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Changes in ranges: trends in distribution of true bugs (Heteroptera) under conditions of the current climate warming

Изменения ареалов: влияние потепления климата на распространение полужесткокрылых (Heteroptera)

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КЛЮЧЕВЫЕ СЛОВА: Hemiptera, потепление климата, распространение, изменение ареала.

ABSTRACT. Many species of true bugs have been recently reported to change their distribution ranges, presumably in response to the current climate change. Such expansion of ranges of individual species can enrich local faunas and change community structure, especially at the northern latitudes. The ongoing warming is expected to further affect ecology and distribution of true bugs, what may result in alternation of their economic importance. Careful monitoring of ranges can reveal timely the species requiring particular attention.

РЕЗЮМЕ. В последние годы появляется много сообщений о расширении ареалов некоторых видов полужесткокрылых (Heteroptera), что, вероятно, связано с потеплением климата. Такие изменения ареалов могут привести к повышению видового разнообразия и изменению структуры сообществ на местном и региональном уровнях, особенно в северных широтах. Ожидается, что продолжающееся потепление климата будет оказывать значительное влияние на экологию, распространение и хозяйственное значение настоящих полужесткокрылых. Тщательный мониторинг изменений ареалов будет способствовать своевременному выявлению видов, требующих особого внимания.

Adapt or perish, now as ever, is nature's inexorable imperative.
Herbert G. Wells (1866–1946)

Introduction

Since the late 19th century the global mean surface temperature has warmed by a mean of approximately 0.6 °C. The 1990s were the warmest decade during the whole period of precise recording [IPCC, 2001a] and the year 2005 was the warmest year since the late 1800s followed by 1998, 2002, 2003 and 2004 [Gutro, 2006]. From 1976 onwards, the Earth has been warming at a rate faster than it has done in the last 1 000 years [IPCC, 2001b]. Further warming is predicted with an estimated increase of 1.4–5.8 °C by 2100 [IPCC, 2001a].

Insects are poikilothermic organisms and all aspects of their biology greatly depend on environmental conditions, especially temperature. The likely and realized responses of insects to the current temperature increase, associated environmental changes, such as elevated CO_2 level, water availability, and their interactions are the subject of rapidly growing literature [e.g., Harrington & Stork, 1995; Walther et al., 2001]. Observed and predicted climate change is likely to affect — both directly and indirectly — insect distribution, abundance, phenology, voltinism, physiology, behaviour, and community structure [Hughes, 2000; Bale et al., 2002].

During the last two decades many studies have focused on responses of individual insect species to climate change and much has been learned about specific taxa [e.g., Hill et al., 2001; Reemer et al., 2003]. While responses of some insect taxa, e.g. Lepidoptera and Homoptera, are extensively studied and well understood [Harrington et al., 1995; Woiwood, 1997], far less is known about responses of other taxonomic groups. Thus, the Heteroptera, a large taxon with some 37 000 described species world-wide including many species of economic importance [Schaefer & Panizzi, 2000], has received little attention and responses of true bugs to climate warming remain mostly unexplored and poorly understood. In this paper we review reported cases of

Heteroptera distribution changes which are believed to be caused by or associated with climate warming at both the individual species and regional fauna levels. Other ecological and physiological responses of true bugs are considered elsewhere [Musolin, 2006].

Changes in insect distribution ranges

Distribution ranges of insects are not invariable. They are constrained by several abiotic and biotic factors such as climate (mostly, through temperature requirements), food and habitat availability. Insects can quickly adjust their ranges when conditions change [Uvarov, 1931; Cammell & Knight, 1992]. Shifts of distribution ranges are the most easily observed, the least controversial and, thus, the most often reported responses of insects to climate change. They may include changes of only one or some of the range's boundaries (e.g., southern or northern ones) or a shift of the entire range [Parmesan, 2001]. Warming is expected to promote the latitude (poleward) or altitude (upward) range shifts in insect species currently limited by low temperature (directly or via ranges of host plants/animals). A 2 °C rise in temperature, which is within the expected warming range [IPCC, 2001a], is roughly equivalent to a shift of current distribution of 600 km latitude or 330 m in elevation [Parry, 1989 – after Harrington et al., 2001]. Range shifts may be massive. For example, studies of 35 non-migratory European butterflies have shown that 63% of them had shifted their ranges to the north by 35–240 km during the 20th century, whereas only 3% had shifted to the south [Parmesan et al., 1999].

Changes in individual Heteroptera species distribution ranges that are likely to be associated with climate warming

Well-developed and established systems of insect species recording (e.g., those based on the 10-km square grids used in the UK or the Netherlands [Judd & Hodkinson, 1998; Aukema, 2003]) allow successful tracking of distribution changes of individual insect species. Recently, several southern European true bug species have been reported as new in northern Europe. Thus, *Deraeocoris flavilinea* (A. Costa, 1862) (Miridae) was first noticed in Britain in 1996 [Miller, 2001] and appears to have established itself and spread rapidly [Nau & Brooke, 2003]. The related species *Deraeocoris olivaceus* (F., 1777) (Miridae) was first recorded in Britain earlier, in 1951 [Sands, 1954], and established itself there, though has not become widespread or numerous [Nau & Brooke, 2003]. Other examples of many species recently arrived to Britain include *Tuponia brevirostris* Reuter, 1883 and *Tuponia mixticolor* (A. Costa, 1862) (both Miridae) [Barclay & Nau, 2003], *Eurydema ornata* (L., 1758) (Pentatomidae), *Cymatia rogenhoferi* (Fieber, 1864) and *Sigara iactans* Jansson, 1983 (both Corixidae) and *Naucoris maculatus* F., 1798 (Naucoridae) [B.S. Nau, pers. comm.].

Jones [2004] reported that *Brachycarenus* (=*Rhopalus*) *tigrinus* (Schilling, 1817) (Rhopalidae) had been recorded in 2003 in London for the first time in Britain. He also discussed several other rhopalid species that had recently appeared or reappeared in Britain and suggested that those arrivals were related to a series of hot dry summers and mild winters.

A colony of the mostly brachypterous *Pyrrhocoris apterus* (L., 1758) (Pyrrhocoridae) was first discovered in Surrey, the UK, in 1996 and survived at least until 2003. Whereas this species had been occasionally reported in the UK, its appearance and – more important – survival in Surrey was believed to provide an evidence of the global warming [Hawkins, 2003].

Biogeography and recent changes in the British Lygaeidae fauna and the effect of climate on distribution of these bugs was discussed by Judd & Hodkinson [1998]. The series of maps showing field records of *Ischnodemus sabuleti* (Fallén, 1826) from pre-1990 until the end of the 20th century clearly demonstrated a northward range expansion of this species. It is stressed that "global warming may produce a major northward expansion of lygaeid ranges" [Judd & Hodkinson, 1998, p. 237].

Nezara viridula (L., 1758) (Pentatomidae) is widespread in the tropics, subtropics and warmer regions of the Temperate Zone in Eurasia, Africa, Australia, North and South America. In Southern Europe it has been distributed north to Germany [Panizzi et al., 2000]. The species has been accidentally but repeatedly brought with produce to Britain [Barclay, 2004] and 45 years ago Southwood & Leston [1959] commented that it was "unlikely to become established" in the British Isles. In 2003, however, a few colonies of *N. viridula* were reported breeding in London [Barclay, 2004; Shardlow & Taylor, 2004] and survived winter of 2003/2004 [M.V.L.Barclay, pers. comm.]. Again, it was suggested that the colonization became possible because of the current climate warming [Shardlow & Taylor, 2004].

Several true bug species of southern European distribution were recorded as new arrivals in the Netherlands since 1980, e.g. *Cymatia rogenhoferi* (Fieber, 1864) (Corixidae), *Brachyarthrum limitatus* Fieber, 1858, *Conostethus venustus* (Fieber, 1858), *Reuteria marqueti* Puton, 1875 (all Miridae), *Coriomeris scabricornis* (Panzer, 1809) (Coreidae), *Eurydema ornata* (L., 1758) and *Stagonomus pusillus* (Herrich-Schaeffer, 1833) (both Pentatomidae) [Aukema, 1989, 2003; Aukema et al., 2005 and references therein].

The North American *Leptoglossus occidentalis* Heidemann, 1910 (Coreidae) had been previously confined to the western third of the USA and Canada, but during the last 50–70 years has shown a strong eastward range expansion [Marshall, 1991; Gall, 1992; Ridge-O'Connor, 2001]. It has been suggested that this natural range expansion was augmented by humans [Gall, 1992] but is also likely to have been promoted by the climate change [Marshall, 1991].

In Western Japan, the northern limit of distribution of *N. viridula* was in Wakayama Prefecture in the early 1960s and it was limited by the +5°C coldest month

Table 1. Recent changes of Heteroptera faunas in three European countries.
Таблица 1. Недавние изменения фауны Heteroptera в трёх странах Европы.

Country	Period	New species (including overlooked)	Definite new arrivals (as per cent of all new species) *	References
The UK	1978–1998	29	17 (58.6)	Kirby et al., 2001
The Netherlands	1980–2002	27	17 (63.0)	Aukema, 2003
Austria	1991–2003	24	14 (58.3)	Rabitsch, 2004

* the definite new arrivals are believed to be linked to climate warming in all three countries (see References above and the text).
* считается, что появление этих видов в указанных странах связано с потеплением климата (см. приведённые ссылки и текст).

mean temperature isothermal line [Kiritani et al., 1963]. By 2000, *N. viridula* was recorded 70 km further north (in Osaka). Historical climate data analysis suggested that the increase of mean and lowest winter month temperatures by 1–2°C in Osaka from the 1950s to the 1990s improved potential overwintering conditions for *N. viridula* and, thus, promoted northward range expansion of the species [Musolin & Numata, 2003; Musolin, 2006]. Several other Japanese heteropterans are believed to respond in a similar manner to the recent increase of temperature [Kiritani, 2006].

The anthropogenic local warming as a form of 'heat island' around large urban areas has been suggested as a factor in the northward range expansion of *Orius* (*Heterorius*) *strigicollis* (Poppius, 1914) (Anthocoridae) in central Japan. The species' distribution is constrained by low temperature in winter and during the last 50 years the range border shifted northwards by approximately 1° latitude, mostly along the coast and around the cities [Shimizu et al., 2001].

Finally, *Calidea dregii* Germar, 1838 (Scutelleridae) has recently expanded its range southwards – from northeastern to southwestern South Africa [Giliomee, 1997]. In the Southern Hemisphere responses modulated by climate change are assumed to have an opposite geographic direction compared with those in the Northern Hemisphere.

Changes in local and regional Heteroptera faunas

The expansion of ranges of individual species stimulated by climate warming can enrich local faunas, especially at northern latitudes. Thus, during a decade prior to 1996, additions to the Heteroptera list of Bedfordshire (south-east of the UK) averaged only 1.5 species per year; but in a single 1996 an additional 10 new, mostly xerophile, species were recorded [Nau, 1997].

Such trends are becoming more-and-more obvious on a national scale too. Kirby et al. [2001] analysed changes in Heteroptera fauna of the UK during 1973–1998 and concluded that over this period 17 new species of terrestrial and aquatic true bugs (from five families) had arrived, established and perhaps further expanded in range (Table 1) and that another 15 native species (seven families) had appeared to expand their former ranges within the UK. It was further emphasized that almost all the recorded changes in Heteroptera fauna (i.e. more than 60 species) were increases [Kirby et al., 2001] in contrast to the Macrolepidoptera where there were many species in decline [Southwood et al. 2003]. Climate change, or at least the particular warm weather conditions experienced over recent years, was considered an obvious candidate for the cause of these changes [Kirby et al., 2001; Southwood et al., 2003].

A similar trend was recorded in the Netherlands (Table 1). The national Heteroptera list increased from 488 in 1951 to 610 by 2002 [Aukema, 2003] and 618 by 2005 [Aukema et al., 2005]. Whereas the early increase of the total species number is likely to represent an initial fauna inventory, the additions to the list since 1980 are most likely to be the consequence of anthropogenic effects and/or global warming. Appearance of 17 new species from eight terrestrial and aquatic families from 1980 to 2002 (i.e. 63.0% of new arrivals) is explained by range expansion of southern species, most likely stimulated by the global warming. This assumption is further supported by the fact that 70.2% of records of these species came from the southern and south-eastern (i.e. 'continental') Dutch provinces, where only two of the 17 new species have not been recorded [Aukema, 2003]. Some Heteroptera species, however, suffered decline in the Netherlands: seven species formerly recorded in the country seem to have become extinct since 1980 and the causes of extinction (other than disappearance of habitat) remain unclear [Aukema, 2003].

Comparable increases of national Heteroptera fauna were recorded in Austria (Table 1), with at least one new species arriving per year in 1991–2004 (along with another 10 species that have probably been overlooked previously). Such mass invasion of southern European species was even called '*Mediterranization*' of the Austrian fauna [Rabitsch, 2004].

While it is difficult to prove causal relationship between the climate warming and recent enrichment of local and national Heteroptera faunas in these three countries (Table 1), the assumption that warming has greatly contributed to this process has some support: in all these countries climate has changed in a similar way and temperature has risen by approximately 1 °C through the 20th century [Böhm et al., 2001; Hulme et al., 2002; Verbeek, 2003].

Conclusions

Much has been learned about the ways insects respond to the current climate warming and, whereas responses to environmental changes are species-specific, some general patterns are becoming obvious [e.g., Harrington & Stork, 1995; Bale et al., 2002; Reemer et al., 2003]. In spite of the economic importance and distribution in a wide range of habitats, the responses of Heteroptera species to the global warming remain less studied and understood than the responses of some other taxa (e.g. Lepidoptera or Homoptera). As a whole, Heteroptera species respond similarly to the general pattern. It has been shown above that many true bug species have recently exhibited northward distribution range expansion. This trend is particularly evident in northern Europe due to the well-developed practice of insect recording. Often the same species are reported new within a few yeas in different countries showing a wide scale pattern of range expansion [Aukema, 2003]. It is likely that the northern boundaries of the ranges of such species are constrained by low temperature (e.g., via seasonal temperature minima or annual amount of available heat).

As discussed elsewhere [Musolin, 2006], some Heteroptera species have improved winter survival, advanced spring phenology and/or shown changes in abundance, behaviour or physiological adaptations. Whereas increases in the number of annual generations have not been recorded in Heteroptera, the analysis of thermal requirements of true bug species suggests that they are expected to occur [Yamamura & Kiritani, 1998].

Finally, range expansion is often promoted by international transportation and trade of plant materials or produce [Kirby et al., 2001; Aukema, 2003], which — along with warming — can lead to considerable changes in the structure of local insect communities.

There is little doubt that further climate warming will affect ecology and distribution of true bugs, what may result in alternation of their economic importance. Careful monitoring of ranges can timely reveal the species requiring particular attention.

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This animation shows the evolving distribution of 12-month average temperature anomalies across the surface the Earth from 1850 to present. Anomalies are measured with respect to 1951 to 1980 averages. The red vertical line shows the global mean, and matches the red trace in the upper-left corner.Â The earth changes constantly, it is hard to know how much of the current climate change is created by Industrial evolution and not just by a significant increase in planetary life. More data is simply needed. permalink. Musolin, D.L. & Fujisaki, K. (2006) Changes in ranges trends in distribution of true bugs (Heteroptera) under conditions of current climate warming. Russian Entomological Journal. 15, 175-179.Â Annalen des Kaiserlichkoniglichen naturhistorischen Hofsmuseum Wien, 22, 33-80. Schaefer, C.W. & Panizzi, A.R. (2000) Chapter I: Economic Importance of Heteroptera: A general view, 3-8. In: Heteroptera of Economic Importance, 828 pp. Schuh, R.T. (1995) Plant bugs of the World (Insecta: Heteroptera: Miridae). Systematic Catalogue Geographic distributions, Host list, and Bibliography. Ed. New York Entomological Society: I-XII, 1-1329. Heteroptera, or true bugs populate many climate zones, coping with different environmental conditions. The aim of this study was the evaluation of their thermal limits and derived traits, as well as climatological parameters which might influence their distribution. We assessed the thermal limits (critical thermal maxima, CTmax, and minima, CTmin) of eight seed bug species (Lygaeidae, Pyrrhocoridae) distributed over four KÃ¶ppenâ€"Geiger climate classification types (KCC), approximately 6Â° of latitude, and four European countries (Austria, Italy, Croatia, Bulgaria).Â Thermal tolerance breadth (TTB) is the temperature range in which the bugs were able to exhibit voluntary coordinated movement. It was calculated as TTB = CTmax âˆ' CTmin.