

Range expansion of the southern green stink bug *Nezara viridula* (Heteroptera: Pentatomidae) in response to the rapid climate change in Japan

Dmitry L. Musolin

Climate warming is unequivocal (IPCC 2007). The average global temperature has increased by about 0.8°C since the beginning of its instrumental measurements in 1880, and the 2000–2009 decade was the warmest decade since then (GISS 2010). The linear warming trend for the last 50 years (0.13°C/decade) is nearly twice that for the last 100 years and a further warming of about 0.2°C/decade is projected for the next two decades (IPCC 2007). There is now considerable attention directed to how the global biota are and will be responding to global warming (Bale et al. 2002; Parmesan 2006; IPCC 2007; Deutsch et al. 2008).

The southern green stink bug, *Nezara viridula* (L.) (Fig. 1), is apparently responding rapidly to climate warming (Musolin 2007; Yukawa et al. 2007; Tougou et al. 2009). The species occurs in an ever-widening range throughout tropical & subtropical regions and Japan is at the northern margin of its Asian range (Fig. 2). In the north, *N. viridula* is replaced by a congeneric species, the oriental green stink bug, *Nezara antennata* Scott. Both species, and especially *N. viridula*, are major agricultural pests.

In the early 1960s, Kiritani & co-workers conducted a wide-scale field survey and mapped the northern limit of the range of *N. viridula* in central Japan (Fig. 3a; Kiritani et al. 1963). They showed that the northern limit of the species' distribution in central Japan occurred in Wakayama Prefecture (latitude approximately 34.1°N). *Nezara antennata* dominated in northern and central parts of the prefecture, whereas coastal and the southern parts of the prefecture were mostly or completely occupied by *N. viridula* (Fig. 3a). In general, *N. viridula* was found to occur sympatrically

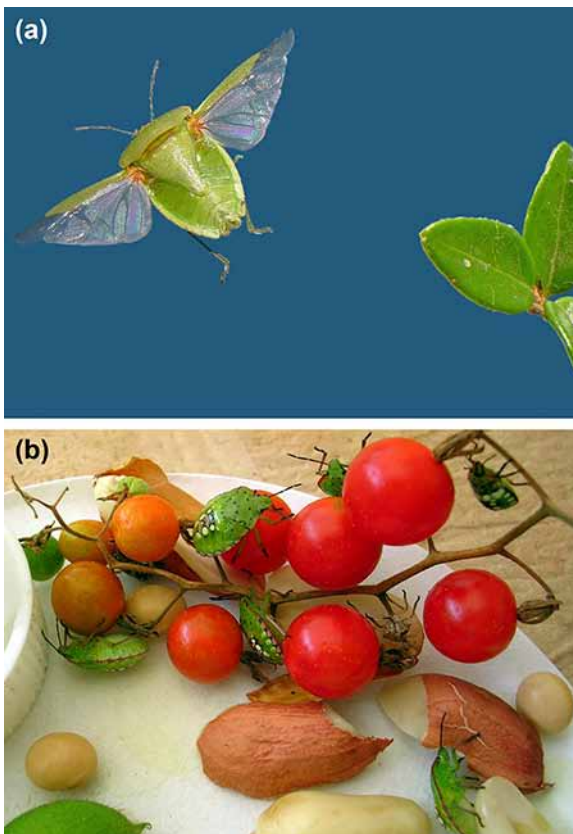


Figure 1 - *Nezara viridula*, (a) adult in flight; (b) nymphs of different instars in laboratory culture.

Photographs: (a) P. Weissbach, (b) D. Musolin.



Figure 2 - Outline of current ranges of *Nezara viridula* & *N. antennata* in Japan, & location of surveys (see Fig. 3).

in the warmer parts of the range of *N. antennata*. The area of co-existence of the two species was shown to lie on the +5°C isothermal line for mean temperature of the coldest month (usually January), therefore January temperature was proposed as the principal factor determining the northern limit of *N. viridula*'s distribution (Kiritani et al. 1963).

Since the 1960s, several records have been published documenting a presence of *N. viridula* at locations in central Japan further north from the previously established limit of the species' distribution (Musolin 2007; Ohno & Nakamura 2007; Yukawa et al. 2007, 2009). Isolated records, however, can neither reveal the current limit of the *N. viridula* range in the region nor show its dynamics. The objectives of this study were to determine the current northern limit of *N. viridula* in central Japan, compare it with the unique 45-year-old data available from the survey of the early 1960s and assess, using historical climate information as well as recently published ecophysiological data on the overwintering of *N. viridula*, what factors could have promoted the change in the ranges of *N. viridula* and *N. antennata* in the region. The results of the study were published elsewhere (Tougou et al. 2009) and briefly summarised below.

To determine the current northern limit of *N. viridula*, an extensive field survey was conducted in six prefectures in central Japan in 2006–2007 (Tougou et al. 2009). At the three northernmost locations in Wakayama Prefecture, only *N. antennata* was recorded in the early 1960s (Fig. 3a; Kiritani et al. 1963). In contrast, *N. viridula* was not only present but even dominated there in the 2006–2007 field survey (Fig. 3b). Inspections in Osaka Prefecture (north of Wakayama Prefecture) showed a wide distribution of *N. viridula*. It was found in 11 of 14 locations and dominated in eight of 10 locations where both species were found. In the three more northern & inland prefectures, viz., Nara, Kyoto, & Shiga Prefectures, only *N. antennata* was recorded in spite of an intensive search. Finally, in the easternmost of all visited prefectures, viz., Mie Prefecture, out of nine locations surveyed, *N. viridula* was present and dominated only at one, situated southernmost and approximately 16 km from the Pacific Ocean (Fig. 3b). Thus, the new survey demonstrated that the

Figure 3
Distribution & relative abundance of *Nezara* spp. in central Japan.

(a) early 1960s (Kiritani et al. 1963)

(b) 2007 (Tougou et al. 2009)

Species:

black = *N. viridula*

white = *N. antennata*

Sample size:

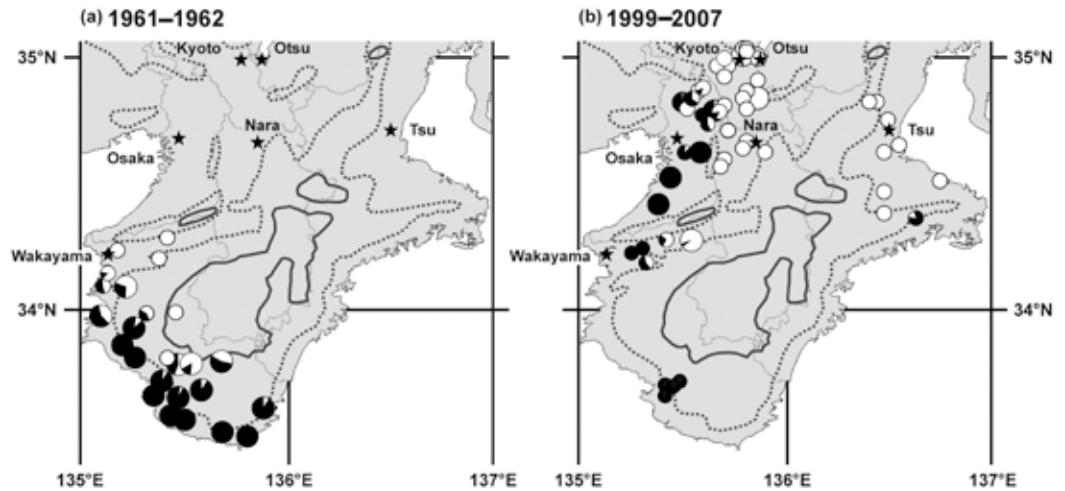
small circle= 1–50

large circle= over 50

Contours:

dotted = 500 m a.s.l.;

solid = 1,000 m a.s.l.



northern limit of *N. viridula*'s distribution range had shifted northward by about 85 km from the early 1960s (Fig. 3).

Overwintering is a critical phase of the seasonal cycle of *N. viridula*. Data on mean monthly temperature during the overwintering period (October–March) at six meteorological stations over the range of the field survey show that at five locations, mean January and February temperature was 1.03–1.9°C higher during the last decade (1998–2007) than it was during the decade of the previous field survey (1960–1969; Fig. 4). The mean temperature increased much less (0.1°C in January and 0.4°C in February) only in Otsu City, though for this location the data set for 1978–1987 was used instead, thus shortening the period for comparison to only 20 years. In the 1960s, the lowest month's temperature exceeded the critical for *N. viridula* +5°C level only in Wakayama City. Due to warming during the last 45 years, the mean January temperature has exceeded the +5°C level in Osaka and Tsu, and Kyoto is also very close (4.8°C; Fig. 4).

The mean number of cold days (i.e. days with daily mean temperature below +5°C) in January–February significantly decreased at five locations from 1960–1969 to 1998–2007 (Fig. 5a). This parameter tended to decrease in Otsu as well, though the difference was not statistically significant. The mean annual lowest temperature significantly increased at five locations from 1960–1969 to 1998–2007 (Fig. 5b), with the mean temperature increase ranging between 1.4 and 3.0°C.

A comparison of the recent climatic and distribution data revealed that the incidence of *N. viridula* tended to be low or the species was absent north of the latitude 34.6°N, at the locations where the mean January temperature was below +5.0°C, annual lowest temperature

was below –3.0°C, and the number of cold days exceeded 26. The constructed general linear model (incorporating three climatic parameters and their interactions) revealed that the mean January temperature and the number of cold days significantly control the northern limit of distribution of *N. viridula*. The effect of the annual lowest temperature is not significant (Tougou et al. 2009).

Thus, the survey demonstrated that the northern limit of *N. viridula*'s distribution had shifted northward by 85 km from the early 1960s to 2006–2007, at a mean rate of 19.0 km/decade (Fig. 3). Analysis of climatic data shows that the mean January–February temperature in the region was 1.03–1.9°C higher in 1998–2007 than in 1960–1969. Altogether, the climatic data suggest that over the last 45 years environmental conditions have become more favourable for overwintering of *N. viridula* at many locations in central Japan. This has likely promoted the northward spread of the species, representing a direct response to climate warming. A sympatrically distributed congeneric *N. antennata* seems to respond to the warming by a retreat from the ocean coast towards cooler elevated habitats, which might be a complex response to elevated temperature and interspecific mating with *N. viridula* (Musolin 2007; Tougou et al. 2009).

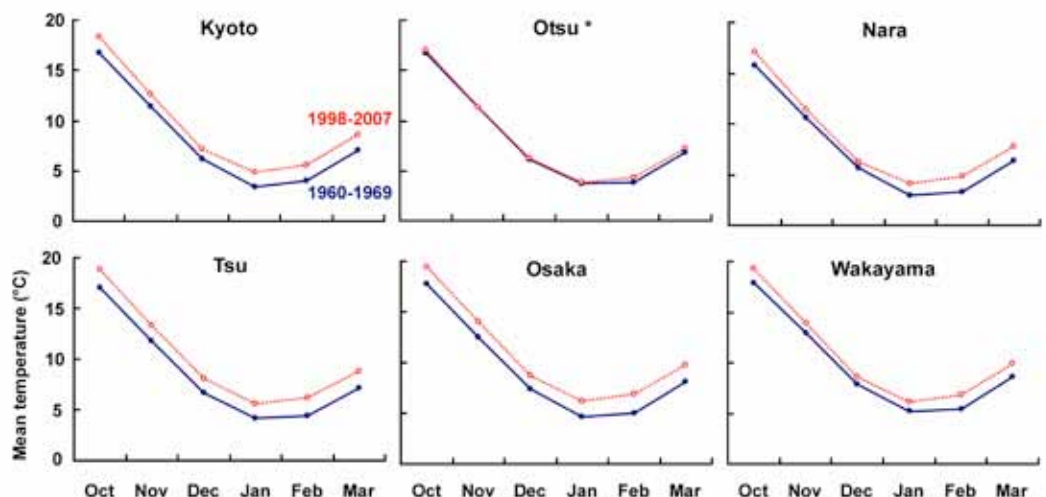
It has been repeatedly suggested that insects as well as other biota would respond to climate warming both directly and indirectly (e.g., Harrington & Stork 1995; Bale et al. 2002; Musolin 2007). *Nezara viridula* is clearly expanding its range northwards and, as this study shows, provides an example of a direct response to increased temperature. It remains unknown whether the overall range of the congeneric species, *N. antennata*, is changing or

Figure 4
Average monthly mean temperature in capital cities of 6 prefectures in central Japan

blue : 1960–1969
 (but Otsu: 1978–1987)

red : 1998–2007

(Tougou et al., 2009)



not, but within its range *N. antennata* retreats from ocean coastal areas towards cooler hills and bottoms of mountains and, thus, might represent a more complex response including, but probably not limited to, reaction to elevated temperature and interspecific mating with *N. viridula*.

In the near future, as global warming continues, *N. viridula* will most probably continue its northward expansion starting along the coast (where winters are milder) and in the urban

areas (due to the 'heat island' effect). Establishing new permanent populations will greatly depend on winter climatic conditions and the ability of the species to adjust its physiological mechanisms of diapause induction (Musolin 2007).

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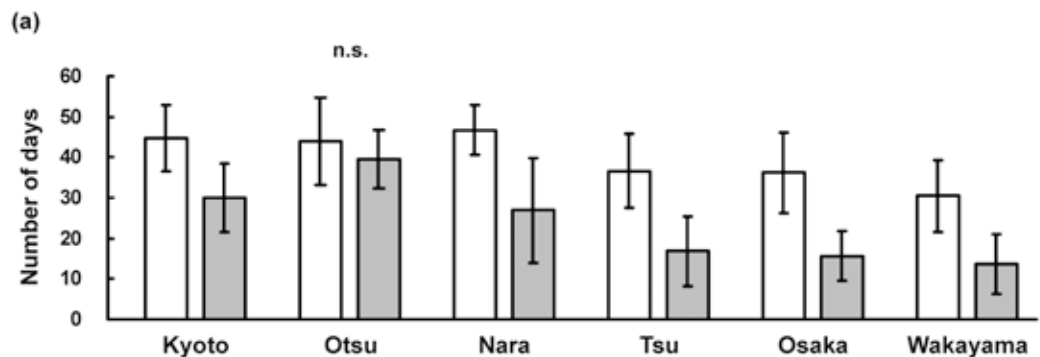
Figure 5 - Winter conditions (mean ± std. dev.) at six cities in central Japan.

White: 1960–1969
(Otsu 1978–1987)
Grey: 1998–2007

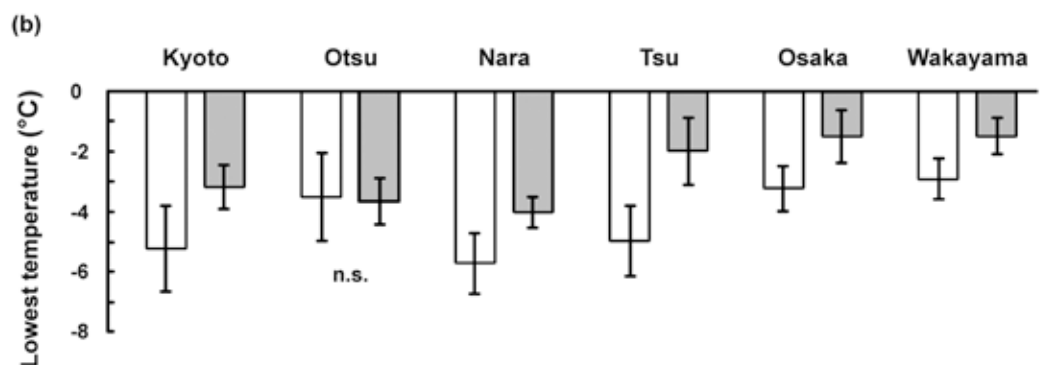
Differences significant, except Otsu.
t-test, $P < 0.001$; n.s. = not significant
(Tougou et al., 2009)

a) 'Cold days' (Jan–Feb).

Mean temperature < 5.0 °C.



b) Mean annual minimum.



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Address:

Dr. Dmitry L. Musolin,

Dept. of Entomology, Faculty of Biology & Soil Sciences,

St. Petersburg State University, Universitetskaya nab., 7/9,

St. Petersburg, 199034, RUSSIA.

musolin@gmail.com

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