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Calling Signals Emitted by Males of Cixiidae (Homoptera, Cicadinea) as Compared with Acoustic Signals of Some Other Fulgoroidea (Homoptera, Cicadinea, Fulgoroidea)

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Abstract—A comparative study of calling signals emitted by males of 10 Cixiidae species, belonging to 6 genera, and 13 species of Delphacidae, Dictyopharidae, Issidae, and Tropiduchidae was carried out. Calling signals of most Cixiidae are rather simple in their temporal structure; no rivalry behavior and relevant signal types are observed in this family. On the contrary, in a closely related family Delphacidae, males display a well-developed rivalry behavior and produce both territorial and aggressive signals; their calling signals generally have a complex amplitude-temporal structure. The acoustic communication in most other Fulgoroidea taxa studied follows the pattern observed in Cixiidae.

Fulgoroidea, comprising more than half of Cicadinea families (about 17), occupy the second place among its 4 superfamilies with respect to the species number. Like all Cicadinea, Fulgoroidea have a well-developed system of acoustic communication; however, descriptions of signals have only been published for representatives of 3 families: one species of Dictyopharidae, *Dictyophara europaea* L. (Strubing, 1977; Strubing and Rollenbach, 1992); some Cixiidae species (Howarth *et al.*, 1990; Hoch and Asche, 1992; Hoch and Howarth, 1993); and about 30 Delphacidae species belonging to 2 subfamilies, Kelisiinae and Delphacinae. Thus, only the last family may be considered rather well studied. The present state of Cixiidae studies is quite strange: although the group has a cosmopolitan distribution and is also well represented in moderate latitudes, the vibration communication has only been studied in very peculiar forms inhabiting lava caves on Hawaii. Like most Cicadinea, the cave-dwelling forms have a bilateral communication: when looking for a mate, the male and female sing in turn and find each other in the course of this exchange. The temporal structure of the signals proved to be very simple in both sexes: all the species emit short (ca. 1–3 s) trills of pulses. At the same time, in the closely related Delphacidae, sometimes considered as a sister-group of Cixiidae, the calling signals are often very complicated phrases consisting of many parts. According to Hoch and Asche (1992), the signal structure is secondarily simplified in relation with such general reduction trends as gradual loss of vision and flight and weakening of pigmentation due to living in caves, or with a reduced number of acoustically active sympatric species.

The aim of this work was a comparative study of calling signals emitted by males of Cixiidae, which would provide a general outline of their structure for the entire family. The female reply signals in most Cicadinea, including Cixiidae, generally have a rather simple temporal structure and often lack distinct species-specific features. This can be explained by the fact that a female recognizes a conspecific mate; the primary function of female signals is to attract a spontaneously singing male and prevent it from leaving the plant. In addition, in order to record the reply signals, receptive females are to be reared separately from males; in the case of Cixiidae this is an especially difficult task, since their larvae have a sheltered way of life and are very rarely found in nature. Because of this, only spontaneous male signals were studied in the first stage of the investigation.

MATERIALS AND METHODS

The insects were collected by sweeping on vegetation. The list of species studied, including the collection localities and temperatures during the recording, is given in the table.

The signals were recorded using a GSP-311 piezocrystal sound-receiver (pick-up) or a similar device, connected to a cassette recorder via an amplifier. One or (less frequently) 2–3 males were placed in a nylon

List of investigated species of Fulgoroidea, with collection locality and temperature during signal recording indicated

Species*	Collection locality	Temperature during signal recording, °C
Family CIXIIDAE		
Cixius cunicularius L.	Moscow Province, environs of Mytishchi, on *Salix cinerea*	24
C. intermedius Scott	N Osetiya, Alagir, Ardon River floodlands, on sea buckthorn	25
Myndus musivus Germ.	Moscow Province, Oka River floodlands, environs of Luzhki (Serpukhov District), on *Salix viminalis*	26
Pentastiridius pallens Germ.	Turkmenia, environs of Dushak, on reed	31
P. kaszabianus Dlab.	S Primorye (Maritime Area = Primorsk Territory), Pogranichnyi District, environs of Barabash-Levada, on *Spiraea salicifolia*	23
P. leporinus L.	E Saratov Province, 10 km E of Ozinki by the road to Ural'sk	26–27
Reptalus concolor Fieb.	Environs of Almaty, steppe slopes of Zaili Alatau foothills	31
R. quinquecostatus Duf.	Volgograd Province, Ilovlya River, 5–7 km down the river from Ilovlya station	24–25
Setapius apiculatus Fieb.	Guberlya River bank near Guberlya station (25 km W of Omsk), steppe on hills, in *Spiraea hypericifolia* and *Caragana* sp.	26
Hyalestes obsoletus Sign.	SE Azerbaijan, environs of Lerik.	20–22
Family DELPHACIDAE		
Kelisia ribauti Wagn.	N Osetiya, Ardon River Basin, Tseiskoye Canyon, spring bog at Nizhnii Tsei, on sedge.	22
Stenocranus major Kbm.	Moscow Province, environs of Pirogovo, Klyaz'ma River bank, on *Phalaroides arundinacea*	25
Megamelus notula Germ.	Moscow Province, environs of Beloozerskii (Voskresensk District), Moskva River floodlands	20
Stiroma bicarinata H.-S.	Moscow Province, environs of Pirogovo	25
Struebingianella lugubrina Boh.	Moscow Province, environs of Naro-Fominsk	
Javesella obscurella Boh.	"	26
J. stali Metc.	Moscow Province, environs of Pirogovo	25
Family DICTYOPHARIDAE		
Dictyophara multireticulata M. R.	Rostov Province, Obliv District, environs of Sosnovyi, on oak.	26
Phyllorgerius jacobsoni Osh.	Environs of Almaty, steppe slopes of Zaili Alatau foothills	30
Sphenocratus hastatus Osh.	20 km E of Almaty, environs of Chemalgan, wormwood-grass steppe	30
Family ISSIDAE		
Alloscelis vittifrons Iv.	Rostov Province, Obliv District, environs of Sosnovyi	30–31
Scorlupaster asiaticum Leth.	Turkmenia, environs of Dushak, on *Alhagi persarum*	30
Family TROPIDUCHIDAE		
Trypetimorpha occidentalis Huang, Bourgoin	Rostov Province, Obliv District, environs of Sosnovyi	30

* The species *Reptalus concolor* Fieb. and *Scorlupaster asiaticum* Leth. were considered according to Mityaev (1972); *Cixius intermedius* Scott and *Setapius apiculatus* Fieb. (*S. fumatipennis* Dlab.), according to Logvinenko (1975). In identifying *Hyalestes obsoletus* Sign., the work by Hoch and Remane (1985) was taken into account.

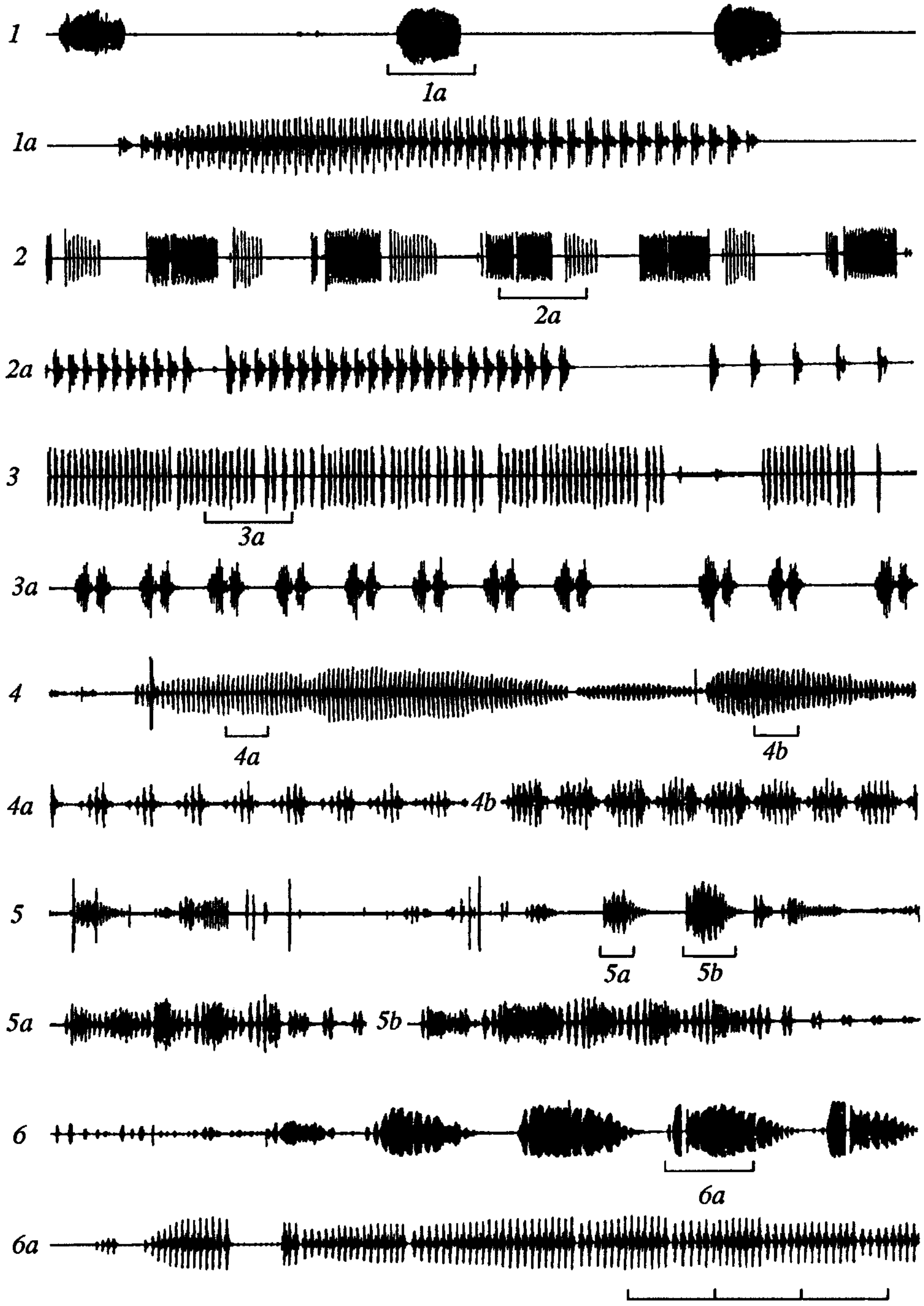

Fig. 1. Oscillograms of calling signals in Cixiidae: (*1, 1a*) *Cixius cunicularius* L.; (2, *2a*) *C. intermedius* Scott; (*3, 3a*) *Myndus musivus* Germ.; (*4, 4a, 4b*) *Pentastiridius pallens* Germ.; (*5, 5a, 5b*) *P. leporinus* L.; (*6, 6a*) *P. kaszabianus* Dlab. Letters *a* and *b* at numbers designate signal fragments shown at expanded time-base. Scale bar: 2 s for *1, 2, 3, 4, 5, 6* and 200 ms for *1a, 2a, 3a, 4a, 4b, 5a, 5b, 6a.*

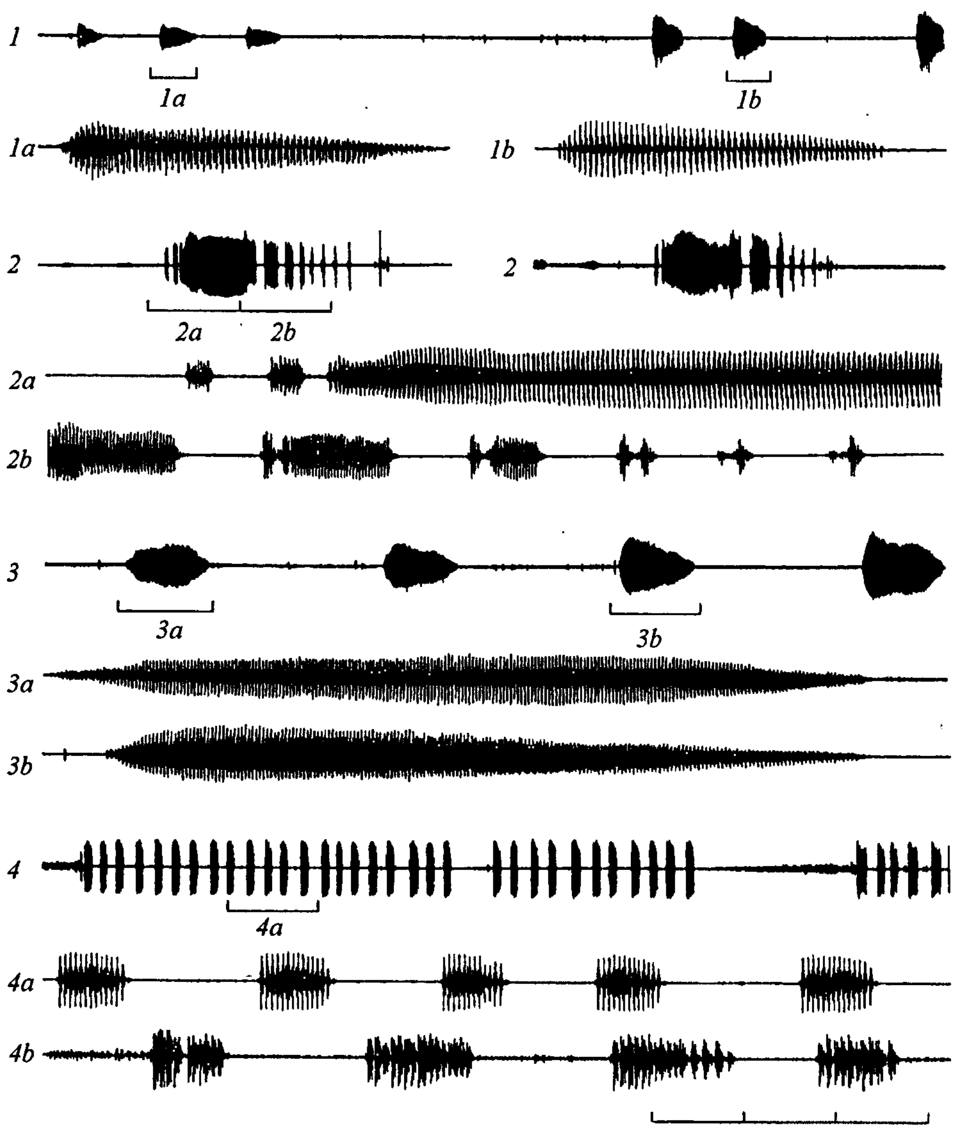

Fig. 2. Oscillograms of calling signals in Cixiidae: (*1, 1a, 1b*) *Reptalus concolor* Fieb.; (*2, 2a, 2b*) *R. quinquecostatus* Duf.; (*3, 3a, 3b*) *Setapius apiculatus* Fieb.; (*4, 4a, 4b*) *Hyalestes obsoletus* Sign. Letters *a* and *b* at numbers designate signal fragments shown at expanded time-base. Scale bar: 2 s for *1, 2, 3, 4* and 200 ms for *1a, 1b, 2a, 2b, 3a, 3b, 4a, 4b*.

cage attached to a short (usually 10–15 cm long) stem of a food plant in such a way that the stem tip protruded from the cage. The stem tip was fixed to the receiver with a thin rubber ring, so that it touched the receiver needle with a slight tension. The receiver and plant were placed on a porolon sheet to reduce noise vibrations. Signals were analyzed using an IBM PC AT equipped with an analog-digital converter.

In all, signals were studied for 10 Cixiidae species, belonging to 6 genera and 3 tribes (Cixiini, Pentastirini, and Oecleini). Oscillograms of signals of 13 species belonging to the families Delphacidae, Dictyopharidae, Issidae, and Tropiduchidae are provided for comparison.

RESULTS AND DISCUSSION

Only one functional type of signals, the calling signals, was observed in males of Cixiidae. A male usually sings while moving over the plant and emits one or several signals following each run or jump. When staying in the same place for a long time, it usually emits signals much more rarely. Such a communication strategy, termed the "call-fly strategy" (Hunt and Nault, 1991) was first described in *Graminella nigri-*

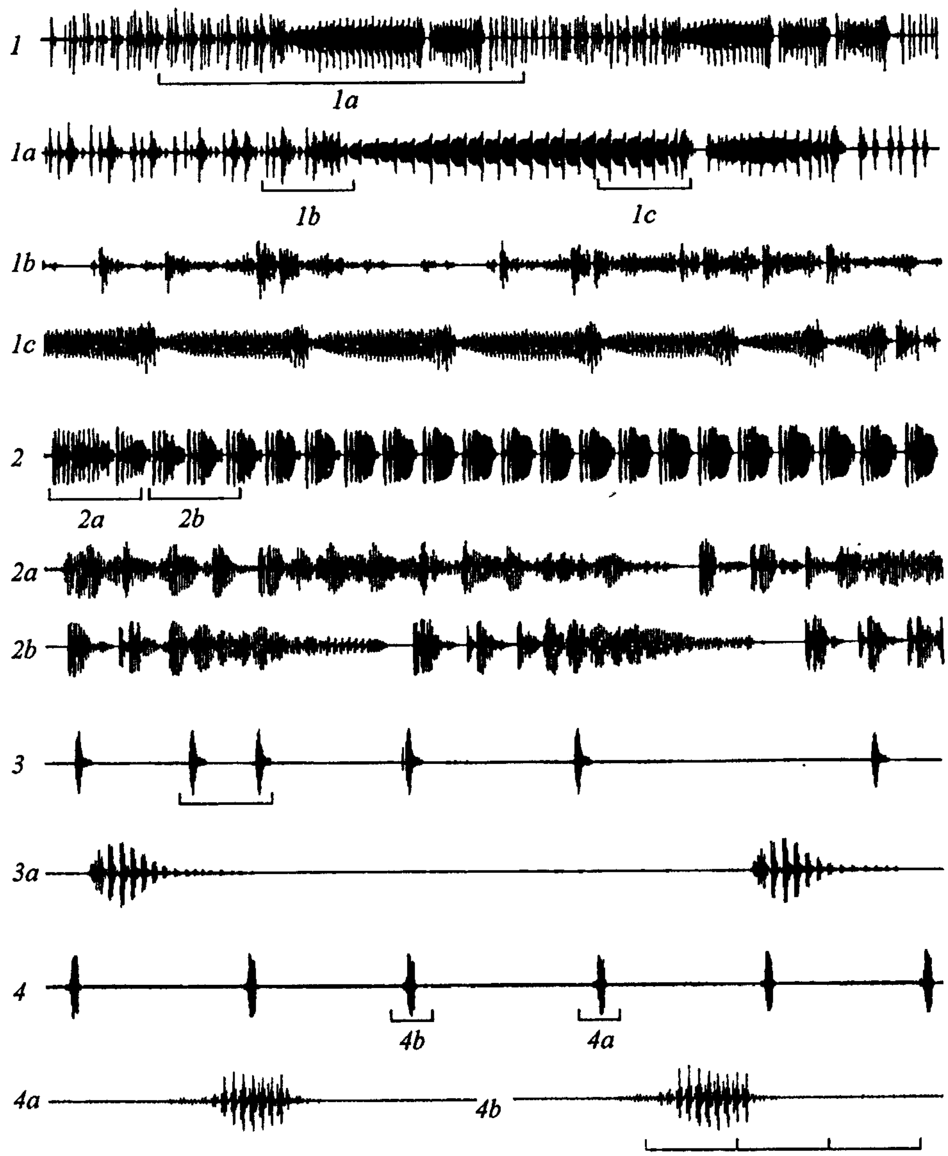

Fig. 3. Oscillograms of calling signals in Delphacidae: (*1, 1a, 1b, 1c*) *Kelisia ribauti* Wagn.; (*2, 2a, 2b*) *Stenocranus major* Kbm.; (*3, 3a*) *Megamelus notula* Germ.; (*4, 4a, 4b*) *Stiroma bicarinata* H.-S. Letters *a, b,* and *c* at numbers designate signal fragments shown at expanded time-base. Scale bar: 5 s for *1*; 2 s for *1a, 2, 3, 4*; and 200 ms for *1b, 1c, 2a, 2b, 3a, 4a, 4b*.

frons Forbes (Homoptera, Cicadellidae, Deltocephalinae) and later proved to be characteristic of many Cicadinea. No more or less distinct rivalry behavior was observed in Cixiidae. Several males placed in the same cage displayed no hostility when meeting and completely ignored one another. If one of them produced a signal, other males, as a rule, also started singing, but their signals did not differ from those emitted by solitary insects. Cixiidae appear to lack any specialized territorial or aggressive signals.

Judging from the available data, Cixiidae are characterized by signals of a rather simple amplitude-temporal structure (Figs. 1, 2). Signals in some species are trills up to 2–3 s long, consisting of evenly separated pulses (Figs. 2, *1a–1b, 3, 3a–3b, 4, 4a*). In other cases, the pulses are combined into short repeated groups or series (Figs. 1, *3, 3a, 4, 4a–4b*). More complicated signals consist of several fragments, usually different in duration or pulse period (Fig. 1, *1, 1a, 2, 4a, 6, 6a*; 2, *2a–2b*). The species-specific temporal signal pattern in nearly all Cixiidae is formed by changing the amplitude of pulses or (less frequently) the length of intervals between them, whereas the pulse shape remains almost constant over the entire

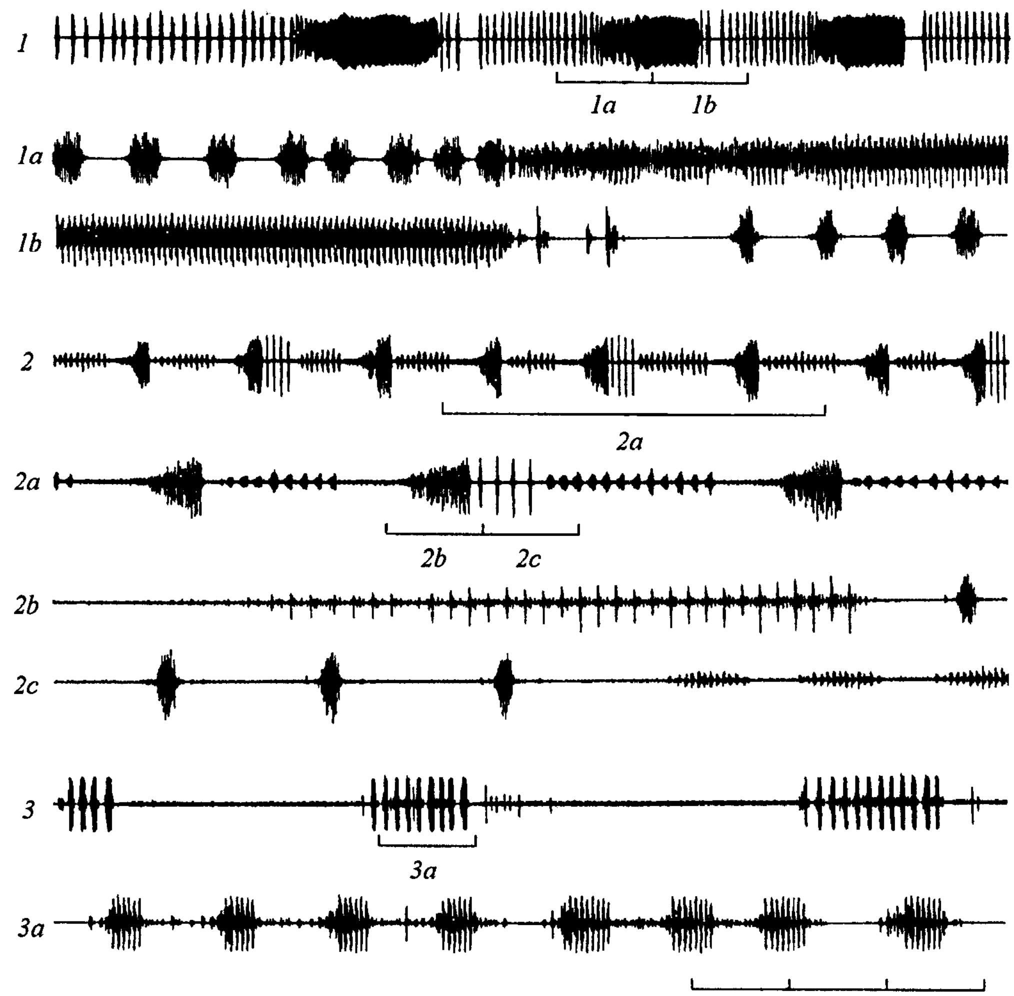

Fig. 4. Oscillograms of calling signals in Delphacidae: (*1, 1a, 1b*) *Struebingianella lugubrina* Boh.; (*2, 2a, 2b, 2c*) *Javesella stali* Metc.; (*3, 3a*) *Javesella obscurella* Boh. Letters *a, b,* and *c* at numbers designate signal fragments shown at expanded time-base. Scale bar: 5 s for 2; 2 s for *1, 2a, 3*; and 200 ms for *1a, 1b, 2b, 2c, 3a*.

signal. The previously described (Howarth *et al.*, 1990; Hoch and Howarth, 1993) signals of the cave-dwelling species belong to the first type, consisting of short trills with unmodulated amplitude; however, many terrestrial forms were found to emit similar signals. Such simple temporal patterns are probably characteristic of the entire family, rather than related to living in caves. A deep adaptation complex developed in some cave-dwelling Cixiidae had no effect on their system of acoustic communication.

Delphacidae, closely related to Cixiidae, possess a much more diverse structure of calling signals (Figs. 3, 4). Some species emit short trills of pulses (Fig. 3, *3, 3a, 4, 4a–4b*), whereas other forms produce highly complicated singular or repeated phrases (Figs. 3, *1, 1a–1b*; 4, *1, 1a–1b, 2, 2a–2c*). Closely related species of the same genus sometimes emit signals with greatly different levels of temporal structure. This fact can be illustrated by Fig. 4 (*2, 2a–2c, 3, 3a*) or by published signal oscillograms of *Javesella* species (Vrijer, 1986).

Unlike Cixiidae, the signal components in Delphacidae are often so diverse that any comprehensive and non-contradictory relevant terminology is difficult to develop. Pulses within a single signal may have a greatly different structure or partly merge, so that their boundaries become blurred (Figs. 3, *1, 1a–1c, 2, 2a–2b*; 4, *1, 1a–1b, 2, 2a–2c*). Similar signals were recorded in more than half of the species studied by me and other authors; thus, one may state that signals in Delphacidae are generally more complicated than in Cixiidae in terms of amplitude-temporal structure;

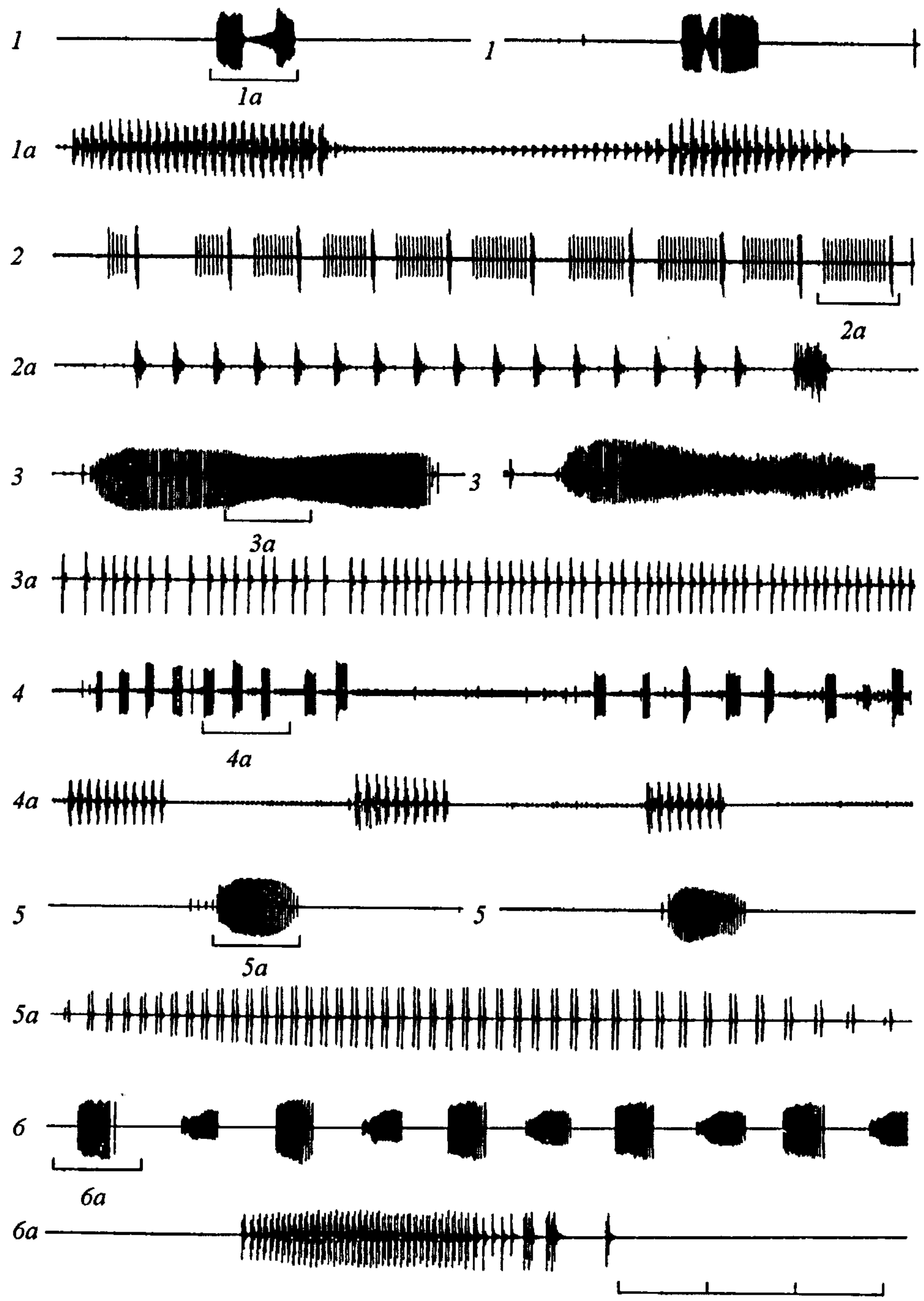

Fig. 5. Oscillograms of calling signals in Dictyopharidae, Issidae, and Tropiduchidae: (*1, 1a*) *Dictyophara multireticulata* M. R.; (*2, 2a*) *Phyllorgerius jacobsoni* Osh.; (*3, 3a*) *Sphenocratus hastatus* Osh.; (*4, 4a*) *Alloscelis vittifrons* Iv.; (*5, 5a*) *Scorlupaster asiaticum* Leth.; (*6, 6a*) *Trypetimorpha occidentalis* Huang, Bourgoin. Letter *a* at numbers designates signal fragments shown at expanded timebase. Scale bar: 2 s for *1, 2, 3, 4, 5, 6* and 200 ms for *1a, 2a, 3a, 4a, 5a, 6a*.

even though this may not be always true in certain particular cases.

Another distinctive feature of Delphacidae is the territorial behavior and related communication, well developed in males of most species. A solitary male usually emits territorial signals, either spontaneously or in response to another male's calling signal. In more obvious conflicts, e.g., on meeting of two males or at a high density of males on a plant, aggressive signals are emitted. Frequently, not restricting themselves to this behavior, the insects attack a rival trying to push it out of the stem.

Thus, Delphacidae and Cixiidae differ in both the temporal structure and the set of functional types of their signals; however, comparative data on other Fulgoroidea are needed for any conclusion to be made. For this purpose, signals were studied for representatives of three more families: Dictyopharidae (Dictyopharinae and Orgeriinae), Issidae (Issinae and Caliscelinae), and Tropiduchidae. In all these groups, except Caliscelinae, the male calling signals are generally trills of a simple structure similar to those emitted by Cixiidae (Fig. 5). As in Cixiidae, the only manifestation of the rivalry behavior in all the observed cases consisted in that males started to sing simultaneously in response to a single calling signal.

On the contrary, the acoustic behavior of Caliscelinae proved to be rather peculiar: the temporal structure of their calling signals is comparable to that of most complicated signals in Delphacidae, whereas the rivalry behavior and territorial signals are often present in females as well as males. This fact can support the recent idea of elevating Caliscelinae to the rank of a separate family; however, this problem is to be discussed in detail in a separate communication. Oscillograms of Caliscelinae signals are not presented in this work, and the species studied are not listed in the table.

Thus, Delphacidae, being one of the closest families to Cixiidae on the fulgoroid phylogenetic tree (Asche, 1988; Emel'yanov, 1990), represent a strongly deviating group with regard to acoustic characters. The similarity with Caliscelinae is most probably a case of convergence, although its cause is still obscure. Representatives of both groups only slightly differ in their biology from the studied species of Issinae, Tropiduchidae, and Dictyopharidae: most species are brachypterous or display wing dimorphism; and all species are hortophilous. On the contrary, according to the available data, the communication system in Cixiidae is essentially the same as in most other Fulgoroidea, including such rather advanced groups as Issinae and Tropiduchidae.

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