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Diurnal and seasonal rhythms of stridulatory activity in the water boatmen *Corixa dentipes* and *Corixa punctata*

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Summary. Two species of water boatmen which live sympatrically in Central Europe, begin stridulatory activity in the autumn. But whereas the activity of *C. punctata* is maximal during autumn, the peak activity of *C. dentipes* occurs in the spring.

The water boatman *Corixa punctata*, like *C. dentipes* and most other Corixidae, reportedly produce stridulatory sounds mainly in the spring, during the reproductive period, and mainly in the twilight hours[2-4]. Although some data on the diurnal and seasonal periodicity of stridulatory activity are available[5-7], no detailed long-term study of the Central European corixids has previously been published. Whereas *C. punctata* males have only 1 song, *C. dentipes* males have a repertoire of 4 different songs (songs A-D)[8]. The mechanism that enables the corixids to produce their acoustic signals under water has been described elsewhere[8,9]. Comparison of the diurnal and seasonal periodicities of stridulatory activity in the 2 species considered here, should be interesting because a) they live sympatrically in Central Europe and b) they use the same frequency band for acoustic communication[9].

For the first experiments, adult animals were caught in the vicinity of Regensburg in the autumn of 1979. Separated by species and sex, the animals were kept in cages in an atrium of the University of Regensburg and fed chironomid larvae. The wire cages had a floor area of 0.6×0.6 m; they were placed in water 0.5 m deep, in 2 concrete tanks each containing about 25 m^3 of water. Each tank housed males and females of only one species; the 2 sexes were not acoustically isolated from one another. The water temperature, light intensity and stridulatory activity were continually monitored electronically beginning at the end of February, and were displayed on a 4-channel pen-writer. The stridulatory sounds were recorded by modified condenser microphones and displayed on the pen-writer after filtering, rectification and integration. Exact numerical data on stridulation activity are given for *C. dentipes* only, because it was uncertain, whether some of the fainter stridulatory signals of *C. punctata*[8] could have been lost in the background noise or that of the recording system.

Surprisingly, most of the *C. punctata* males died during the winter of 1979. From the few males still surviving in the spring, only weak, irregular stridulatory sounds could be recorded. Examination of the females of this species, which had been kept in isolation from the males since November, showed that the seminal receptacle of some of them was already full. Evidently, in contrast to other reports[2,4], the reproductive phase of *C. punctata* in our latitudes already begins in the autumn. The *C. dentipes* males stridulated as soon as the recording of activity was begun, at a water temperature of 4–5 °C at the cage floor. A high noise level caused by falling snow or rain appears to have no appreciable effect on stridulatory activity. In March 1980 the main activity phase occurred during the day (fig. 1,a). The minimum in the stridulation curve often observable in the early afternoon resulted from an increase in the animals' swimming activity at this time of day. The daily stridulatory activity became maximal in April (fig. 1,b) when it was uniformly distributed throughout the 24 h. The presence of special activity peaks during the morning and evening twilight could not be confirmed. By the end of June all of the *C. dentipes* males had died.

In the field, imagines of the new generation of both species begin to appear in August. In a 2nd experiment, the stridulatory activity of the 2 species was recorded under the same conditions as previously described, from August 1980 to May 1981. *C. punctata* males began to stridulate in September. The activity reached a prominent peak in this month, and then decreased until December. Some slight stridulatory activity then persisted throughout the entire winter, even though the tanks containing the cages were completely covered with ice for at least 3 months and the water temperature at the floor of the cage at times fell to +2 °C. Stridulation activity remained low in the spring of 1981. No clear activity maxima at particular times of day could be observed. *C. dentipes* males also occasionally stridulated as early as September. But in contrast to *C. punctata* the stridulation rate remained low in autumn, and in October and November it was about half as high as in the 2nd week of March 1981 (fig. 2). In autumn all 4 songs are produced mainly at night, song A being most common. The stridulatory activity ceased as soon as the water temperature fell below 5 °C.

The observations of *C. dentipes* in spring of 1980 were repeated in the following spring with males that had been kept in the same cage with females. In a 2nd tank, *C. dentipes* males were kept without females, and their stridulation was also recorded. The frequency of occurrence of the 4 songs was plotted separately (fig. 2). The first stridulations

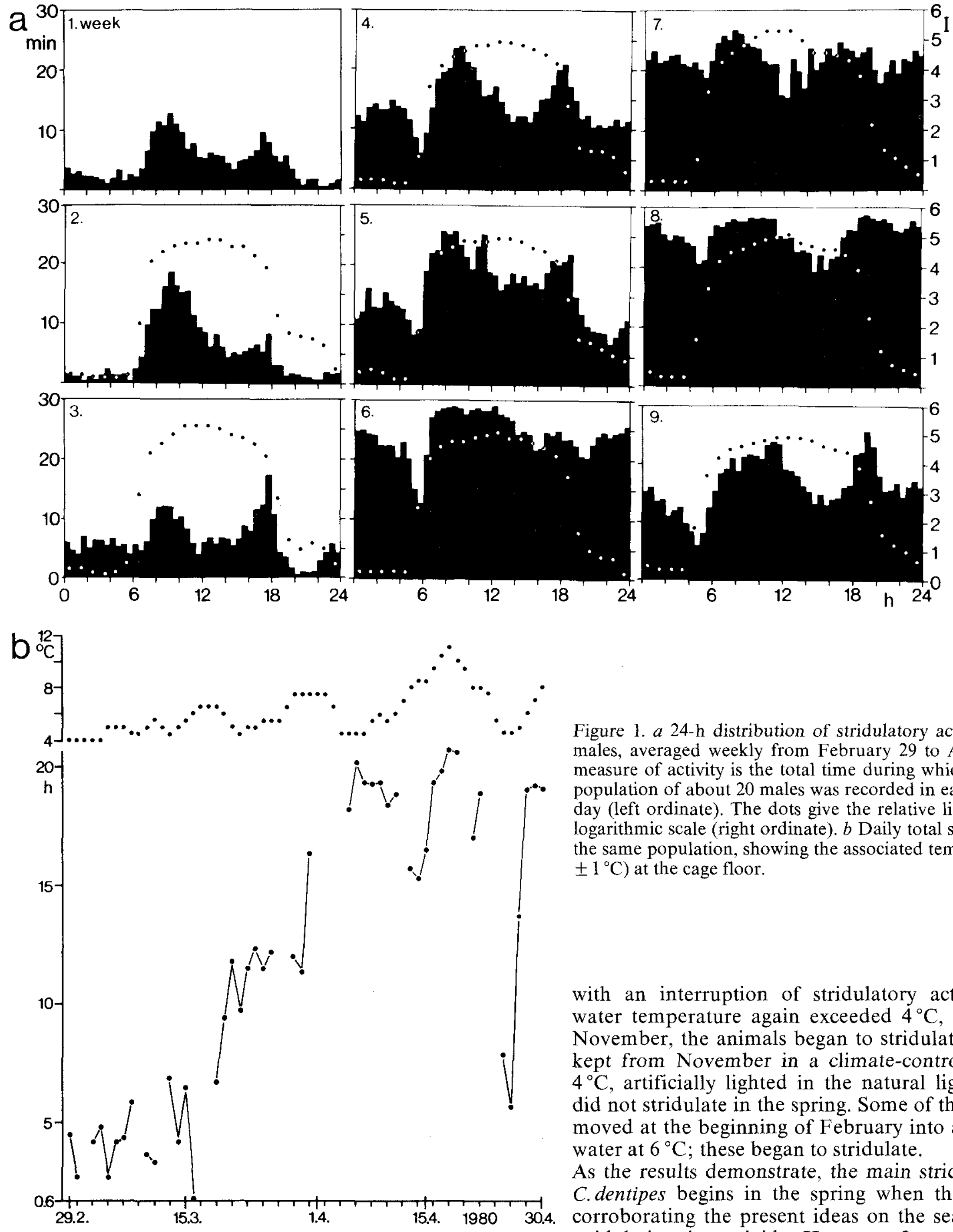

Figure 1. *a* 24-h distribution of stridulatory activity of *C. dentipes* males, averaged weekly from February 29 to April 30, 1980. The measure of activity is the total time during which stridulation by a population of about 20 males was recorded in each half hour of the day (left ordinate). The dots give the relative light intensity I on a logarithmic scale (right ordinate). *b* Daily total stridulation times of the same population, showing the associated temperature (to within ± 1 °C) at the cage floor.

appeared as soon as the water temperature rose above 4 °C. It is evident that song D is sung mainly at the beginning of the activity period, and chiefly at night. Song A exhibited no distinct diurnal periodicity. Song B + C was at first sung more often by day than by night, but from the 3rd week the main production of this song shifted to nighttime hours. Males with and without females produced all 4 songs.

Additional observations and experiments indicated that in *C. dentipes* the termination and onset of stridulation in the autumn and spring are likely determined by water temperature. A cold spell in the first half of November 1980, in which the water temperature fell below 4 °C, was associated with an interruption of stridulatory activity. When the water temperature again exceeded 4 °C, in the middle of November, the animals began to stridulate again. Animals kept from November in a climate-controlled chamber at 4 °C, artificially lighted in the natural light:dark rhythm, did not stridulate in the spring. Some of these animals were moved at the beginning of February into a tank containing water at 6 °C; these began to stridulate.

As the results demonstrate, the main stridulation phase of *C. dentipes* begins in the spring when the ice melts, thus corroborating the present ideas on the seasonal rhythm of stridulation in corixids. However, 3 unexpected findings have been reported here: 1. *C. dentipes* exhibits a low stridulation activity as early as autumn, 2. *C. punctata* stridulates mainly in autumn, 3. *C. punctata* maintains a low level of stridulation activity throughout the winter and spring. Thus, the periods of main stridulatory activity are seasonally separated in the 2 congeneric species. This may be an indication of a seasonal isolation mechanism, an idea supported by the fact that both species live sympatrically in Central Europe, hardly differ morphologically and use the same carrier frequency for their acoustic signals. Furthermore, it has been shown for other corixids that mating occurs during the main stridulatory period[10]. The relationship between mating and stridulation in *Corixa* is being investigated.

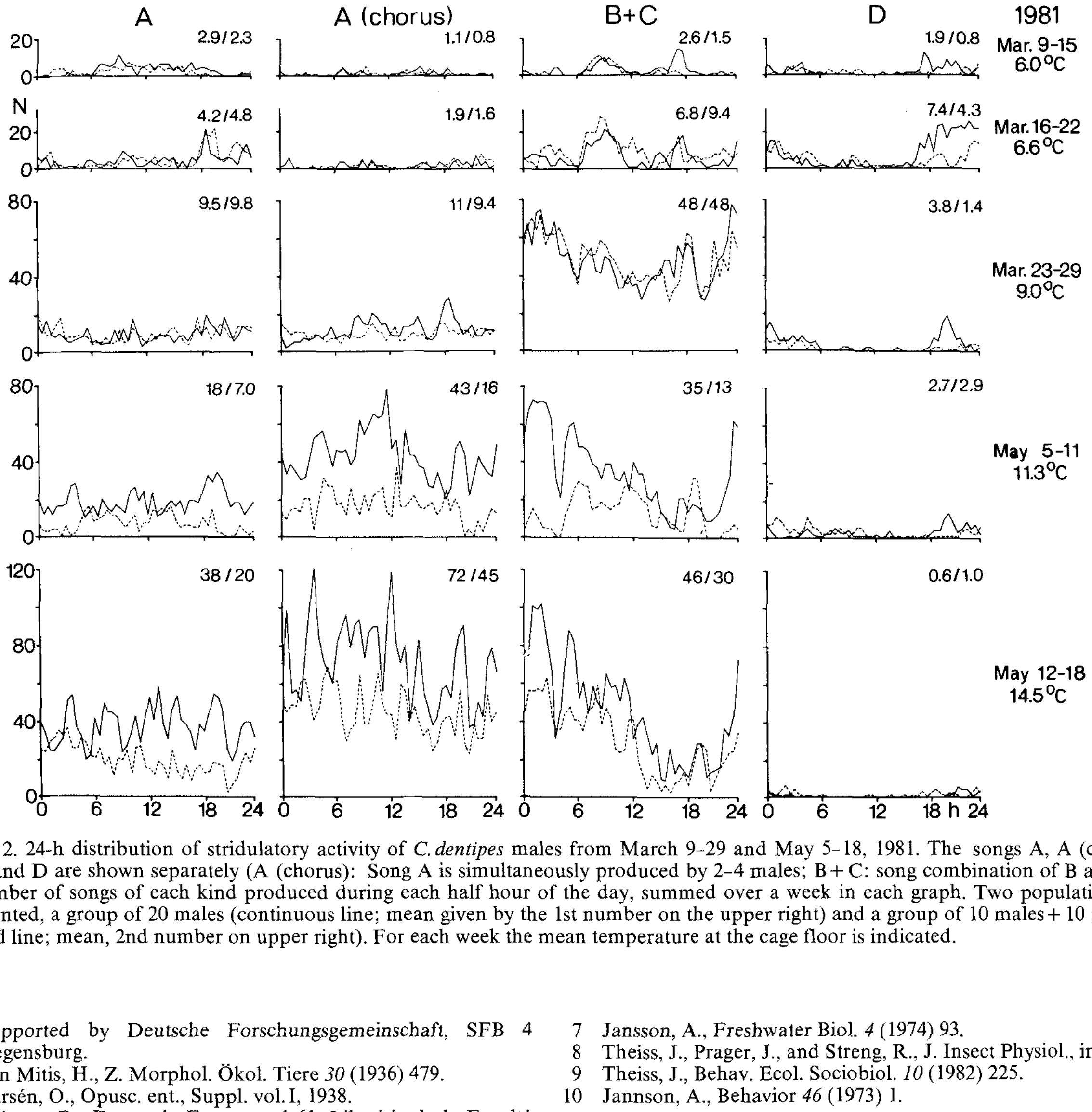

Figure 2. 24-h distribution of stridulatory activity of *C. dentipes* males from March 9-29 and May 5-18, 1981. The songs A, A (chorus), B+C and D are shown separately (A (chorus): Song A is simultaneously produced by 2-4 males; B+C: song combination of B and C[8]). N: number of songs of each kind produced during each half hour of the day, summed over a week in each graph. Two populations are represented, a group of 20 males (continuous line; mean given by the 1st number on the upper right) and a group of 10 males+10 females (dashed line; mean, 2nd number on upper right). For each week the mean temperature at the cage floor is indicated.

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Feeding aversions in terrestrial slugs

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Summary. Terrestrial slugs *(Limax flavus)* were administered a feeding test in which they were presented 2 pieces of lettuce. One piece was treated with distilled water, the other with a solution of blended conspecifics in distilled water. Subjects consumed significantly more of the control lettuce treated with distilled water.

The release of alarm substances from stressed or injured invertebrates has been demonstrated for a variety of species including insects[2], earthworms[3,4], sea anemones[5], sea urchins[6], snails[7-10], and terrestrial slugs[11]. Organic gardeners have maintained that releasing alarm substances by grinding up agricultural pests such as insects and slugs is an effective means of controlling these animals, although the evidence for this claim is anecdotal[12,13]. The purpose of the present study was to laboratory test the hypothesis that a solution of blended slugs and water, applied to lettuce, will deter feeding by conspecific slugs.

14 adult slugs (2-3 cm), *Limax flavus,* obtained from gardens in Northern New Jersey served as subjects. They were individually housed in plastic petri dishes (12.7 cm in