Prediction of Occurrence of the Arrowhead Scale, *Unaspis yanonensis* (Kuwana), with Statistical Methods in Japan

By RYOJI KORENAGA

Okitsu Branch, Fruit Tree Research Station
(Okitsu-nakacho, Shimizu, Shizuoka, 424-02 Japan)

Until about 15 years ago, the most serious citrus insect pests in Japan were the arrowhead scale, *Unaspis yanonensis*, the citrus red mite, *Panonychus citri*, and the citrus rust mite, *Aculopus pelekassi*. To control them effectively, a joint research project was started in 1960 with participation of 10 experiment stations. In the begining, studies on bionomics and prediction of occurrence of these insect pests were carried out. We took part in this project with the assignment on the arrowhead scale.

Larval appearance of the scale always occurs three times annually in southern parts of Kyushu or Shikoku of Japan while it fluctuates between two and three times a year in other districts. In Shizuoka, larval occurrence of the 1st and 2nd generation begins from early May and late July, respectively, and that of the 3rd generation begins from late September if late summer was warm enough for larval appearance. Larvae of the 1st generation grow up to the 2nd instar after about 25 days. After another 23 days or so, they become adults. About one month later, larval appearance of the 2nd generation occurs, and they become the 2nd stage larvae, and then the adults after two weeks, respectively, in Shizuoka.[6]

As mentioned above, the appearance of 3rd generation larvae fluctuates year by year in this district. This occurrence is very important because 3rd generation larvae cause serious damage of fruit and lower its market price. The occurrence was influenced by the temperature during the period of 5th to 10th day after the last molt. If the temperature of this period is higher than 24°C, the adult females can develop their ovaries and lay eggs. Otherwise, the adult females undergo diapause and do not develop their ovaries till next spring. The higher the autumn temperature, the more the larval appearance.[7,8]

To achieve an effective control of the arrowhead scale by the use of pesticides, bionomics of the scale insect was studied. According to the results, it became clear that the appropriate time of application of organophosphorus insecticides is at the initial date of the occurrence of female adults.[10] Therefore, we have to predict, in practice, the initial date of occurrence (hereafter referred to IDO) of female adults. As the durations of each instar are relatively stable over the years as shown in Table 1, it is easy to predict IDO of female adults from IDO of the 1st generation larvae. However, the IDO of

Table 1. Initial date of occurrence and duration of each developmental stage of the arrowhead scale in Okitsu (1961—1975)

Stage	1st generation		2nd generation	
	Occurrence date	Duration	Occurrence date	Duration
		days		days
1st instar	May 8 ± 6.2[a]	25.2 ± 3.9[a]	July 27 ± 3.8[a]	14.3 ± 0.9[a]
2nd instar	June 2 ± 5.2	22.7 ± 4.1	Aug 10 ± 4.0	15.7 ± 2.6
Female adult	June 25 ± 6.1	32.1 ± 5.2	Aug 26 ± 5.0	37.9 ± 7.6

a) : Standard deviation

the 1st generation larvae fluctuates more than 20 days from year to year. Therefore, we attempted to know how to predict IDO of the 1st generation larvae.

Prediction of IDO of 1st stage larvae of the 1st generation

1) Prediction based on the development of male larvae in spring

The male hibernates at the 2nd stage larvae and its pupation begins in late February or March. When it is warm in late winter, the pupation takes place earlier. Thus, the time of pupation shows yearly fluctuations more than 20 days. Therefore, the relation between the time of the pupation and IDO of the 1st instar larvae of the 1st generation was examined in a citrus orchard of about 20 years of age which was kept free from the insect control. A high correlation as shown by the following equation was found between IDO of the 1st stage larvae of the 1st generation and the date of pupation.[2]

$Y=0.75\,X+4.5 \quad r=0.86 \quad df=12$

where Y: IDO of the 1st stage larvae (counted from April 30)

X: date of pupation of more than 10% of the hibernated male larvae (counted from March 31).

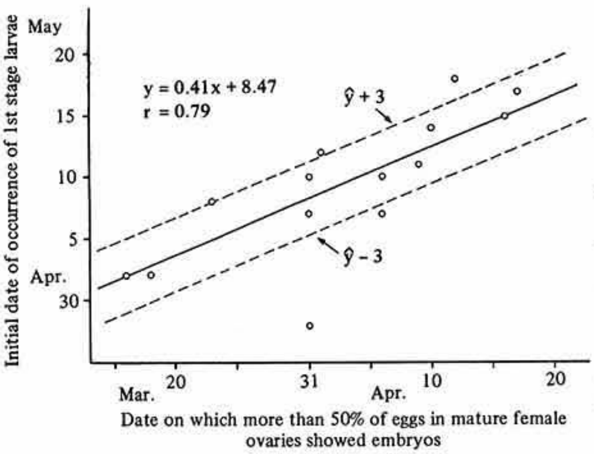

Fig. 1. Relation between development of ovary and initial date of occurrence of larvae of the 1st generation

2) Prediction of IDO based on the development of ovaries in early spring

The female insect overwinters mainly in the form of mature female adults and their ovaries begin to develop in late March. Number of eggs (or oocytes) in ovaries was counted according to our standard method.[5] A high correlation expressed by the following equation was found between IDO and the ovarian development[2]:

$Y=0.41\,X+8.47 \quad r=0.79 \quad df=12$

where Y: IDO of the larvae (counted from April 30)

X: date on which more than 50% of eggs in mature female ovaries show the development of embryo (counted from March 31).

By the use of these equations, it was made possible to predict the IDO one month or one and a half month in advance with errors of ±3 days. However, when it was very warm or cool in April, the error of estimation was increased, showing sometimes an error of 10 days (Fig. 1). This trouble occurs similarly in both methods of prediction shown above. It was obvious that April temperature exerted a great effect on IDO too.

3) Prediction with multiple regression equations and nomograph using ovarian development and temperature of April[12]

The prediction methods described above require many field observations during the period from winter to spring, and they show big errors in some years. To improve such disadvantages and to get better fitness of prediction, an attempt was made to utilize multiple regression equations. As variables, we used development of ovaries and total effective temperature (above the threshold temperature for ovarian development). As a result, the multiple regression equations shown below were obtained.

The prediction of IDO is made by two steps. The first step is to predict the degree of ovarian development from the temperature during the winter, and the second step is to predict IDO from the ovarian development and the April temperature.

$$Y_1 = 15.00 + 2.272X_1 - 0.678X_2$$
$$r = 0.886,\ n = 16$$
$$Y_2 = 24.43 - 0.360Y_1 - 0.380X_3$$
$$r = 0.934,\ n = 16$$

where Y_1: Percentage of mature eggs to the total number of eggs in ovaries on March 1 (transformed into arcsine, $\sin^{-1}\sqrt{\%}$)

Y_2: (Number of days between observation date of ovaries and IDO) − 60.

X_1: Total effective temperature during a period between January 1 and the day preceding the date of observation of the ovaries. Threshold temperature is 13°C.

X_2: Number of days showing daily minimum temperature below 0°C during the same period as X_1.

X_3: Total effective temperature during a period of April 1 to 15. Threshold was 13°C for mature egg formation.[9]

X_1 and X_2 were calculated by the triangle method.[11] The prediction of Y_2 by the use of Y_1 calculated from X_1 and X_2 gave good fitness. However, the use of Y_1 actually measured gave much better fitness as shown in Fig. 2. In this case only one observation of ovaries is required at the beginning of March. Even at that time of observation, IDO could be predicted with some accuracy if the temperature in April was moderate. Instead of calculating the equation, a nomograph is presented in Fig. 2. In this graph, the A axis is a vernier and zero point should be adjusted to the date of ovary observation. Percent of mature eggs is an estimated or observed value. Using this graph, we can predict the IDO with reasonable accuracy about two months in advance. When the total effective temperature for the first half of April is known, the prediction as of April 16 can greatly increased the accuracy (Fig. 3).

Prediction of population

The prediction of the insect population is very

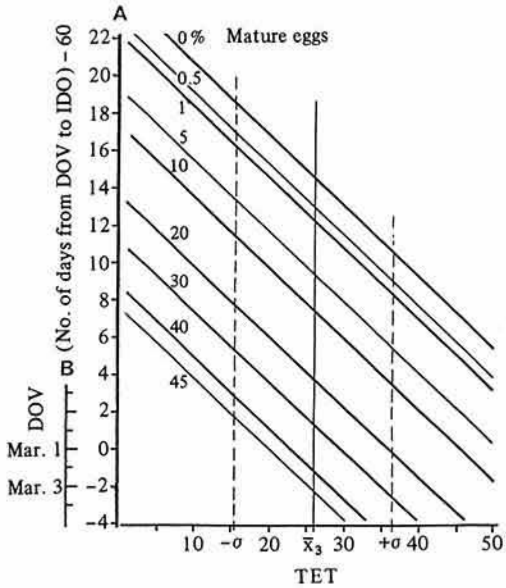

Fig. 2. Nomogram for prediction of initial date of occurrence of the first generation A axis is vernier. Set 0 of A axis to the date when ovaries are observed on B axis.

IDO: Initial date of occurrence of the 1st generation

DOV: Date ovaries observed

TET: Total effective temperatures during April 1 to 15, calculated by triangulation method[12] with developmental threshold temperature 13°C

$\bar{x}_3$: TET of average year

$\pm\sigma$: Standard deviation of $\bar{x}_3$

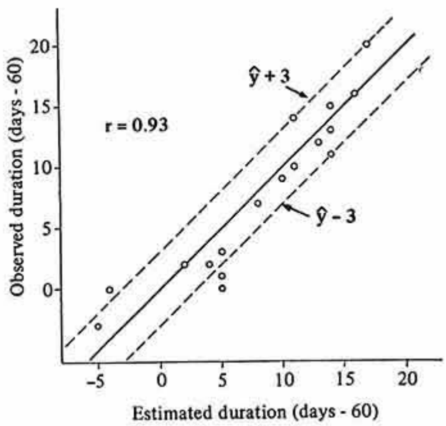

Fig. 3. Relation between observed durations and estimated duration as of April 16

important in making decisions whether the control treatment will be needed or not. To establish a method of predicting population, we introduced multiple regression analysis.[3,4] Data used for the analysis were obtained from Okitsu, Kanagawa, Hiroshima, and Kumamoto Experiment Stations. These data had been accumulated from 1960 to 1977 under the same standard in the joint research project on prediction of occurrence of insect pests. Dependent variables were the final population density of female adults in each generation, and independent variables were the initial population density of female adults, number of settled nymphs, air temperature, local rainfall, etc.

Linear multiple regression equations were first constructed by a stepwise forward regression method using the variables shown in Table 2 for the 2nd generation. There are two types of programme in this method: one based on the smallest residual sum of squares (RSS) and the other based on the smallest prediction sum of squares (PSS).[1] Both methods were applied to the data of each station and the pooled data of the 1st and 2nd generation. The results by PSS in the 2nd generation are shown in Table 3.

Next, several independent variables which are commonly included in the multiple equations of different prefectures or which seem to be significant ecologically were selected as few as possible. By using those variables multiple regression equations were constructed. Every equation of each prefecture used the same variables, so that every variable was not always significant. These results were shown in Table 4.

We postulated the predicition equations by using the data of 1960–1972 and again postulated by using the additional data of 5 years: 1973–1977. Comparison of the regression coefficients between the former case and the latter case

Table 2. Variables used in analysis of population density of the 2nd generation

Variable no.	Explanation		
1[a]	Population of female adults of the 1st generation (late July)		
2[a]	Population of female adults of the 1st generation on the initial occurrence date of larvae of the 2nd generation		
3[a]	Population of female adults of the 2nd generation (October): dependent variable		
4	Activity of natural enemies (none: 0, moderate: 1, high: 2)		
5	Initial occurrence date of the 2nd generation (April 30=0)		
6	(Maximum number of fixed larvae of the 2nd generation)/No. 2		
7	Mean temperature (July)		
8	Mean temperature (August)		
9	Mean temperature (September)		
10	$(\text{No. } 7 - 25.63)^2$		
11	$(\text{No. } 8 - 27.44)^2$		
12	$(\text{No. } 9 - 23.81)^2$		
13[a]	A (> 5 mm/day)	1−10 days	after the initial date of occurrence of the 2nd generation larvae.
14[a]	A (>15 mm/day)		
15	B (> 5 mm/day)		
16	B (>15 mm/day)		
17[a]	A (> 5 mm/day)	11−20 days	
18[a]	A (>15 mm/day)		
19	B (> 5 mm/day)		
20	B (>15 mm/day)		
21[a]	A (> 5 mm/day)	21−30 days	
22[a]	A (>15 mm/day)		
23	B (> 5 mm/day)		
24	B (>15 mm/day)		
25	Kanagawa=1, others=0 (dummy variable)		
26	Hiroshima=1, others=0		
27	Kumamoto=1, others=0		

a) : transformation of variables with $\log(x+1)$. Same in Tables 3 and 4.
A : amount of precipitation
B : number of rainy days
Units of variable No. 1 to 3: number of individuals/branch

Table 3. Multiple regression equations for prediction (by PSS) (2nd generation; dependent variable: no. 3)

Variable No.	Kanagawa	Okitsu	Hiroshima	Kumamoto	Pooled
1[a]	0.466**				
2[a]		0.522**	0.750**	0.777**	0.833**
6	0.019**		0.013+	0.021**	0.022**
4		−0.158**	−0.221**	−0.263**	−0.166**
5			−0.025**		
7					
10			0.198**		
8	0.236*		−0.191**	−0.158**	
11	−0.150**				−0.038**
9					
12		−0.080*			
13[a]					
14[a]	1.089**				
15		0.080**			
16	−0.952**				0.059**
17[a]		−0.169**			
18[a]			0.324**		
19		0.114**		−0.092**	
20			−0.494**		
21[a]	0.268**			0.231**	0.081**
22[a]					
23					
24					
25	—	—	—	—	−0.469**
26	—	—	—	—	
27	—	—	—	—	
Constant	−6.365	1.049	8.196	5.024	0.437
$100R^2$	83.7	65.0	85.3	86.7	81.4
PSS/N	0.085	0.053	0.063	0.095	0.097

R: multiple correlation coefficient
+, *, **: significant at 10, 5, 1% levels, respectively
N: namber of samples

Table 4. Multiple regression model for prediction (2nd generation; dependent variable: no. 3)

Variable no.	Kanagawa	Okitsu	Hiroshima	Kumamoto	Pooled
2[a]	0.868**	0.610**	0.821**	0.853**	0.874**
6	0.025**	0.011**	0.030**	0.025**	0.023**
4	−0.228**	−0.152**	−0.009	−0.236**	−0.150**
21[a]	0.083*	−0.104*	0.139*	0.306**	0.108**
25	—	—	—	—	−0.531**
26	—	—	—	—	−0.072
27	—	—	—	—	−0.006
Constant	−0.076	1.364	0.233	0.233	0.363
$100R^2$	74.2	58.0	73.2	83.7	79.4
SE	0.322	0.238	0.294	0.321	0.323

R: multiple correlation coefficient
SE: standard error

Table 5. Population density predicted by the use of multiple negression equations and that actually measured (1978, 2nd generation)

Locality	Type	Four trees 1	2	3	4
Kanagawa					
Actually measured		57	20	8	15
PSS[a]	type 1	19	18	16	21
	type 2	20	12	6	13
model[b]	type 1	18	11	5	12
	type 2	20	11	5	13
Okitsu					
Actually measured		46	33	22	43
PSS[a]	type 1	43	46	43	88
	type 2	82	28	31	111
Model[b]	type 1	107	64	67	162
	type 2	68	22	25	95
Kumamoto					
Actually measured		100	32	43	93
PSS[a]	type 1	14	7	11	46
	type 2	27	15	22	100
Model[b]	type 1	36	19	28	141
	type 2	42	22	34	155

unit : number of individuals/branch
type 1 : equation using data of each station
type 2 : equation using pooled data
[a] : by equations in Table 3
[b] : by equations in Table 4

showed that the regression coefficients became more stable among different prefectures in the latter than in the former.

The equations of PSS and RSS types were actually employed to predict the population density in the following years. An example of predicted and actually observed populations is shown in Table 5. The results can be summarized as follows: (1) Multiple regression equations based on PSS method had higher predictability than those based on the RSS, (2) By any method, the equations obtained from pooled data showed better fittness than those obtained from the data of each station, although the regression coefficient was low, (3) The best fitness was obtained by the equations constructed with pooled data with fewer variables. One of the weak points of this method is that if any variable, such as air temperature, is beyond the range of past fluctuation, the errors become large. To overcome those troubles, data should be collected from many districts during many years as far as possible.

As often pointed out, there are some critical comments on applying the multiple regression analysis for the prediction of insect occurrence. But it is clear that if data were collected from many districts and for many years under the same standard, this method is very useful for the prediction of occurrence.

References

1) Hirosaki, S. & Kobayashi, F.: Some selection methods of criterion variables by prediction sum of squares (PSS) in regression analysis. *Bull. Comp. Cent. Res. Agr. Forest. Fish. A* **15**, 45–104 (1979) [In Japanese].

2) Korenaga, R., Okudai, S. & Sakagami, Y.: Studies on forecasting the occurrence of the arrowhead scale. *Unaspis yanonensis* Kuwana. I. Forcasting occurrence date of the first generation first instar larvae from the development of male larvae and of ovaries of mature female in late hibernating period. *Bull. Fruit Tree Res. Sta.* **B1**, 85–99 (1974) [In Japanese with English summary].

3) Korenaga, R. et al: Models for prediction of the population of the arrowhead scale, *Unaspis yanonensis* Kuwana, on citrus tree by multiple regression. I, *Jpn. J. appl. Ent. Zool.* **22**, 141–151 (1978) [In Japanese with English summary].

4) Korenaga, R., Hirosaki, S. & Shiyomi, M.: Models

for prediction of the population of the arrowhead scale, *Unaspis yanonensis* Kuwana, on citrus tree by multiple regression. II,*Jpn. J. appl. Ent. Zool.* **25**, 17–25 (1981) [In Japanese with English summary].

5) Okudai, S., Korenaga, R. & Ando, K.: On the development of the female adults of the arrowhead scale. *Unaspis yanonensis*, in the preovipositional period. *Bull. Hort. Res. Sta.* **B4**, 139–148. (1965) [In Japanese with English summary].

6) Okudai, S., Korenaga, R. & Sakagami, Y.: Studies on the seasonal appearance of each stages of the arrowhead scale, *Unaspis yanonensis*. I. *Bull. Hort. Res. Sta.* **B9**, 199–220 (1969) [In Japanese with English summary].

7) Okudai, S., Korenaga, R. & Sakagami, Y.: Studies on the autumnal appearance of larvae of the arrowhead scale, *Unaspis yanonensis*. I. Effect of temperature and diapause of the female adults on the autumnal appearance of larvae. *Bull. Hort. Res. Sta.* **B11**, 203–213 (1971) [In Japanese with English summary].

8) Okudai, S., Korenaga, R. & Sakagami, Y.: Studies on the autumnal appearance of larvae of the arrowhead scale, *Unaspis yanonensis*. II. On the relationship between temperature in the early stage of the autumn adults and autumnal apperance of larvae. *Bull. Fruit Tree Res. Sta.* **B1**, 101–113 (1974) [In Japanese with English summary].

9) Okudai, S. Korenaga, R. & Sakagami, Y.: Effect of temperature on the ovarian development of the arrowhead scale, *Unaspis yanonensis* Kuwana, in the late hibernating period. *Bull. Fruit Tree Res. Sta*, **B2**, 97–106 (1975) [In Japanse with English summary].

10) Sadai, K.: On the suitable period for spreading chemicals and occurrence forcast of arrowhead scale (*Prontaspis yanonensis* Kuwana). *Bull. Hiroshima Agr. Exp. Sta.* **23**, 65–79 (1966) [In Japanese with English summary].

11) Sakagami, Y. & Korenaga, R.: "Triangle method," a simple method for the estimation of total effective temperature. *Jpn. J. appl. Ent. Zool.* **25**, 52–54 (1981) [In Japanese with English summary].

12) Sakagami, Y. & Korenaga, R.: Studies on forcasting the arrowhead scale, *Unaspis yanonensis* Kuwana. II. Forcasting initial occurrence date of the first larvae using multiple regression equations. *Bull. Fruit Tree Res. Sta.* **B9**, 35–51 (1982) [In Japanese with English summary].

(Received for publication, November 7, 1984)