

## Insects under global warming. Review and retrospective analysis

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We have tried to assess the morphological changes in insects under conditions of global warming using the example of three mass species. We analyzed collection funds for 140 years from the same territory in Western Siberia. We found out that the climate of Siberia is systematically drying up and the average temperatures are increasing, and as a result, the species composition of the fauna of Western Siberia changes, as well as the morphology of some insect species.

**Keywords:** Western Siberia, climatic changes, Insects, Pompilidae, Sphecidae, Vespidae

### Introduction

Insects are highly adaptable to changing environmental conditions. Knowing the reactions of insects to changes in a particular factor, it is possible to predict or describe changes in the biocenosis. Biologists around the world are now studying the effects of climate change extensively. Entomologists have long known the morphological reaction of the honey bee *Apis mellifera* Linnaeus, 1758 to an increased temperature in the process of ontogenesis - the venation of the wing changes into the flesh until the appearance of new veins and cells (the exact direction of the process and the final result depending on temperatures is currently being studied). The study of the process of faunogenesis (tracking the species of invaders) can also serve to describe the consequences of climate change, along with changes in the physiology of a number of insect species.

We tried to determine what morphological changes a species undergoes within one geographic point for 120 years under conditions of climate transformation, and also to review changes in the abundance of some species and in the fauna of Western Siberia.

### Materials and Methods

To describe morphological changes, 3 cosmopolitan species (one species from three families) with a high population density were chosen as the object of research: Pompilidae - *Anoplius* (*Arachnophroctonus*) *viaticus* (Linnaeus, 1758); Sphecidae - *Ammophila sabulosa* (Linnaeus, 1758); Vespidae - *Vespa crabro* Linnaeus, 1758. For each species, three groups of individuals were analyzed: group no. 1 - wasps collected in 1893, group no. 2 - wasps collected in 1956, group no. 3 - wasps collected in 2017 (Fig. 1). The minimum number of specimens in the sample was 20 (*A. sabulosa*, group of 1893), the maximum - 60 (*V. rabro*, group of 1893) (Table 1).

**Table 1.** Amount of analyzed material

Species	1893 year, specimen	1956 year, specimen	2017 year, specimen	Total, specimen
<i>A. (Ar.) viaticus</i>	20	31	23	74
<i>Am. sabulosa</i>	37	29	44	110
<i>V. crabro</i>	60	54	38	152
The total number of analyzed specimens is 336				

For each individual, morphometric measurements of the fore wing (right and left) were carried out according to three parameters: 1) L / H - the ratio of the wing length to its width 2) Pt / r - the ratio of the pterostigma length to the length of the first segment of the radial vein 3) cell shape 2Rs, expressed by the ratio of the lengths of the segment of the radial sector and the sum of the lengths of the 4 and 5 segments of the basal vein (in *A. viaticus* and *A. sabulosa*), or the ratio of the lengths of the segment of the radial sector and the length of the 5 segment of the basal vein (in *V. crabro*), conventionally designated as 2Rs and 2Rs\*. On the basis of the wing morphometric parameters of the right and left sides, the asymmetry of each individual was calculated. The ratio of the distances between the simple eyes and the faceted eye POL / OOL and the variability of body color (changes in the color and shape of the pattern) were also evaluated (Fig. 2).



Fig. 1. Example of labels (A) and collection material *Anoplius (Ar.) Viaticus* (B), *Ammophila sabulosa* (C)  
\*Note: These authors and collection points are also valid for *Vespa crabro* material.

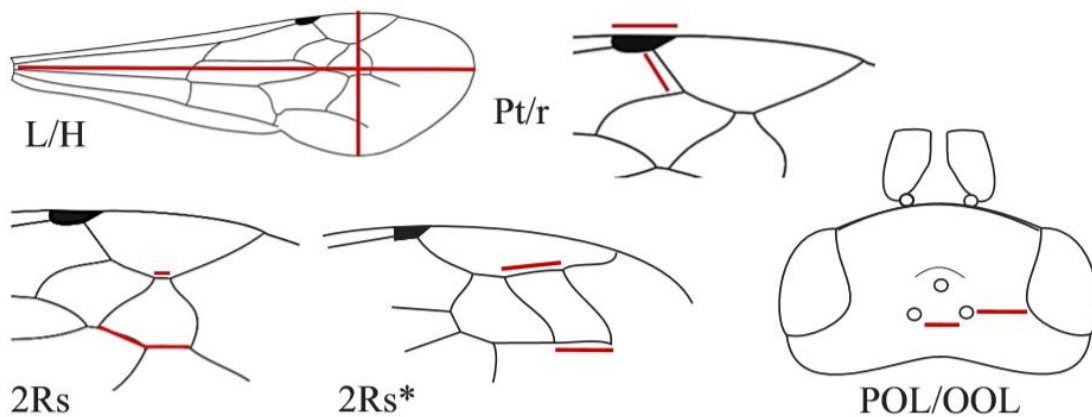


Fig. 2. Schemes of estimated wing metric parameters and ocellar distances.

Data on weather conditions are taken from the archive [www.pogodaiklimat.ru/](http://www.pogodaiklimat.ru/) (date of reference 03/13/2020). To calculate the hydrothermal coefficient (HTC), the following formula was used:

$$HTC = (\sum R (t \geq 10^{\circ}C) * 10) / (\sum t \geq 10^{\circ}C);$$

where  $\sum t \geq 10^{\circ}C$  is the sum of average daily air temperatures higher than or equal to  $10^{\circ}C$ .

The sum of average daily temperatures was taken 5 years before the year in which the insects were caught. In order to indicate the value  $\sum t \geq 10^{\circ}C$  for 1893,  $\sum t \geq 10^{\circ}C$  were calculated for 1888, 1889, 1890, 1891, 1892, 1893 and  $\sum t \geq 10^{\circ}C$  was calculated from the obtained values. It is this average value of average temperatures for the previous 5 years that is designated  $\sum t \geq 10^{\circ}C$  in 1893. The values for 1956 and 2017 were calculated in the same way.

$\sum R (t \geq 10^{\circ}C)$  is the amount of precipitation at an average daily air temperature above or equal to  $10^{\circ}C$ . The HTC value was calculated for the indicated years (1893, 1956, 2017). The graph of the secular variation of air temperature in Tomsk is taken from the literature (Sevast'yanov et al., 2000).

The Siberian silkworm *Dendrolimus sibiricus* Tschetverikov, 1908, according to literature data, was taken to review the changes in abundance in response to changing climatic conditions. To describe the transformation of the fauna of Western Siberia,

literature data on 5 species were used: *Polygraphus proximus* Blandford, 1894; *Ips amitinus* (Eichhoff, 1871); *Chalybion turanicum* (Gussakovskij, 1935), *Podalonia alpina* (Kochl, 1888); *Evagetes trispinosus* (Kohl, 1886).

## Results and Discussion

Analysis of meteorological data for 140 years allows us to make a conclusion about a systematic increase in the sum of average daily air temperatures during the warm period of the year (Fig. 3).

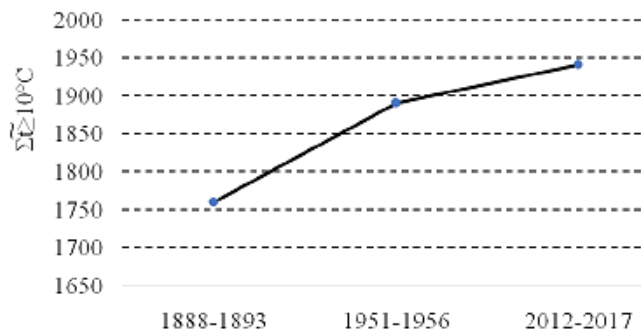


Fig. 3. Change  $\Sigma t_{\geq 10^{\circ}\text{C}}$  Tomsk

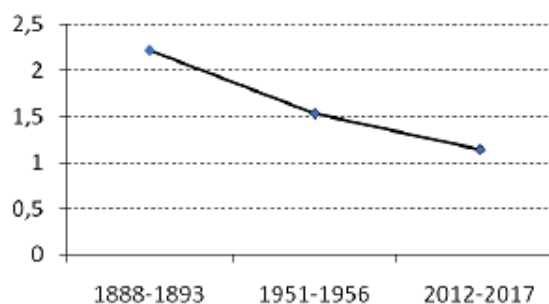


Fig. 4. Change HTC Tomsk

The graph shows that changes in  $\Sigma t_{\geq 10^{\circ}\text{C}}$  in the first 63 years (from 1893 to 1956) are more rapid – the difference in values between  $\Sigma t_{\geq 10^{\circ}\text{C}}$  in 1893 and  $\Sigma t_{\geq 10^{\circ}\text{C}}$  in 1956 was 130.3°C. The second time interval of 61 years (from 1956 to 2017) is characterized by smoother temperature changes, and the difference in values between  $\Sigma t_{\geq 10^{\circ}\text{C}}$  1956 and  $\Sigma t_{\geq 10^{\circ}\text{C}}$  2017 was 50.63°C.

The hydrothermal coefficient (HTC) changes in antiphase with temperature, which is quite natural. The graph shows a systematic decrease in the hydrothermal coefficient (Figure 4). In the period from 1893 to 1956 (63 years) there is a more rapid decline (HTC) – the difference between the values of HTC 1893 and HTC 1956 was 0.69. The second time interval of 61 years (from 1956 to 2017) is characterized by a more gradual decrease in the indicator. The difference in values between HTC 1956 and HTC 2017 was 0.39.

The change in the average annual air temperature over 120 years is positive (Fig. 5).

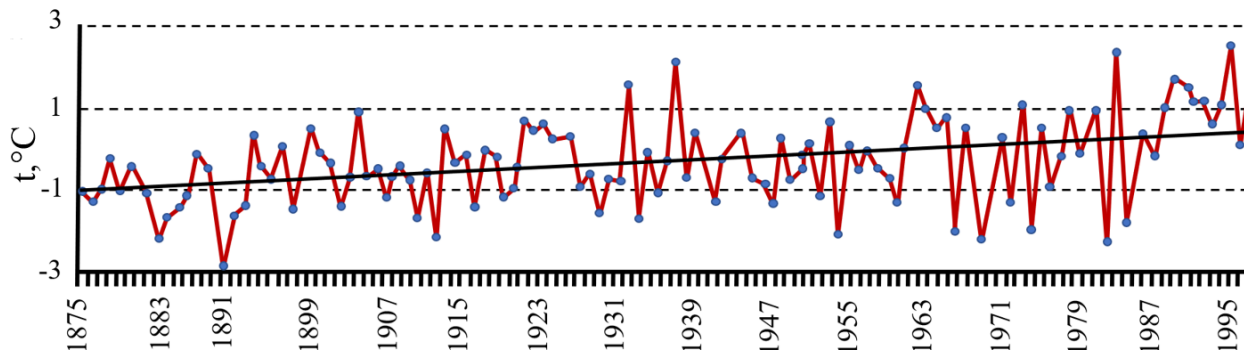


Fig. 5. Changes in the average annual temperature in Tomsk over 120 years

This graph shows a systematic increase in average annual temperatures with an increase in the amplitude of fluctuations between the maximum and minimum indicators in different years. Thus, it can be concluded that the tendency of climatic changes in this area to warming and aridization (the climate becomes hotter and drier). This climatic trend is typical not only for the Tomsk region. Our faunistic studies of recent years indicate changes in the composition of the West Siberian faunistic complex. Increasingly, on the territory of Western Siberia, we find typical representatives of the arid fauna (Central Asian and

Mongolian). For example, in 2010 we discovered *Podalonia alpina* (Kochl, 1888) (Baghirov, 2010), in 2011 *Chalybion turanicum* (Gussakovskij, 1935) (Baghirov, 2011), in 2014 – *Evagetes trispinosus* (Kohl, 1886) (Baghirov, 2014). All newly recorded species are southern and tend to arid and semi-desert biotopes. In other taxonomic groups, a similar picture can be observed. For example, in 2011 the *Polygraphus proximus* Blandford, 1894 was recorded for the first time (Baranchikov et al., 2011; Kerchev, 2014; Krivets et al., 2015a,b), later in 2014 in the Kemerovo region, and then in 2019 in the Tomsk region, a new species was discovered – *Ips amitinus* (Eichhoff, 1871) (Klimycheva, 2019). All this is the result of the expansion of the range due to changes in the climatic conditions of the Siberian region. Under the influence of global climate changes, the original range of all the listed species moved to the north of Russia, settling the western and northwestern regions from the Bryansk region to the Kola Peninsula. Now we find them in Siberia.

Another reaction to climate warming and drying can be observed in *Dendrolimus sibiricus* Tschetverikov, 1908. This species normally has a two-year life cycle (Rozhkov, 1965), but under conditions of a changed climate changes the normal physiological reaction and passes to a one-year life cycle. It should be noted that climatic factors only prepare the conditions for a breeding outbreak, but do not determine the dynamics of the process. If we turn to the history of the issue, then we find a clear correlation between outbreaks of numbers with dry and warm years. An outbreak of mass reproduction of the Siberian silkworm in Siberia was described in 1897 in Irkutsk. For the first time a Siberian silkworm was found in the Tomsk region in 1924 (Loganzen, 1924; Burdavitcyn et al., 1957). Figure 5 shows that the average annual temperature during this period did not fall below 0 °C. Then, in 1953-1955, described a grandiose wave of mass reproduction in the Tomsk region (Burdavitcyn et al., 1957). As we remember from Figures 3 and 4 in the period from 1893 to 1956 there is a sharp rise in temperature and a decrease in moisture content.

Currently, biologists around the world are widely studying the effects of climate change. Entomologists have long been aware of the morphological reaction of the honey bee *Apis mellifera* Linnaeus, 1758 to an elevated temperature during ontogenesis – the wing venation changes until new veins and cells appear (these morphological structures for many insects are hallmarks of a species or even a genus).

For 6 years, we studied the morphological changes of several species of insects within the same geographical point (collection materials for 120 years from 1893 to 2017) under the conditions of climate transformation.

All studied species were analyzed by a complex of 7 characters (Figs. 2, 6).

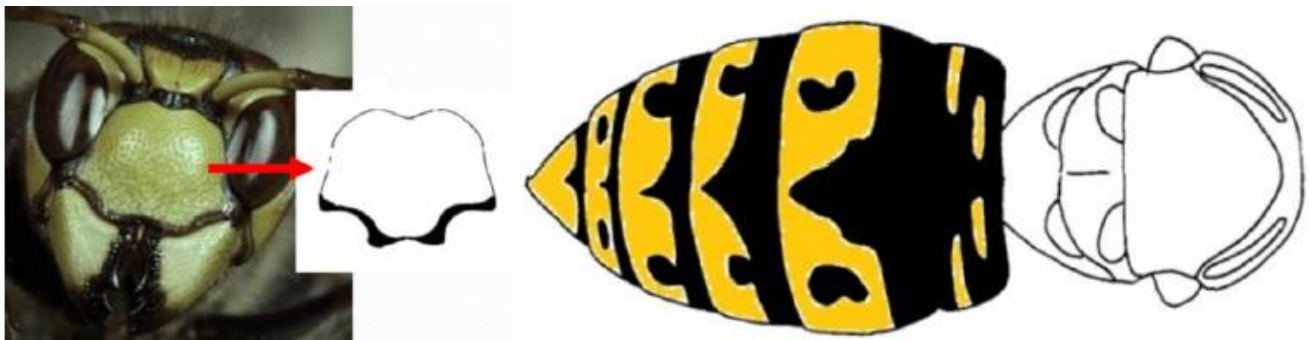


Fig. 6. Schemes of the studied parameters

In this article, we present the results of three widespread wasp species from three different families: Pompilidae - *Anoplius (Arachnophroctonus) viaticus* (Linnaeus, 1758); Sphecidae - *Ammophila sabulosa* (Linnaeus, 1758); Vespidae - *Vespa crabro* Linnaeus, 1758.

We have found that in all three species, a change in the symmetry of the head occurs – the distance between the posterior parietal ocelli increases and decreases between the parietal ocellus and the facet eye (Fig. 7).



Fig. 7. Scheme of changes in the proportion of the head (POL / OOL).

Also, in all three species, the proportion of the wing changes – the pterostigma (Pt) becomes shorter (Fig. 8).



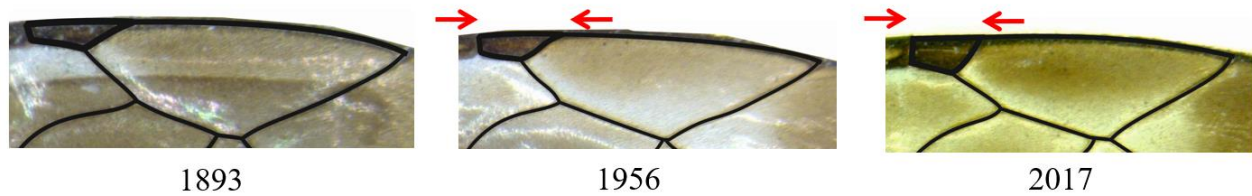


Fig. 8. The scheme of changes in the proportion of the wing (Pt / r).

The venation of the wing of *Anoplius (Ar.) viaticus* (L.) acquired high variability (for example, the shape of the 2Rs cell). The shape of this cell in the modern population varies from trapezoidal to triangular on the leg.

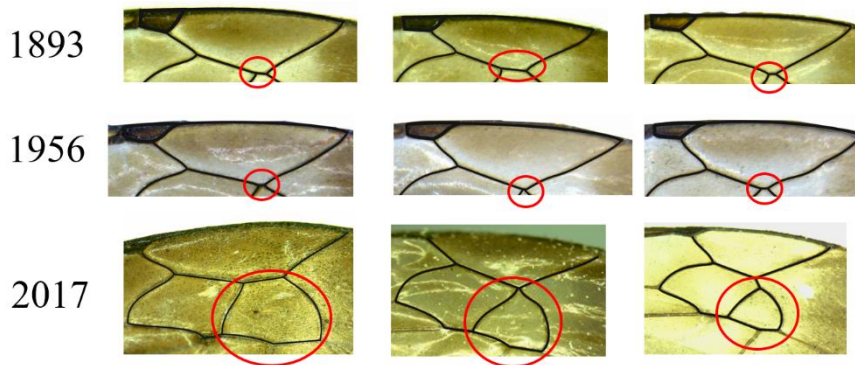


Fig. 9. The scheme of changes in the proportion of the wing (2Rs) *Anoplius (Ar.) viaticus*.

Along with other changes in *Vespa crabro* L., we noted a complication of the pattern on the abdomen and clypeus, as well as the replacement of light yellow in color with a dark yellow, almost orange color (Fig. 10).

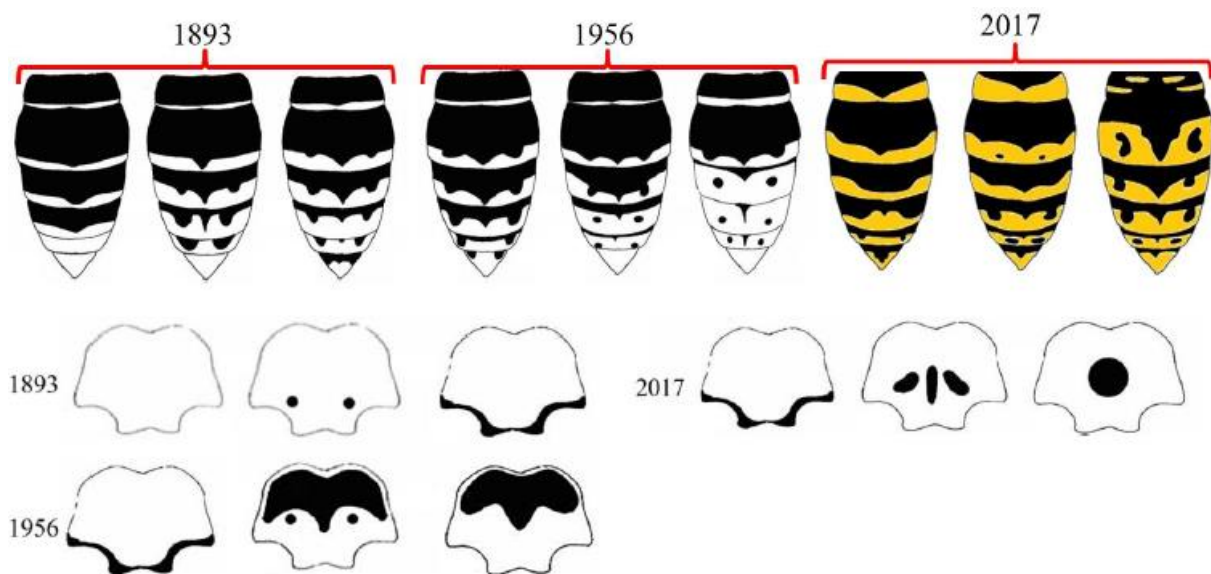


Fig. 10. Variants of pattern changes on the abdomen and clypeus in *V. crabro*.

## Conclusion

Thus, for 120 years, we have been observing aridization of biotopes in Western Siberia and, as a result, we can observe the reaction of natural insect populations to climate changes in various manifestations - changes in the species composition, changes in the appearance of an insect, changes in the life cycle of a species.

## Acknowledgements

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