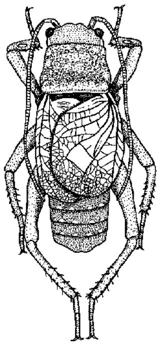

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COLD TOLERANCE AND DISTRIBUTION OF THE BUSH-CRICKET *GAMPSOCLEIS SEDAKOVII* (ORTHOPTERA: TETTIGONIIDAE) IN YAKUTIA

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The cold hardiness of overwintering eggs of *Gompsocles sedakovii* is studied. The mean super cooling points (*SCP)* of the eggs was –35.4°C and varied from –23.1 to –40.7°C. On average, the *SCP* of the eggs of *G. sedakovii* were 3-5 °C lower than in any of the earlier studied 16 species of Orthoptera. Thus, *G. sedakovii* is the one of the most cold tolerant species of the Orthoptera, and cold hardiness cannot limit its distribution in Yakutia.

KEY WORDS: Orthoptera, Tettigoniidae, *Gampsocleis sedakovii,* overwintering, cold tolerance, Yakutia.

З. А. Жигульская[1*)], Ю. В. Ермакова[2)], Е. Н. Мещерякова[1)]. Холодоустойчивость и распространение кузнечика *Gampsocleis sedakovii* (Ortoptera: Tettigoniidae) в Якутии // Дальневосточный энтомолог. 2016. N 322. С. 1-10.

Исследована холодоустойчивость зимующих яиц кузнечика *Gomsocleis sedakovii*. Средняя температура максимального переохлаждения (*Tп*) яиц составила –35.4°C при варьировании от –23.1 до –40.7°C. В среднем *Tп* яиц *G.*

sedakovii на 3-5°C ниже ранее изученных 16 видов прямокрылых. Таким образом, *G. sedakovii* является одним из наиболее выносливых видов прямокрылых по отношению к отрицательным температурам, и холодоустойчивость не может ограничивать его распространение в Якутии.

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INTRODUCTION

In understanding the faunogenesis in the Northeast Asia, it is important to study the factors, which allow the existence of the steppe and polyzonal xerophilic insects in Yakutia and further to the northeast. Some of these species are relicts in this area, probably dating back to the late Pleistocene (Berman *et al.*, 2001).

Especially interesting is one of these steppe species, the bush-cricket *Gampsocleis sedakovii* (Fischer von Waldheim, 1846). It is found in the steppe zone from Volga River to the Pacific Ocean (Sergeev, 1986). The majority of the range is occupied by the nominotypical subspecies, while *G. sedakovii obscura* (Walker, 1869) distributed in the southern part of the Russian Far East, Northeast China and Korea (Storozhenko, 2004). In Yakutia nominotypical subspecies has a disjunctive range (Ermakova, 2010, 2011). It is widespread in Southwest and Central Yakutia. Scattered records exist also from the steppe slopes in the Northeast Yakutia on the Yana Plateau (Tuostakh River, 67°92'44" N) and Momo-Selennyakh Depression (the mouth of the Arga-Eseleekh River, 66°81'76" N) (Fig. 1).

A similar pattern of distribution is found in two mesoxerophilic Yakutian bush-crickets, *Decticus verrucivorus* (Linnaeus, 1758) and *Metrioptera brachyptera* (Linnaeus, 1761), which are recorded sporadically in the northeast up to the Korkodon River, a right tributary of the Kolyma River (Berman *et al.*, 1983, 2001).

Nothing is known about the factors that determine sporadic distribution of these bush-crickets, as well as some other insect species (e.g. a weevil *Hypera diversipunctata* Schrank), and their complete absence to the northeast from Yakutia. Decreasing of minimal winter temperatures from Central Yakutia toward the northeast allows suggesting that this distribution could be due to low cold tolerance of the overwintering stage – the insect's eggs. Their cold tolerance has never been studied.

Thus, the goal of our work was to establish the parameters of the cold tolerance for the eggs of *Gampsocleis sedakovii*: (a) the supercooling point (*SCP*); (b) the extent of supercooling (*SCP–TF*), the difference between *SCP* and the freezing temperature (*TF*); and (c) the limit of the tolerated temperature.

MATERIALS AND METHODS

Eggs for this study were obtained from *Gampsocleis sedakovii* caught near Yakutsk, in the steppe meadows and next to the forest, and kept in lab cages with natural substrate (soil). The substrate was periodically sieved and eggs and egg pods were placed in plastic tubes with some litter, and buried at 5 cm depth in soil in the places where insects were caught. In late fall (19.10.2015), the eggs and egg pods were moved to the Laboratory of Biocenology, IBPS DVO RAN (Magadan), where they were kept in thermostatic refrigerators at 5°C for one month. For further acclimation, eggs were kept for one month each at a succession of temperatures 0, –5 and –10°C.

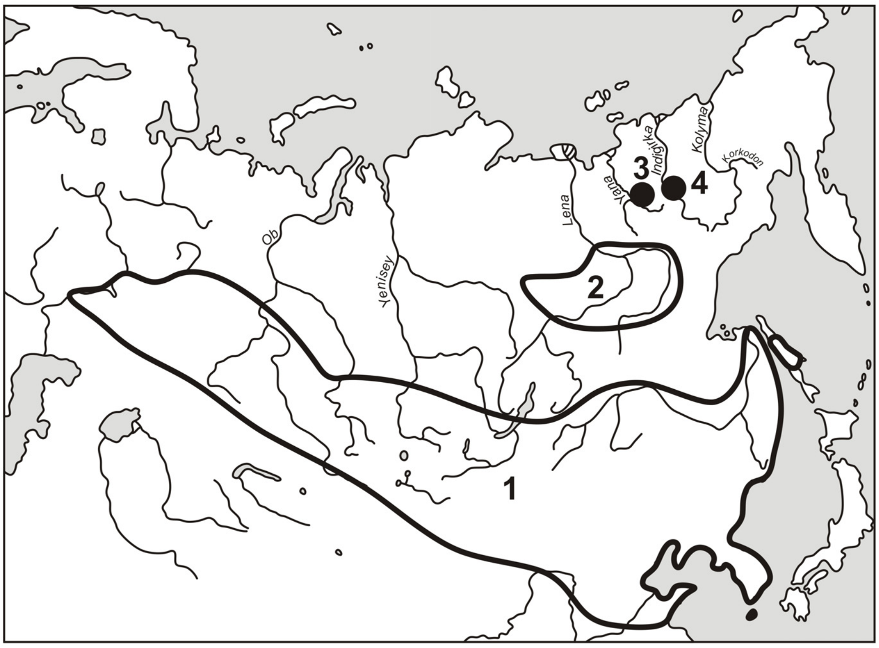

Fig. 1. Distribution of *Gampsocleis sedakovii:* basic range (1), disjunctive range (2) and scattered records exist on the Tuostakh River (3), and the Arga-Eseleekh River (4).

Cold tolerance was estimated according to the supercooling point (*SCP*) using the methods described earlier (Berman *et al.*, 2010). The supercooling point was determined using the 20-liter Dewar flask, which contained 3–4 liters of liquid nitrogen. With the help of a universal holder, we placed inside the flask a pipe chamber with two manganin-constantan thermocouples. A single egg (3–5 mg in mass) was attached to these thermocouples with a layer of Vaseline. The supercooling point *SCP* was registered at the moment of temperature shift as the egg fluid crystallized being cooled at a rate of 1°C per minute.

For a comparison of cold tolerance of this species and published data on other Orthoptera, we have determined the cold tolerance of the eggs of the Siberian grasshopper *Gomphocerus sibiricus* (Linnaeus, 1758). It was previously studied for the populations of this species from the Upper Kolyma river watershed (Berman & Leirikh, 2006) and Central Yakutia (Ermakova, 2015). The new results completely matched the earlier data (Table 1).

Table 1. Supercooling point in *Gomphocerus sibiricus* according to various sources

Sources	*SCP*, *m*±*SE* °C	*n*
Ermakova (2015)	–32.4±0.19	51
Berman & Leirikh (2006)	–31.8±0.4	53
This stidy	–31.9±0.5	44

Therefore, the differences in cold tolerance among some species are likely due not to the method used for measurements but to the physiological condition of the embryos. A good example is the *SCP* of *Bryodemella tuberculata* (Fabricius, 1775), which, according to Ermakova (2015) was –27.8±0.21 (*n* = 22), and according to Berman & Leirikh (2006), was –36.8±0.5 (*n* = 51). In addition, we measured cold tolerance of the grasshopper *Euthystira brachyptera* (Ocskay, 1826). These data added a new species to our knowledge on Orthoptera overwintering in Central Yakutia and adjacent areas; this list now includes 16 species.

RESULTS

According to Sergeev (Sergeev, 1986), *Gampsocleis sedakovii* has a northern steppe (by its latitudinal position) and East Palaearctic (by its longitudinal position) geographic range. It is common in the middle taiga subzone of the Southwest Yakutia (Miram, 1933) as well as in Central Yakutia. Further to northeast this species is recorded at the Tuostakh River (Yana Plateau) (Ermakova, 2010, 2011) and at the mouth of the Arga-Eseleekh River, a left tributary of the Indigirka River, 77 km downstream from Khonu Village (Momo-Selennyakh Depression). The Tuostakh River record represents the northernmost locality for bush-crickets in Asia.

Gampsocleis sedakovii prefers xerophytic habitats such as relict steppe slopes, dry belt of alas depressions, and anthropogenic meadow-steppes. More rarely it is found in mesophytic meadows with herbaceous-grass cover (Ermakova, 2010).

The grasshoppers *Gomphocerus sibiricus* and *Euthystira brachyptera* (Orthoptera: Acrididae) are polyzonal trans-Eurasian species. *Gomphocerus sibiricus* is widespread in Yakutia as well as further to the northeast, including the Kolyma River watershed; it prefers mesoxerophytic areas next to the forest boundary, steppe meadows of alas depressions, meadow-steppes, steppe areas; in the mountain areas, it is found in the mesoxerophytic southern slopes. *Euthystira brachyptera* is much less common in Yaкutia where it is found only in the central region, in various meadows, meadow-steppes, and steppe slopes.

All three species overwinter at the egg stage. *Gampsocleis sedakovii* lays its eggs into the soil one by one, inserting onto substrate not only the ovipositor but also its basal segments (i.e. to 5 cm of depth), while *Gomphocerus sibiricus* and *Euthystira brachyptera* produce egg pods with 5-8 eggs in each, and also place them approximately at 3-5 cm depth (Ermakova, 2015) (Fig. 2).

Temperatures in Central Yakutia are expectedly low. The minimal temperature in the steppe meadow under 30-40 cm thick snow cover at the places where eggs overwintered, at the depth of 5 cm, dropped below –20°C (Fig. 3); in the mesoxerophytic and wet meadows, minimal temperature was 2-3°C above –20°C (Desyatkin, 2008).

In the three studied species, as well as in other Orthoptera, overwintering eggs are not frozen but overcooled. A mean *SCP* for the eggs of *Gampsocleis sedakovii* was –35.4±0.3 ($n = 52$) varying in individual eggs from –23.1 to –40.7°C. Judging from a compact graph of distribution of the *SCP* (Fig. 4), the percentage of eggs insufficiently prepared for low temperature was only 4% (2 eggs out of 52). This can

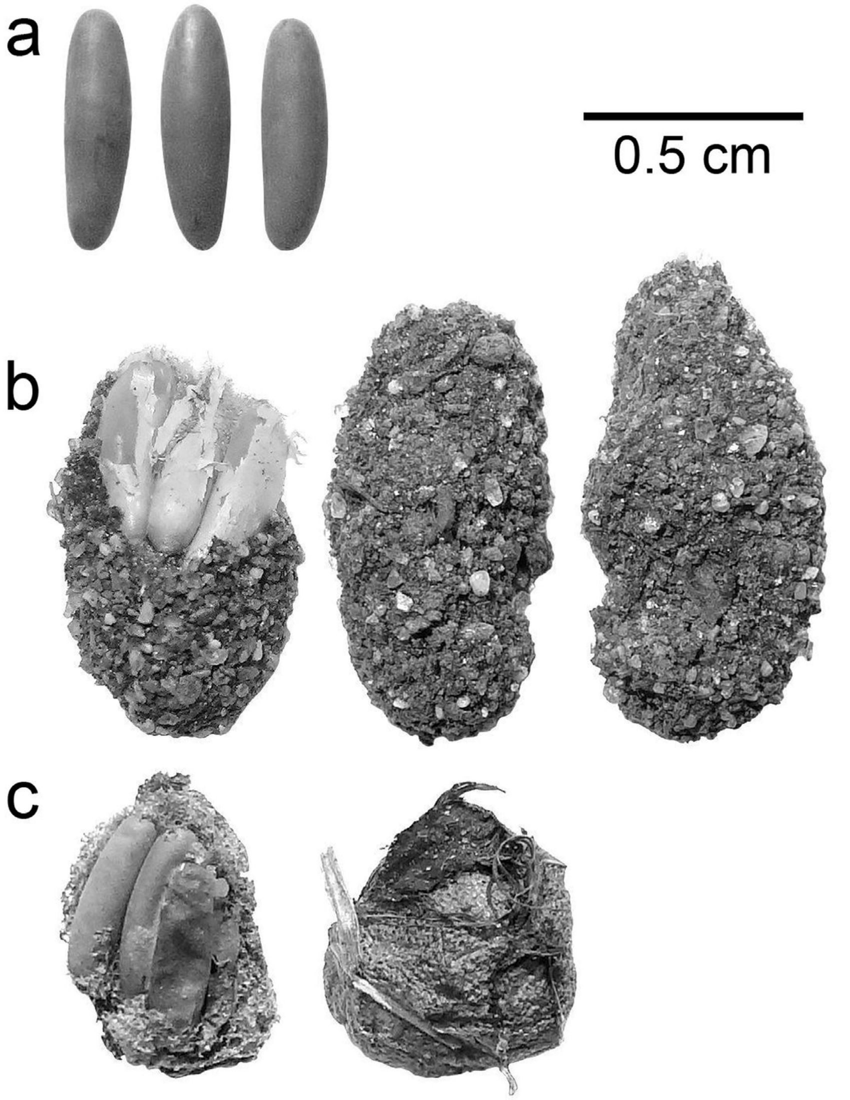

Fig. 2. Eggs of *Gampsocleis sedakovii* (a) and the egg pods of *Gomphocerus sibiricus* (b) and *Euthystira brachyptera* (c).

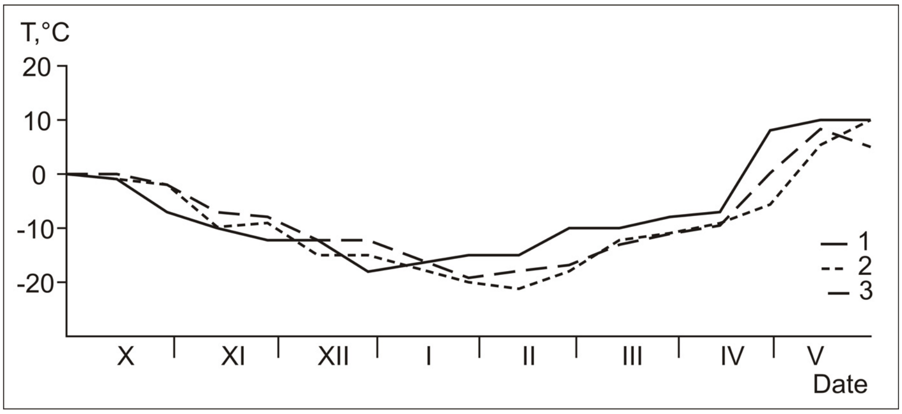

Fig. 3. Seasonal dynamics of the minimal soil temperature at the depth of 5 cm, Tyungyulyu biological station of the IBPC SB RAN (50 km NE of Yakutsk), in three types of meadows: 1 – mesoxerophytic, 2 – wet, 3 – steppe meadow (from Desyatkin, 2008).

be seen from the small difference between minimal soil temperature in overwintering localities (which reaches –22°C) and the *SCP* values (–23.1 and –25.3°C). The majority of laid eggs (with *SCP* values from –31.1 to –40.7°C) would tolerate even very harsh and snowless winters.

The range of *SCP* values for the eggs of *Gomphocerus sibiricus* (from –14.3 to –38.8°C) and *Euthystira brachyptera* (from –23.3 to –40°C) is much broader than in *Gampsocleis sedakovii* (Fig. 4), due to the increase of the percentage (up to 40%) of less cold tolerant eggs with *SCP* down to –30°C. However, the minimal *SCP* values in all species differed only within a degree, as well as their mean extent of supercooling (*SCP-TF*) (Table 2). On average, the eggs of this bush-cricket (*SCP* = –35.4°C) were 3-5°C more cold tolerant than in the two other Orthoptera species.

Table 2. Cold tolerance parameters (°C) for the overwintering eggs of the Orthopera in the environs of Yakutsk (measurements taken from 25.01 to 10.02.2016)

Species	*SCP, m±SE*	Min *SCP*	*n*	*TF, m±SE***	*n*	*SCP-TF, m±SE* ***	*n*
Gampsocleis sedakovii	–35.4±0.3	–40.7	52	–18.6±0.6	50	–16.8±0.6	50
Gomphocerus sibiricus	–31.9±0.5	–38.8	44	–13.8±0.9	44	–18.1±0.9	44
Euthystira brachyptera	–30.4±1.2	–38.7	53	–14.1±0.6	53	–17.1±0.6	53

* *SCP*, supercooling point, ***TF*, freezing temperature, *** *SCP-TF*, extent of supercooling.

Based on previously published data (Hao & Kang, 2004; Ermakova, 2015) one can assume that the limits of long-term tolerance for negative temperatures in the studied species are 4-5°C higher than their mean *SCP*, i.e. lie within a range from –23 to –30°C.

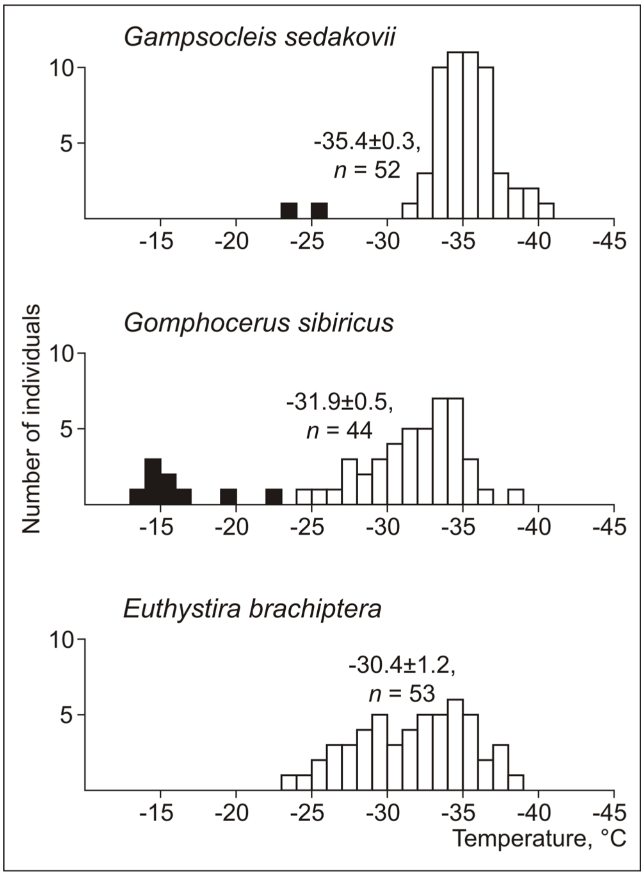

Fig. 4. Distribution of maximal supercooling temperatures (*SCP)* of the eggs. Dark shaded: values of *SCP* for the individuals that are insufficiently prepared for the winter. Measurements were conducted from 25 January to 10 February 2016.

DISCUSSION

A comparison of minimal temperatures in the localities where the eggs are overwintering and the parameters of their tolerance toward negative temperatures revealed a very considerable "reserve of cold tolerance", which equals –10 to –15°C. This guarantees that at least a portion of a population would survive even in the cold winters with low snow cover in most Yakutian habitats. In other words, the overwintering conditions are not critical for the studied species.

A comparison of cold tolerance of the eggs for all discussed species, and for all the Orthoptera (except the genus *Tetrix*, family Tetrigidae) where overwintering stages were studied, shows that *Gampsocleis sedakovii* is one of the most tolerant species toward negative temperatures (Table 3).

Table 3. Mean minimal *SCP* (°C) of the overwintering orthopteran eggs from the Upper Kolyma and Central Yaкutia

No	Species	*SCP, m±SE*	*n*
1	*Bryodemella tuberculata**	–36.8±0.5	22
2	*Gampsocleis sedakovii****	–35.4±0.3	52
3	*Aeropedellus variegatus borealis* *	–35.6±0.3	55
4	*Chorthippus fallax**	–34.8±0.2	48
5	*Chorthippus montanus**	–34.6±0.2	53
6	*Podismopsis gelida**	–34.9±0.2	50
7	*Stethophyma grossum**	–34.5±0.2	51
8	*Prumna polaris**	–34.2±0.3	66
9	*Melanoplus frigidus**	–33.7±0.3	61
10	*Omocestus haemorrhoidalis***	–33.1±0.17	51
11	*Glyptobothrus maritimus maritimus* *	–32.1±0.6	51
12	*Glyptobothrus maritimus jacutus***	–31.9±0.14	51
13	*Gomphocerus sibiricus***	–32.4±0.19	51
14	*Euthystira brachyptera****	–30.4±1.2	53
15	*Chorthippus albomarginatus***	–29.7±0.23	51
16	*Prumna primnoa***	–29.3±0.16	51

* from Berman & Leirikh (2006); **from Ermakova, (2015); *** this study

Cold tolerance cannot limit its distribution toward the northeast from the Central Yakutia, and, in particular, it cannot be responsible for its disjunctive range.

It is clear that the sporadic distribution of *Gampsocleis sedakovii*, as well as possibly other bush-cricket species in the areas lying northeast from Yakutia, is not due to their insufficient cold tolerance. This conclusion is supported by a comparison of the fauna of xerophylic Orthoptera of Yakutia and the territories located further northeast. In Yakutia, there are five steppe species (including three bush-crickets) and seven polyzonal xerophylic Orthoptera species. At the same time, only three polyzonal xerophilic species (*Bryodemella tuberculata*, *Gomphocerus sibiricus* and *Aeropedellus variegatus borealis* Mistshenko, 1951) are known from the watershed of the Kolyma River and the Pacific coast rivers, as well as one forest-steppe species, *Chorthippus fallax* (Zubovsky, 1900). The absence of three other polyzonal xerophilic taxa in the Northeast Asia, namely *Omocestus haemorrhoidalis* (Charpentier, 1825), *Chorthippus albomarginatus* (De Geer, 1773) and subspecies *Glyptobothrus maritimus jacutus* Storozhenko, 2002, cannot be due to their insufficient cold tolerance since it is quite high and lies in the range between –29.7 and –33.1°C (Table 3).

Thus, the sporadic distribution of xerophilic bush-crickets in Yakutia, as well as their absence to the northeast from Yakutia, is most likely due to the history of steppe habitats. A small, sometimes even very small area occupied by steppe vegetation as well as their complete isolation by mesophytic plant communities, which are "impermeable" for xerophilic insects, could lead to irreplaceable loss of some species under unfavorable conditions, first of all during the fires.

Our study also allows to assume that the main limiting factors determining geographic distribution of *Gampsocleis sedakovii*, as well as other polyzonal xerophilic species of Orthoptera mentioned above, are summer climatic factors, first of all insufficient amount of heat.

However, the ability to overwinter at the egg stage at very low temperatures in the upper centimeters of the soil, in a deeply overcooled condition, is undoubtedly one of the main elements of the adaptive strategy of the discussed species, which secures their existence in the coldest regions of Asia.

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