positive or negative value, respectively. On the other hand, when it begins simultaneously, b is zero. The value of D' at a given temperature was calculated as $3\sum n_i/N$, where N is the total number of egg masses laid, and n_i is the total number surviving females at the i th time of examination which was made at 3-day intervals. Thus, the thermal law may be modified as,

$$(T - t_0)(D' + b) = K \quad (2)$$

where T is a constant temperature, t_0 is the threshold temperature for oviposition, and K is the thermal constant in day-degrees. Equation (2) takes the form of a rectangular hyperbola with the asymptote of $T = t_0$ and $D' = -b$, and it can be arranged as

$$TD' = (K + bt_0) - bT + t_0D' \quad (3)$$

The maximum probability estimates of t_0 , b and K can be obtained with multiple regression analysis by putting the observed values of D' and T into Eq. (3). The estimated values were 10.8°C, 4.9 days and 104.2 day-degrees for t_0 , b and K , respectively. The observed values of D' fit sufficiently well with theoretical values (Fig. 1). This equation (Eq. 2) may have general applic-

Fig. 1. Theoretical and observed values of the mean duration between successive ovipositions at the various constant temperatures.

ability for egg-laying phenomena of many insects, and may be useful in forecasting the mean date of oviposition with adequate knowledge of the survival rate of the adult female population in the field.

Geographic Trend in the Annual Population Fluctuation of the Green Rice Leafhopper, *Nephotettix cincticeps* UHLER (Hemiptera: Deltocephalidae)¹

Takashi KIDOKORO

Miyagi Prefectural Agricultural
Research Center, Natori, Miyagi
981-12, Japan

(Received September 14, 1978)

It was recently shown that the green rice leafhopper, *Nephotettix cincticeps*, is a typical insect whose density is regulated by density-dependent processes (KUNO, 1968). However, with this insect, which is spread over a wide geographic range, the controlling factors and mode of population fluctuation may depend on the area. In fact, populations in the Tohoku and Hokuriku districts show a marked population fluctuation and sometimes

reach a high density, causing measurable yield reduction due to sucking of rice plants and grains. Analyzing light-trap records in the Tohoku district, KOSHIHARA (1972) demonstrated that the abundance of adults in the late season positively depended on that in the early part of the year. At Toyama, located in the Hokuriku district, the seasonal trend of population increase was similar to that in Tohoku, although the abundance of later generations was regulated to a lesser extent by the density of the preceding generations (JOHRAKU et al., 1976). In the present paper, the author examined the geographic variation in the annual light-trap catch of *N. cincticeps* throughout Japan.

The catch records utilized here were obtained from the "Annual Totals of Important Rice Pest Insects Caught in Light-Traps in Japan" compiled by ÔTAKE (1976, unpublished). In order to secure the reliability of data, he mainly used the catch records obtained by light-traps located at Prefectural Agriculture Experiment Stations. In the

¹ Appl. Ent. Zool. 14 (1): 127-129 (1979).

present work, the author analyzed only the data taken for ten years or more at the same location.

Three typical examples of the annual fluctuations in catch are shown in Fig. 1. Type A shows an enormous fluctuation from nearly zero to 1,000,000 individuals. This type of fluctuation was observed in the northern parts of the Tohoku district, which forms the northern limit of distribution of *N. cincticeps*. In type B, the mean number caught by a light-trap was greater than A, and a saw-toothedlike fluctuation appeared in the annual catch. This type occurred both in Hokuriku and the southern parts of the Tohoku district. The magnitude of the annual fluctuation and the mean number of the catch were relatively small in type C, which was commonly observed in the Kanto district and southward.

In order to examine the geographic trend in the magnitude of the annual population fluctuation, the coefficients of variation (C.V.) of annual catches were plotted against the latitude of trap location (Fig. 2). The value of C.V. tends to increase with increasing latitude, which means that the magnitude of fluctuation in northern Japan is greater than in the south.

The means of the five higher records and five lower records for each trap are plotted against their latitude (Fig. 3). Although the points are greatly scattered, the value for higher records tends to increase toward the north, but decreases drastically near the northern boundary. The value for lower records gradually decreases toward the north, but with a sharp decline around 39°N.

There is a possibility that low temperatures which prevail late in the season in northern Japan

Fig. 2. Relation between coefficient of variation of annual light-trap record in *N. cincticeps* and the latitude of recording site.

Fig. 3. Mean annual catches of *N. cincticeps* for five higher years (closed circles) and five lower years (open circles) in relation to latitude of trap location.

Fig. 1. Selected examples of annual fluctuation of light-trap record in *Nephotettix inciticeps* for different geographic sites. Dotted line: northern limit of distribution.

may reduce the trapping efficiency of the light-trap and may also reduce the number of generations per year. In spite of these factors which may contribute to reducing the number of catches in the northern area, the positive correlation between the latitude and the mean catch for abundant years may validate the relatively high population density during abundant years in northern Japan. The catastrophic shift in this trend suggests that the population near the northern extreme is usually held to a low density, but sometimes reaches an epidemic level.

The results obtained here coincide well with the assertion that the population density of species in the central part of its distribution range or in favorable habitat will be relatively stable because

of density-dependent processes, while it will change greatly and sometimes peak and escape from density-dependent processes in peripheral or unsuitable habitats (HUFFAKER and MESSENGER, 1964). In southern parts of Japan, several intensive studies on the population dynamics of *N. cincticeps* showed that the annual fluctuation in peak density was extremely small as compared with some planthoppers which inhabit the same rice paddy field. With regard to their regulation mechanism, MIYAI et al. (1978) observed that in Shikoku spiders frequently played a critical role in keeping the population density of *N. cincticeps* below the level where the intraspecific regulatory mechanism would operate. HOKYO (1973) pointed out that the change in fecundity caused by adult dispersal was the most important feedback mechanism of the population density of *N. cincticeps* in Kyushu. In the Tohoku and Hokuriku districts, on the other hand, the density of peak generation fluctuates greatly, directly reflecting the variation in the density of the early generation, which is determined by the temperature or the amount of snowfall during the winter (KOSHIHARA, 1972; ÔTAKE, 1966; JOHRAKU and KATO, 1974). Furthermore, the predominant role played by climatic conditions in this area has been demonstrated by the fact that synchronous outbreaks over a wide range are likely to occur, as reported by ÔTAKE (1966) and KOSHIHARA (1972). Although the reason regulatory processes are lacking or weak in northern Japan remains to be determined, one of the reasons may be the poor action of the natural enemy complex on the population of *N. cincticeps*. The great variation in the density of the early generation may facilitate escape from

natural enemy control in abundant years and the low number of generations inhibits the regulatory mechanism in northern Japan.

The increasing importance of climatic factors rather than biotic regulation factors, thus, may cause an increasing magnitude of fluctuation in population density toward the north, resulting finally in extinction in the area where the winter weather is too severe for *N. cincticeps* to survive.

The author wishes to express his sincere thanks to Dr. A. ÔTAKE, Fruit Tree Research Station, for providing the records. Thanks are also due to Dr. K. KIRITANI, Kochi Prefectural Institute of Agricultural and Forest Science, for his critical reading of the manuscript.

REFERENCES

- HOKYO, N. (1973) *Bull. Kyushu Agri. Expt. Stn.* **16** : 283-382.
- HUFFAKER, C. B. and P. S. MESSENGER (1964) In *Biological Control of Insect Pests and Weeds* (ed. P. DEBACH), pp 74-117. Chapman & Hall, London.
- JOHRAKU, T. and S. KATO (1974) *Proc. Assoc. Pl. Hokuriku* **22** : 30-31.
- JOHRAKU, T., S. KATO and T. WAKAMATSU (1976) *Proc. Assoc. Pl. Prot. Hokuriku* **24** : 19-21.
- KOSHIHARA, T. (1972) *Ann. Rept. Plant Prot. North Japan* **23** : 71-77.
- KUNO, E. (1968) *Bull. Kyushu Agri. Expt. Sta.* **14** : 131-246.
- MIYAI, S., K. KIRITANI and T. SASABA (1978) *Protection Ecology* **1** : 9-21.
- ÔTAKE, A. (1966) *Res. Popl. Ecol.* **8** : 62-68.