MODELS FOR MEDIUM- AND LONG-RANGE FORECASTING OF THE AMOUNT OF MIGRATION OF FIRST-GENERATION MOTHS INTO THE OUTBREAKING AREA OF THE SECOND-GENERATION ARMYWORM

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ABSTRACT

With the aim to establish an "optimum" regression, an attempt is made through stepwise regression analysis to construct medium- and long-range models for forecasting the amount of migrants of the first-generation adults of armyworm into the outbreaking area of the second-generation armyworm in Northeast China and Inner Mongolia by applying precedent data of meteorological elements, general circulation features and insect pest situation. The formulas established are found to be rather satisfactory, which add a new approach to the simulation prediction of the armyworm.

I. INTRODUCTION

Armyworm (*Mythimna separata Walker*) is one of the chief pests to grain crops in China. They have the habit of long distance migration, moving northward in spring and summer and southward in autumn and spreading damages through their successive generations along the way. On the basis of their migration tracks and the information of their source and growth conditions, essentially correct qualitative forecast of the plague of armyworm has been made[1,2]. In order to push forward the objective, quantitative prediction, the authors of the present work have carried on investigations on constructing models for predicting the amount and period of migration of overwintered adults into the outbreaking area of the first-generation armyworm; for forecasting the time period of migration of the first-generation adults into the outbreaking area of second-generation armyworms; and for the long-range prediction of the extent of outbreaking of the second-generation armyworms[3—4]. Based on the preceding investigations, the present work concentrates on the exploration of a medium- and long-range prediction models for the amount of migration of the first-generation adults into the outbreaking area of second-generation armyworm, such as the Northeast, and Inner Mongolia, using the precedent data of meteorological elements, circulation patterns and pest growth as predictors.

II. RATIONALE

The outbreaking of second-generation armyworm in such areas as the Northeast and

Inner Mongolia results from the migration of first-generation adults which plagued the Changjiang–Huaihe River valley or the Huanghe–Huaihe River valley. The size of the adult migrants depends not only on the amount of the first-generation larvae but also on the environmental meteorological conditions during the period of their growth in the source area and that of their migration. It has been found[1] that the armyworm is moderately thermophilic but moisture-loving and that its incidence is closely related to the meteorological conditions under natural environment. A general survey has been made about the weather conditions, the general circulation patterns and the pest situation itself preceding the outbreaking of the first-generation armyworm and before its migration from the area over the Changjiang–Huaihe and Huanghe–Huaihe River valleys to determine the key factors affecting the amount of the first-generation adults migrating into the area of outbreaking of the second-generation armyworm. Then stepwise regression analysis is used to establish a feasible optimum model for medium- and long-range prediction.

III. METHODOLOGY

The relation between the first-generation armyworm outbreaking growth declining and the various meteorological elements is complex and complicated so that great care must be exercised in determining the key meteorological variables of biological and ecological significance to simulate the amount of migrant first-generation adults. The correlations are examined and the predictors are screened through stepwise regression in order that a biologically significant formula be established. The procedure may be described as follows.

(1) Representative stations such as Harbin Mudanjiang, Gongzhuling, Baicheng and Zhemeng (Fig. 1) are picked out and the respective amount of migrants of the first-generation adults into each of these stations is taken as the predictant.

(2) 12 stations in the Changjiang–Huaihe–Huanghe River valleys, Shanghai, Nanjing, Xuzhou, Fuyang, Ganyu, Linyi, Heze, Hefei, Nanyang, Zhengzhou, Suxian and Dongtai (Fig. 1) are selected whose climatological data from February to May are believed to be representative of the average climate of the area during the period of growth of the first-generation armyworm. It has been discovered that temperature and humidity are the most important meteorological elements related to the growth of the armyworm. Thus monthly and decadal mean values of air temperature, maximum air temperature, ground-surface temperature, maximum ground-surface temperature, precipitation, number of rainy days, amount of sunshine, days with maximum temperature $\geqslant 300°C$, etc. are calculated. The upper winds at 1500 m level, which are found to be related to the amount of migrants of first-generation armyworm out of the area, are also considered. In addition, characteristic features of the Subtropical High from January to May, which affect greatly the weather condition over the area, are also taken into account. These include the magnitude of the area covered by the Subtropical High, its indices of intensity, the limit of its westward extension, the location of its axis and the northernmost limit of the 5880-gpm contour (at the 500 hPa level) around the High, which are indications of the general circulation pattern. The situation on the growth of the first-generation armyworm at Xuzhou, Linyi, Fuyang, etc. is then gathered, the interrelation of the combination of factors analyzed, and tables (not shown) of correlations worked out.

(3) Through the analysis of correlations among the factors and after the tests for significance, predictors pending further screening by stepwise regression are thus chosen for medium- and long-range predictions. Simulation calculation can then be performed to

establish models for these predictions.

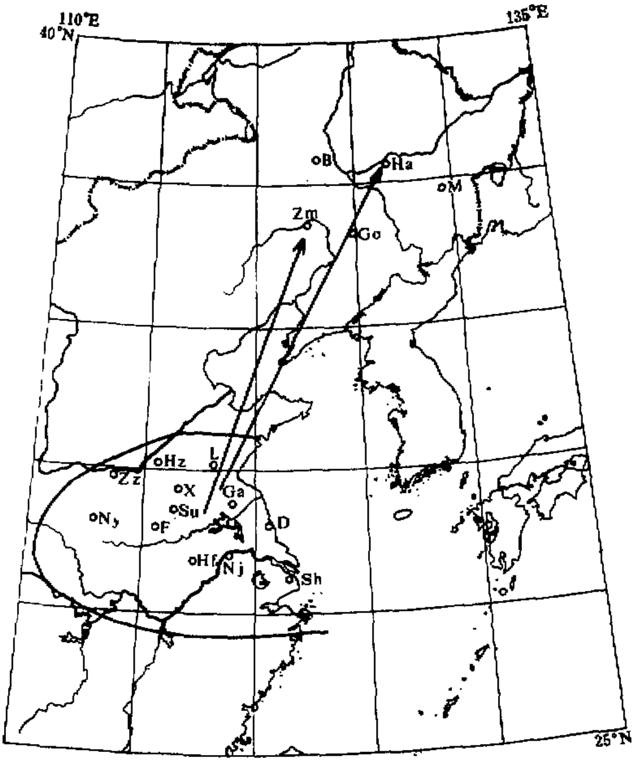

Fig. 1. The outbreaking area of the first-generation armyworm (enclosed by solid curve) and its direction of migration (shown by arrows).

B: Baicheng; D: Dongtai; F: Fuyang; Ga: Ganyu;
Go: Gongzhuling; Ha: Harbin; Hf: Hefei; Hz: Hezhe;
L: Linyi; M: Mudanjiang; Nj: Nanjing; Ny: Nanyang;
Sh: Shanghai; Su: Suxian; X: Xuzhou; Zm: Zhemeng;
Zz: Zhengzhou.

IV. ESTABLISHING PREDICTION MODELS

Examples for Harbin and Zhemeng areas may be cited as follows:

1. *Prediction Models on the Amount of First-Generation Moths ($\hat{y}$) for Harbin Area*

(1) *Two long-range models*

(a) $\hat{y} = 52.8675 - 3.3097x_1 + 0.1435x_2 - 0.1468x_3 - 0.1815x_4 - 9.5207x_5$

where, x_1 is the mean ground-surface temperature for the first decad of March of the current year at Nanyang; x_2, the monthly rainfall for March of the current year at Fuyang; x_3, the total rainfall for the first decad of April of the current year at Fuyang; x_4, the monthly rainfall for April of the current year at Hefei; and x_5, the extent of incidence of first-generation armyworm at Fuyang.

The multiple correlation coefficient R is found to be 0.92; F, the value of F-test, is 16.23, a very high significant value; and S, the standard deviation of the regression, is 10.164.

Substituting the past data from 1961 to 1980 to find the fitted values, the results are as follows: if evaluation of the score of prediction is done according to a two-way tendency, that is, above or below average number (the average number being 3299 moths per utensil of captured moths), the checking by historical data yields a successful score of 19/20. Attempts were made in 1981 and 1982 by using the above formula to forecast the tendency of development of the armyworm moths in those years. A deficiency (2733 moths per utensil) was forecasted for 1981 and it did happen in that year. The amount of moths was again predicted to be below normal (1895 moths per utensil for 1982), which was verified by actual observations as well.

(b) $\hat{y}=66.5664+7.9910x_1-4.4578x_2-0.1604x_3-0.1716x_4$

where, x_1 is the density of first-generation armyworm at Fuyang area; x_2, the mean ground-surface temperature for the first decad of March of the current year at Nanyang; x_3, the monthly rainfall for April of the current year at Dongtai; and x_4, the total rainfall for the first decad of April of the current year at Fuyang.

R is found to be 0.98; F, 14.04, a highly significant value; and S, 11.763.

The result of tests with historical data shows a rate of success of 17/20. Current forecasts for 1981 and 1982, both being predicted to be below the average number (2937 and 1501 moths per utensil respectively) were found to be correct.

The mean forecast values of the two preceding formulas, 2845 and 1698 respectively for 1981 and 1982, also conform with the actual below-normal tendencies.

(2) *A medium-range model*

$$\hat{y}=92.6232-0.2010x_1-4.6377x_2-3.7374x_3-0.3521x_4,$$

where, x_1 is the total rainfall for the second decad of May of the current year at Nanyang; x_2, the mean ground-surface temperature for the first decad of March of the current year at Nanyang; x_3, the number of days with maximum air temperature$\geqslant$30°C during the last decad of May of the current year at Nanjing; and x_4, the total rainfall for the first decad of April of the current year at Fuyang.

R is found to be 0.92; F, 22.19, again highly significant; and S, 9.734.

The ratio of success is 20/22 according to historical data. Current forecasts for 1981 (3136 moths per utensil) and 1982 (634 moths per utensil) agree with the fact as far as the below-normal tendency is concerned.

2. *Prediction Models of the Amount of First-Generation Moths for Zhemeng Area*

(1) *Three long-rang models*

(a) $\hat{y}=15.8266+0.4445x_1-0.3043x_2-0.1872x_3-2.4837x_4+0.8413x_5$

where, x_1 is the intensity index for the Subtropical High for March, the current year; x_2, the total of sunshine hours for the first decad of February of the current year at Heze; x_3, the total rainfall for the last decad of April of the current year at Shanghai; x_4, the number of days with the maximum air temperature$\geqslant$30°C during the second decad of May of the current year at Linyi; and x_5, the mean maximum ground-surface temperature for the second decad of March of the current year at Zhengzhou. R is found to be 0.87; F, 8.34; S, 7.519.

(b) $\hat{y}=23.8117+5.2285x_1-3.4848x_2+0.8862x_3-7.9076x_4+3.5760x_5+1.3028x_6$

where x_1 is the mean air temperature for March of the current year at Fuyang; x_2, the mean air temperature for the last decad of April of the current year at Linyi; x_3, the area index of the Subtropical High for February of that year; x_4, the area index of the Subtropical High for March of that year; x_5, the intensity index of the Subtropical High for March of that year; and x_6, the intensity index of the Subtropical High for April of that year. R is found to be 0.88; F, 17.65; and S, 7.313.

(c) $\hat{y} = -12.0130 + 0.8687x_1 - 3.9582x_2 + 1.0326x_3 + 0.2056x_4$

where, x_1 is the mean ground-surface temperature for the second decad of March of the current year at Zhengzhou; x_2, the area index of the Subtropical High for February of the current year; x_3, the area index of the Subtropical High for February of the current year; and x_4, the intensity index of the Subtropical High for February of the current year. R is found to be 0.86; F, 10.27 and S, 7.497.

The ratio of successful prediction as judged by historical data is respectively 17/20, 18/20 and 18/20 for the three preceding models. Current forecasts of amount of moths for 1981 by these formulas were respectively 4167, 2838 and 1989 moths per utensil, all showing an above-normal tendency (the average from 1961 to 1980 being 1625). The mean of the three forecast values was 2998, which was in good agreement with the actual observed value later that year. For 1982, all the three formulas predicted a below-normal trend, 805, 863 and 904 respectively, with a mean of 834 moths per utensil and the result was confirmed by observations.

(2) *A medium-range model*

$\hat{y} = -37.9994 + 8.0744x_1 + 6.3482x_2 + 2.8213x_3$

where, x_1 is the mean air temperature for the last decad of April of the current year at Shanghai; x_2, the frequency of occurrence of upper winds with directions from 109° to 209° at 1500 meter level in the last decad of May of the current year over Zhengzhou; and x_3, the frequency of occurrence of upper winds with directions from 270° to 350° at 1500-meter level in the last decad of May over Zhengzhou. R is found to be 0.85; F, 14.01; and S, 7.368.

The accuracy of forecasts achieved with historical data is 17/20. An excess of moths (3905 head/per utensil) was experimentally predicted for 1981 and a deficiency (404 head/per utensil) for 1982. Both were confirmed by actual observations.

V. CONCLUDING REMARKS

(1) All the models constructed yield relatively high multiple correlation coefficients, large F-test values and small standard deviations, all passing the 0.01 significant level. Fitting with historical data and experimental forecasts (in 1981 and 1982) have been proved to be successful.

It is, therefore, feasible to predict, on a medium- or long-term basis, the amount of migrants of first-generation adults into the area of outbreaking of second-generation armyworm by numerical models constructed through stepwise regression with the aid of computers, employing as predictors the weather conditions, general circulation factors and the situation of the growth of the first-generation armyworm during the time of their development and emigration out of their source areas. These models provide forecasts with valid time long enough to take necessary precaution against the plague and are thus of useful application. They will, of course, be improved as investigations go on.

(2) From the correlation tables and the predictors adopted in the models, it can be seen that surface meteorological elements such as temperature, precipitation and sunshine; upper

winds and general circulation features as well as the situation of the development of the armyworm are highly related to the amount of migrants of first-generation adults into the area to be plagued by second-generation armyworm. For the meteorological elements, temperature and precipitation are found to be most important. The migration of the first-generation adults into the to-be-plagued areas is positively correlated to the amount of precipitation due to the fact that oviposition and incubation and the growth of the larvae all require a damp environment. It is in negative correlation with temperature since lower temperature and higher humidity offers a favorable ecological condition for the armyworm. Directions of upper winds at the 1500-meter level also affect the migration of the first-generation adults into Northeast China and Inner Mongolia, the southerlies (190°—209°, 150°—169°) being favorable and the westerlies (270°—350°, 250°—269°) being unfavorable. The intensity of the Subtropical High is related to the growth of the first-generation armyworm in such a way that, in general, the stronger the Subtropical High, the higher the amount of precipitation over the areas concerned. The density of the first generation larvae is also incorporated into the Harbin model.

As to the time intervals in which the selected predictors occur, they usually fall in somewhere between March and May, especially from March to April. This is because the overwintering moths become most abundant in the Changjiang-Huaihe-Huanghe River valleys in March and the eclosion and emigration away of the adults take palce in the latter part of May. Hence the environmental conditions during March to May are determinative to the amount of immigrant first-generation adults into the outbreaking areas of the second-generation armyworm as well as to the evolution of the first-generation armyworm. That is to say biological significance is taken into account in the models presented.

(3) The models presented are confined to the Harbin and Zhemeng areas and they have to be modified for application to similar regions.

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REFERENCES

[1] 中国农作物病虫害编辑委员会编，中国农作物病虫害，农业出版社， 1979, 881—882.
[2] 农业部病虫测报总站，我国农作物主要病虫测报办法，农业出版社， 1981.
[3] 赵圣菊，科学通报， 1982, 9: 568—570.
[4] 赵圣菊，生态学报， 3(1983); 1:377—382.
[5] 赵圣菊、周朝东，科学通报， 1984, 2:117—120.
[6] 赵圣菊、周朝东，气象，1983, 11期.