *A. costalis* Matsumura, 1903, распространен в центральных районах Европейской России и в Сибири на восток по крайней мере до Бурятии. *A. itiliensis* **sp.n.** пока обнаружен только в Нижнем Поволжье. Все три вида четко различаются по временному рисунку призывных сигналов самцов и могут встречаться в одной географической точке. Морфологически *A. salicina* и *A. willemsi* различаются длиной яйцеклада и длиной волосков на надкрыльях; *A. itiliensis* **sp.n.** отличается от этих видов формой отростков пигофора.

Introduction

For a long time, it was believed that *Aphrophora salicina* (Goeze, 1778) (Homoptera: Cercopoidea: Aphrophoridae) has no closely related species in Europe. In the middle of the XX century a related species, *A. willemsi* Lallemand, 1946, was described from Belgium. However, later it was not found anywhere by any authors.

Ossiannilsson [1981] in his famous monograph on Auchenorrhyncha of Fennoscandia and Denmark, indicated that, in addition to *A. salicina*, a closely related species, *A. costalis* Matsumura, 1903, described from Hokkaido, Japan, occurs in Europe. He showed that these species differ in the length of the ovipositor, coloration, and the length of the hairs on the forewings, but are indistinguishable in the shape of the male genitalia. Komatsu [1997b] reinvestigated the type specimens of *Aphrophora* from the Matsumura collection and established a synonymy *A. pectoralis* Matsumura, 1903 = *A. costalis* Matsumura, 1903.

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Van Stalle [1989] studied the types of *A. willemsi* and concluded that this name is a junior synonym of *A. alpina* Melichar, 1900, of which he did not investigated types; it should be noted that presently, *A. alpina* is considered a junior synonym of *A. major* Uhler, 1896 described from Japan. Later, Liang [2006] also reinvestigated the types of *A. willemsi* and established the synonymy *A. salicina* = *A. willemsi*. In his article, he does not mention the work of Van Stalle [1989] and, apparently, did not know about its existence.

In the east of the Palearctic, the genus *Aphrophora* includes a large number of closely related species [Anufriev, Emelyanov, 1988; Komatsu, 1997a, b, c]. In this regard, we performed a comparative study of the male calling signals of six species of this genus in Primorsky Krai and revealed signal traits suitable for species diagnostics. It was shown that in species producing long single or irregularly repeated signals, including the members of the *A. salicina* species group, the most reliable signal traits are the temporal pattern and the repetition period of syllables [Tishechkin, 2011]. Subsequently, we continued the investigation of *Aphrophora* signals in European Russia, Siberia, Kazakhstan, and Central Asia. This made it possible to clarify the status of *A. willemsi* and obtain new data on its distribution, establish a new synonym, and reveal an undescribed species from the *A. salicina* species group. The results of these studies are presented below.

Material and methods

Froghopper vibrational signals were recorded by means of portable recording equipment consisting of a piezocrystal gramophone cartridge GZP-311 connected to the microphone input of a cassette recorder Elektronika-302 (before 2005), minidisk recorder Sony Walkman MZ-NH900 (2005–2016), or Roland R-05 wave/mp3 recorder (since 2017) via a custom-made matching amplifier. For recording, a stem of the host plant about 10–15 cm in length was attached to the cartridge by a rubber ring with the cartridge needle slightly touching the stem. Then a nylon cage containing a male froghopper was put on the twig. After some time, the male usually sat on the twig and started singing.

Oscillograms of signals were produced with Cool Edit Pro 2.1 software.

For elements of signal temporal pattern, the following terms are used. **Pulse** is a brief elementary fragment of signal (or succession of sine waves) with rapid increase and subsequent decrease of amplitude, i.e. separated from similar fragments by amplitude minimums. Short fragments with constant temporal pattern repeated with regular intervals and consisting of uniform or different pulses are referred to as **syllables**. Any more or less prolonged signal with complex pattern (e.g. succession of similar or different syllables) is referred to as a **phrase**.

Digital images of male genitalia were obtained with a Micromed 3 LED M microscope equipped with a MIchrome 5 Pro camera (Tucsen). The map of signal recording localities was produced using free software from www.simplemappr.net.

Materials studied, including the type series of the new species, are deposited in the collection of the Zoological Museum of M.V. Lomonosov Moscow State University.

Small Auchenorrhyncha use for intraspecific communication vibrational signals transmitted via plant stems or leaves on which the insects occur. The differences in the structure of the calling signals emitted by males to attract conspecific females constitute the principal precopulatory reproductive barrier in this group. Species that do not perceive each other's signals due to allopatry or differences in host specialization can produce signals with an almost identical temporal patterns, so the similarity of signals is not always the basis for establishing synonymy. On the other hand, clear differences in signal patterns always indicate that the studied taxa are biological species (review: Tishechkin [2013]). Therefore, when differentiating close forms by their signals, one can actually discriminate between biological species based on the very criterion of their reproductive isolation.

Based on this, at the first stage of research, we recorded the signals of *Aphrophora* spp. from different host plants and from different geographic locations. Comparative analysis of signal patterns made it possible to divide the collected material into three biological species (Fig. 1–32). The morphological study of individuals whose signals were recorded, in turn, made it possible to reveal morphological traits for species diagnostics and, consequently, for the identification of specimens for which no signal recordings exist.

Species of the *A. salicina* group of Russia, Kazakhstan, and Central Asia

Aphrophora salicina (Goeze, 1778)
Figs. 1–11, 17–26, 32–38, 43, 46–47, 52–58

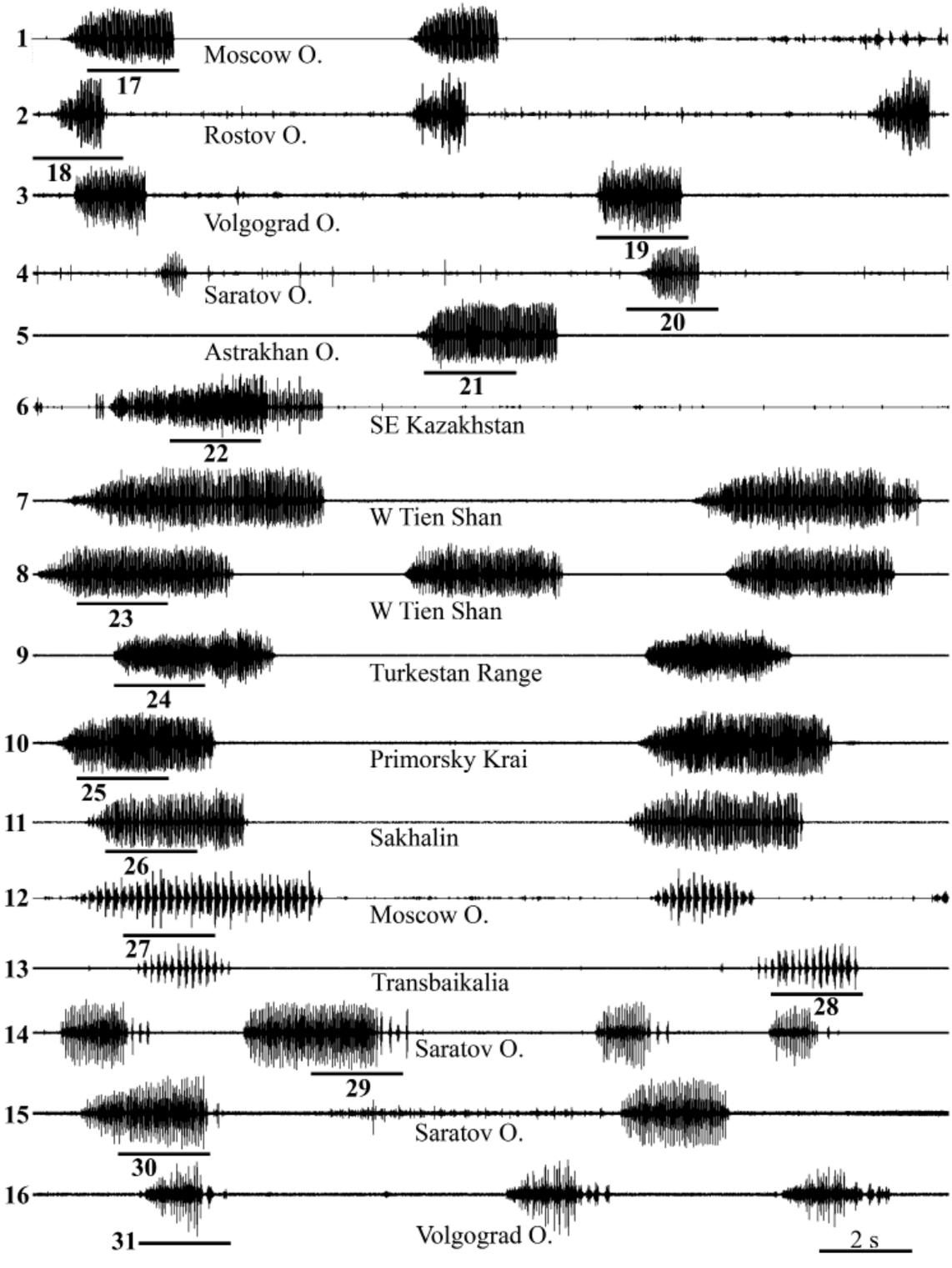
A. pectoralis Matsumura, 1903, **syn.n.**

MALE CALLING SIGNALS. Calling signal is a phrase lasting from about 1 up to 5–6 s (Figs 1–11). In males from European Russia, on average, phrases are shorter, than in males from Central Asia and the Russian Far East (cf. Figs 1–5 and 6–11), but it is impossible to clearly distinguish between European and Asian populations based on this trait. The male can produce phrases irregularly or with intervals from 4–5 up to several tens of seconds. The phrase consists of uniform syllables, normally including three pulses each (Figs 17–19, 21–26); only very occasionally some syllables consist of two pulses (Fig. 20).

The most constant signal trait is the syllable repetition frequency, although, like in all other insects, it increases with temperature. We investigated the signals of *A. salicina* from the central and southern regions of European Russia, from Kyrgyzstan, southeastern Kazakhstan, and from the Russian Far East (Fig. 32). Throughout this vast territory, this parameter remained constant and averages 12–13 syllables/s at 22 °C, 15 syllables/s at 23–24 °C, and 16–17 syllables/s at 27–31 °C.

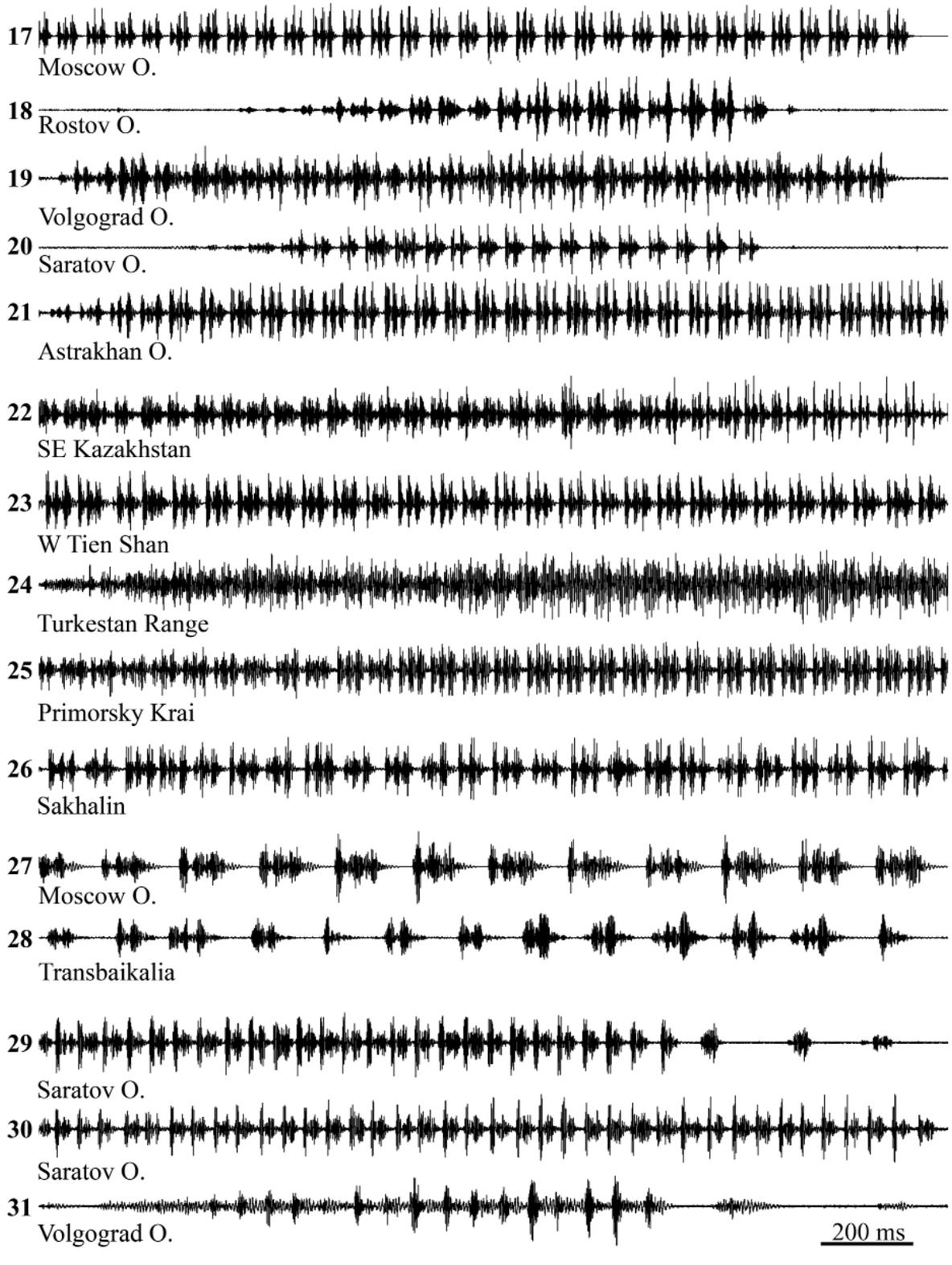
DESCRIPTION. Yellowish brown with lighter area at the base of the costal margin of the forewing (Figs 33–36). Specimens from the Russian Far East are darker, with yellowish spot at the base of costal margin (Figs 37–38). Thus, contrary to the assertions of some authors, in particular, Ossiannilsson [1981], a yellowish spot at the base of the costal margin cannot be used as a reliable trait for species diagnostics, since it is not always developed. This fact was also pointed out by Komatsu [1997b].

The hairs on the forewings are about two to three times as long as punctures (Fig. 43) (about one and a half to two times as long as punctures in two other species; Figs 44–45). The end of the ovipositor does not extend or only slightly extends beyond the end of the anal tube (Figs 46–47). Pygofer appendages widened in the middle or somewhat distally, with narrow apices (Figs 52–55). Styles and penis of the same shape as in other species of the *A. salicina* group (cf. Figs 56–58, 60–61, 66–69).



Figs 1–16. *Aphrophora* spp., male calling signal oscillograms. 1–11 — *A. salicina*; 12–13 — *A. willemsi*; 14–16 — *A. itiliensis* **sp.n.** Faster oscillograms of the parts of signals indicated as "17–31" are given under the same numbers, signal recording localities are given under the oscillograms. Scale mark at the bottom is the same for all oscillograms.

Рис. 1–16. *Aphrophora* spp., осциллограммы призывных сигналов самцов. 1–11 — *A. salicina*; 12–13 — *A. willemsi*; 14–16 — *A. itiliensis* **sp.n.** Фрагменты сигналов, помеченные цифрами "17–31", представлены при большей скорости развёртки на осциллограммах под соответствующими номерами, места сбора насекомых для записи сигналов указаны под осциллограммами. Отметка времени внизу общая для всех осциллограмм.



Figs 17–31. *Aphrophora* spp., male calling signal oscillograms. 17–26 — *A. salicina*; 27–28 — *A. willemsi*; 29–31 — *A. itiliensis* **sp.n.** Signal recording localities are given under the oscillograms. Scale mark at the bottom is the same for all oscillograms.

Рис. 17–31. *Aphrophora* spp., осциллограммы призывных сигналов самцов. 17–26 — *A. salicina*; 27–28 — *A. willemsi*; 29–31 — *A. itiliensis* **sp.n.** Места сбора насекомых для записи сигналов указаны под осциллограммами. Отметка времени внизу общая для всех осциллограмм.

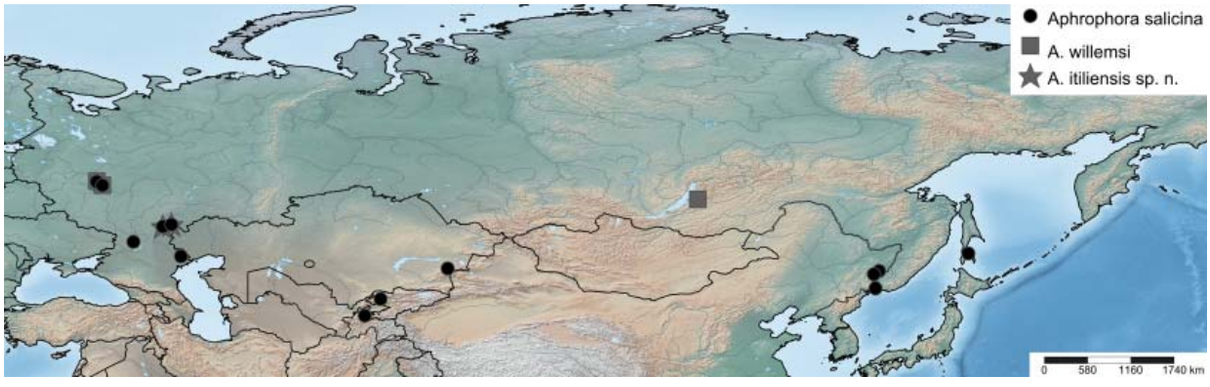


Fig. 32. Map of froghopper signal recording localities.
Рис. 32. Точки сбора насекомых для записи сигналов.

Body length (including tegmina): ♂, 8.8–10.1 mm; ♀, 10.0–10.9 mm.

DIAGNOSIS. Differs from two other species of the *A. salicina* group by the male calling signal pattern and longer hairs on the forewings. Also differs from *A. willemsi* by shorter ovipositor and from *A. itiliensis* **sp.n.** by widened pygofer processes (of almost equal width throughout all their length, with widely rounded apices in *A. itiliensis* **sp.n.**).

HOST PLANTS. Was collected from *Salix vinogradovii* A.K. Skvortsov, *S. alba* L., and *S. schwerinii* E.L. Wolf in Russia, from unidentified *Salix* sect. *Helix*, *S. wilhelmsiana* M. Bieb., *S. tenuijulis* Ledeb., and *S. niedzwieckii* Goerz in Kyrgyzstan; apparently, can feed on many other willow species. Also, dense population of *A. salicina* was found on *Populus laurifolia* Ledeb. in southeastern Kazakhstan.

DISTRIBUTION. Transpalearctic; the northern limits of the range are unclear.

REMARKS. Identification of *A. pectoralis* is based on the works of Anufriev, Emelyanov [1988] and Komatsu [1997b] and on investigation of morphology and calling signals of specimens from Primorsky Krai and southern Sakhalin. Comparison of the materials, including signal recordings, from the Russian Far East and from European Russia showed that *A. pectoralis* is conspecific with *A. salicina*.

A species with a longer ovipositor and shorter hairs on the forewings mentioned by Ossiannilsson (1981) and subsequent authors (e.g., Van Stalle, 1989; Biedermann, Niedringhaus, 2009; Anufriev, 2017) under the name *A. costalis* = *A. pectoralis* is actually a misidentified *A. willemsi* (see below).

Aphrophora willemsi Lallemand, 1946, **stat.rest.**
Figs. 12–13, 27–28, 32, 39–41, 44, 48–50, 59–62

MALE CALLING SIGNALS. In general, the pattern of the calling signal is the same as in *A. salicina*, but the syllable repetition frequency is almost half as much and averages 7–8 syllables/s at 24–27 °C, 8–9 syllables/s at 28–29 °C, and 9–10 syllables/s at 31 °C (Figs 12–13, 27–28).

DESCRIPTION. Similar to *A. salicina*, but the yellowish spot in the basal part of the costal margin of the forewing is usually more distinct (Figs 39–41).

The hairs on the forewings are about one and a half to two times as long as punctures (Fig. 44). The end of the ovipositor extends far beyond the end of the anal tube (Figs 48–50). As in *A. salicina*, pygofer appendages widened in the middle or somewhat distally, with narrow apices (Figs 59, 62). Styles and penis of the same shape as in other species of the *A. salicina* group (Figs 60–61).

Body length (including tegmina): ♂, 8.9–9.8 mm; ♀, 9.9–10.5 mm.

DIAGNOSIS. Differs from two other species of the *A. salicina* group by the male calling signal pattern and longer ovipositor. Also differs from *A. salicina* by shorter hairs on the forewings and from *A. itiliensis* **sp.n.** by widened pygofer processes (of almost equal width throughout all their length, with widely rounded apices in *A. itiliensis* **sp.n.**).

HOST PLANTS. Was collected from *S. cinerea* L., unidentified *Salix* sect. *Vetrix*, *S. purpurea* cultivar "nana", and *S. alba* in Moscow Oblast and on unidentified *Salix* species in Transbaikalia. Obviously, like *A. salicina*, can also feed on many other willow species. In Moscow Oblast, sometimes was found on the same plant with *A. salicina*.

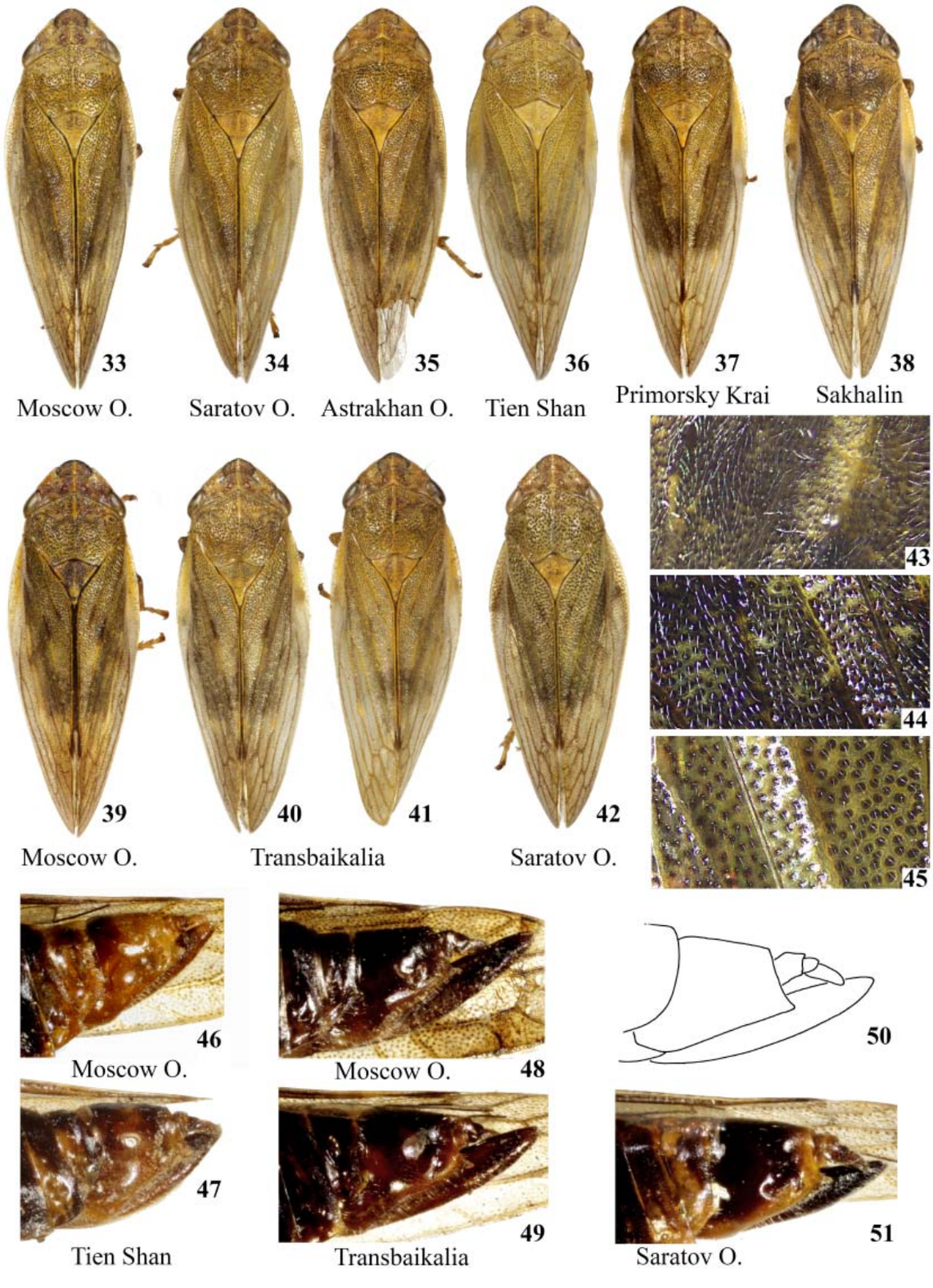
DISTRIBUTION. Western Europe, European Russia southwards at least to the northern border of Volgograd Oblast (Shcherbatovka about 50 km north-north-east of Kamyshin), Western Siberia (Tomsk, Tyumen, and Kemerovo Oblasts), Transbaikalia (Buryatia). Until now, was not found in Central Asia and in the Russian Far East.

REMARKS. *A. willemsi* is the only European species of the *A. salicina* group with such a long ovipositor. Identification of this species is based on descriptions, drawings, and photo of the holotype in Van Stalle [1989] and Liang [2007]; both on the drawing in Van Stalle [1989] (reproduced on Fig. 50) and on the photo in Liang [2007] long ovipositor is distinctly visible.

Distinct differences between the male calling signal patterns of *A. salicina* and *A. willemsi* from the same locality and host indicate that these taxa are different biological species.

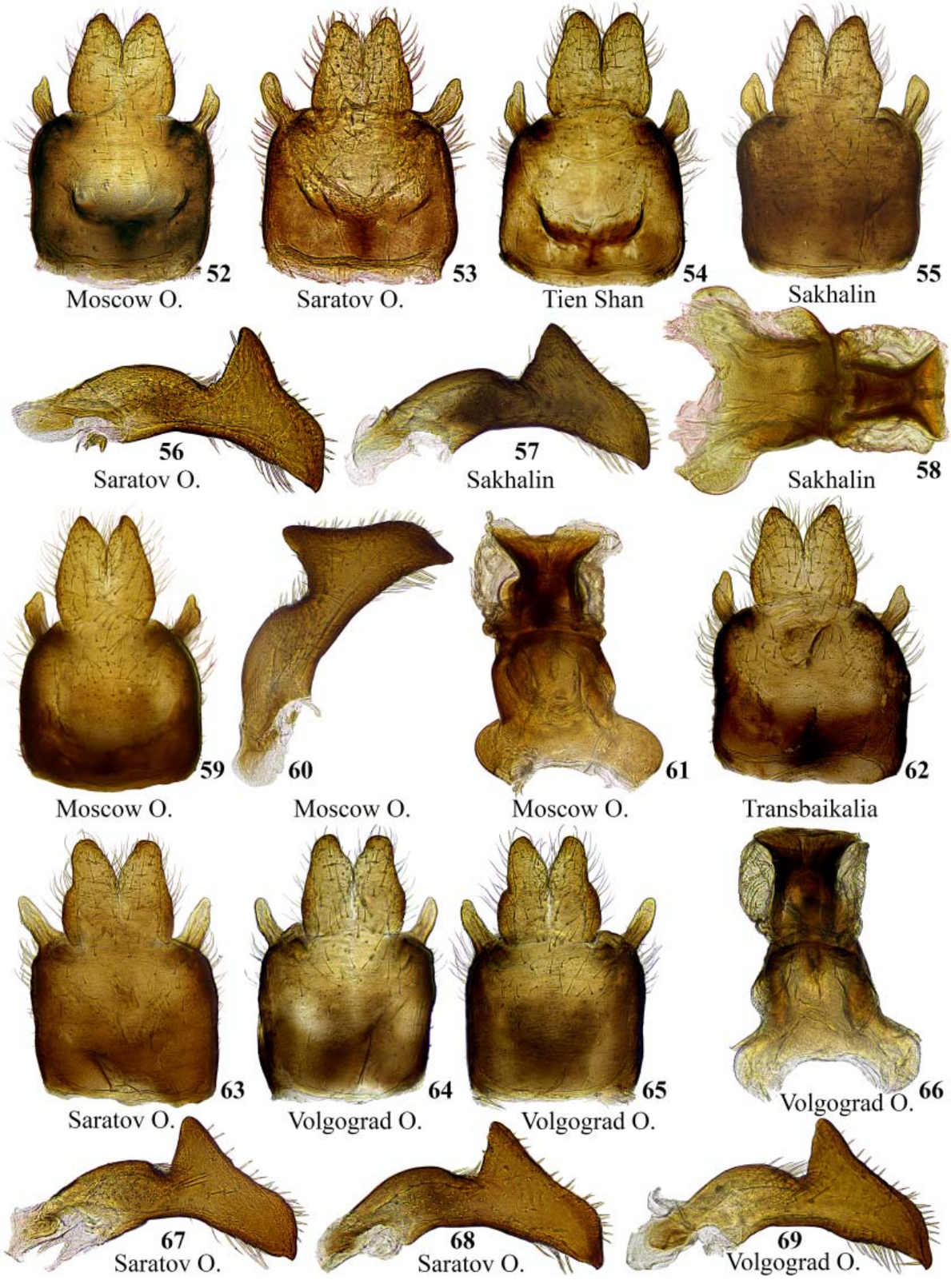
Male calling signals of *A. major* from the Russian Far East (described in Tishechkin, 2011) distinctly differ from the signals of *A. willemsi* from Moscow Oblast and Transbaikalia in the syllable temporal pattern and repetition frequency. Also, *A. major* has another shape of the genital plates and is much larger (body length in male 11.0–13.2 mm, in female 12.2–14.0 mm). All this indicates that synonymization of these species by Van Stalle [1989] is erroneous.

Signals of *A. willemsi* and *A. obliqua* Uhler, 1896 (described in Tishechkin, 2011) are very similar. Still, *A. obliqua* Uhler, 1896 is a smaller species (body length in male 7.5–8.0 mm, in female 7.8–8.3 mm) with quite another coloration and shape of head and pygofer appendages. It occurs in the southern part of the Russian Far East (Primorsky Krai), south-eastern China, Korea, and Japan. Thus, it is allopatric with *A. willemsi*. Due



Figs 33–51. *Aphrophora* spp. 33–38, 43, 46–47 — *A. salicina*; 39–41, 44, 48–50 — *A. willemsi*; 42, 45, 51 — *A. itiliensis* **sp.n.** 33–42 — dorsal habitus; 43–45 — hairs on the forewing; 46–51 — end of female abdomen, lateral view. Collection localities are given under the photos. 50 — holotype, after Van Stalle [1989].

Рис. 33–51. *Aphrophora* spp. 33–38, 43, 46–47 — *A. salicina*; 39–41, 44, 48–50 — *A. willemsi*; 42, 45, 51 — *A. itiliensis* **sp.n.** 33–42 — вид сверху; 43–45 — волоски на переднем крыле; 46–51 — конец брюшка самки сбоку. Места сбора указаны под фотографиями. 50 — голотип, по Ван Сталле [Van Stalle, 1989].



Figs 52–69. *Aphrophora* spp., male genitalia. 52–58 — *A. salicina*; 59–62 — *A. willemsi*; 63–69 — *A. itiliensis* **sp.n.** 52–55, 59, 62–65 — pygofer, ventral view; 56–57, 60, 67–69 — style; 58, 61, 66 — penis, dorsal view. Collection localities are given under the photos.

Рис. 52–69. *Aphrophora* spp., гениталии самца. 52–58 — *A. salicina*; 59–62 — *A. willemsi*; 63–69 — *A. itiliensis* **sp.n.** 52–55, 59, 62–65 — пигофор, вид снизу; 56–57, 60, 67–69 — стилус; 58, 61, 66 — пенис, вид сверху. Места сбора указаны под фотографиями.

to this fact, these taxa do not come into acoustic contact, and, consequently, the similarity of temporal patterns of their signals does not prevent their existence as different biological species.

Aphrophora itiliensis Tishechkin, **sp.n.**
Figs. 14–16, 29–32, 42, 45, 51, 63–69

MATERIAL EXAMINED. Holotype, male, Russia, Transvolga part of Saratov Oblast, environs of Dyakovka village, from *Salix cinerea*, 12.VII.2004, D. Tishechkin, calling signals recorded at 26–29 °C; paratypes: same locality, date, host, and collector, 3 ♂♂, calling signals recorded at 26–29 °C; same locality, host, and collector, 10.VII.2004, 1 ♂; same locality and collector, from *S. vinogradovii*, 13.VII.2004, 1 ♂; Russia, northern part of Volgograd Oblast, Kamyshin Region, environs of Shcherbatovka village, Shcherbakovsky National Park, from *S. cinerea*, 11.VII.2005, D. Tishechkin, 1 ♀; same locality, host, and collector, 12.VII.2005, 3 ♂♂, calling signals recorded at 22–23 °C; same locality, host, and collector, 13.VII.2005, 1 ♂, 3 ♀♀.

MALE CALLING SIGNALS. Calling signal is a phrase lasting for about 1–4 s (Figs 14–16). Usually, the male produces several phrases separated by gaps averaging from 2–3 up to 10 s. The phrase is a succession of syllables; each syllable consists of one shorter higher-amplitude pulse followed by longer lower-amplitude one (Figs 29–31). Syllable repetition frequency averages 19–20 syllables/s at 26–29 °C and 16 syllables/s at 22–23 °C. As a rule, at the end of the phrase there are 2–4 syllables of another shape, following each other with longer intervals.

DESCRIPTION. Similar to *A. salicina* and *A. willemsi* but coloration grayish, almost without yellowish tinge even at the base of the costal margin of the forewings (Fig. 42).

The hairs on the forewings only slightly exceed the diameter of punctures (Fig. 45). The end of the ovipositor does not extend or only slightly extends beyond the end of the anal tube (Fig. 51). Pygofer appendages elongated, of almost equal width throughout all their length, with widely rounded apices (Figs 63–65). Styles and penis of the same shape as in other species of the *A. salicina* group (Figs 66–69).

Body length (including tegmina): ♂, 8.5–9.4 mm; ♀, 9.7–10.2 mm.

DIAGNOSIS. Distinctly differs from other species of the *A. salicina* group by another male calling signal pattern and longer pygofer appendages without expansion near the middle and with widely rounded apices (widened near the middle, with narrow tips in other members of this group).

DISTRIBUTION. The Lower Volga region, Saratov and Volgograd Oblasts. Despite repeated searches, was not found in the Moscow Oblast. On the other hand, further findings in the southern regions of European Russia seems to be quite probable.

HOST PLANTS. Was found mainly on *S. cinerea*, both on single-growing bushes and in mixed thickets of several willow species; only once single male was collected from *S. vinogradovii*.

ETYMOLOGY. The name of the new species derives from the name Itil, the ancient name of the Volga River in the Turkic languages. It is given because this species was collected in the Lower Volga region.

Thus, in Russia and adjacent territories, the *A. salicina* group includes three taxa. Distinct differences in the calling signal temporal patterns and the fact that in some localities these taxa are sympatric and can even live on the same plant, convincingly indicate that they are good biological species. Distinguishing between these species by coloration is very difficult. *A. salicina* and *A. willemsi* differ from each other in the length of the ovipositor and the length of the hairs on the forewings; *A. itiliensis* **sp.n.** differs from these species in the shape of the pygofer processes.

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