CALIFORNIA RED SCALE

California red scale is one of the three major arthropod pests of citrus in California, causing an annual economic crop loss of approximately $15 million. CRS infestations can lower the market grade of fruit as well as cause reduced tree vigor and twig and branch dieback.

Management of California red scale, Aonidiella aurantii *(Maskell), in the southern part of the state relies heavily on biological control with several beneficial insect parasites. Red scale is still under eradication in most southern California desert production areas. In San Joaquin Valley citrus growing areas, parasites are much less effective than in southern California and chemical control is the standard management practice. A major concern in the Valley is the potential development of pesticide resistance in California red scale, such as has been observed in Israel and South Africa.*

Recent research has been aimed at developing new control strategies for CRS, and at evaluating pheromone monitoring devices as a way to improve control timing and reduce the use of pesticides. The following articles report on some aspects of research funded by the Citrus Research Board, the U.S. Department of Agriculture, and the University of California Integrated Pest Management Project.

Computer simulation of CRS populations

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Model supports field monitoring

Population models aid in decision-making to reduce the number and concentration of pesticide treatments for California red scale by predicting population peaks for critical life stages and by forecasting CRS levels at the season's end and the following season. We describe here one such modeling system, which has been used in combination with male pheromone trap catch data in the San Joaquin Valley. This system does not as yet contain a model for CRS parasites and thus may be less useful in simulating CRS populations in southern California, where parasites are effective natural control agents.

The Generalized Population Model (GPM) was developed at the University of California, Riverside. Parts of the model were borrowed from the Michigan State University PETE program, which is also used in population phenology (timing) predictions. The GPM system was designed to be flexible so that it might be used to construct models for a number of insect pests. To date, it has been used to build preliminary models for the California red scale, citrus thrips, amorbia, and tomato pinworm.

The GPM system works by simulating the natural developmental cycle of the insect, aging the insect from one life stage to the next based on a biological model. In general, the rate of aging is proportional to the accumulation of degree-days, but aging based on calendar days is an option.

Although the GPM was initially designed as a research model to formulate and test biological variables in various insect pests, other uses for the system have developed. A public version is used as a forecasting model. This program utilizes "biological parameter files" developed in GPM along with the UC Integrated Pest Management (IPM) Meteorological Data Base (which is stored on the UC-IPM computer system) to predict pest insect population peaks in the field. To run Public GPM, the user enters a biological parameter file name, accesses weather information from a file of his or her own making or one from the UC-IPM Meteorological Data Base, decides on a model starting date, and runs the simulation. The resulting model output is used to produce graphs or tables useful in interpretation of model results.

Estimates for the following biological information are needed to simulate an insect: (1) for each life stage, lower and upper (optional) temperature thresholds for development to occur, mean length of the developmental period, the variability in the developmental period, and the levels for nonseasonal (normal) mortality in the field; (2) estimates of the reproductive rates of females over their life; and (3) initial numbers of each life stage on the starting date.

For the California red scale model, this information has been obtained from published and unpublished field data and the results of laboratory studies by a number of citrus researchers. Although developmental threshold data for individual life stages were not available, the best estimate for red scale upper and lower temperature developmental thresholds was

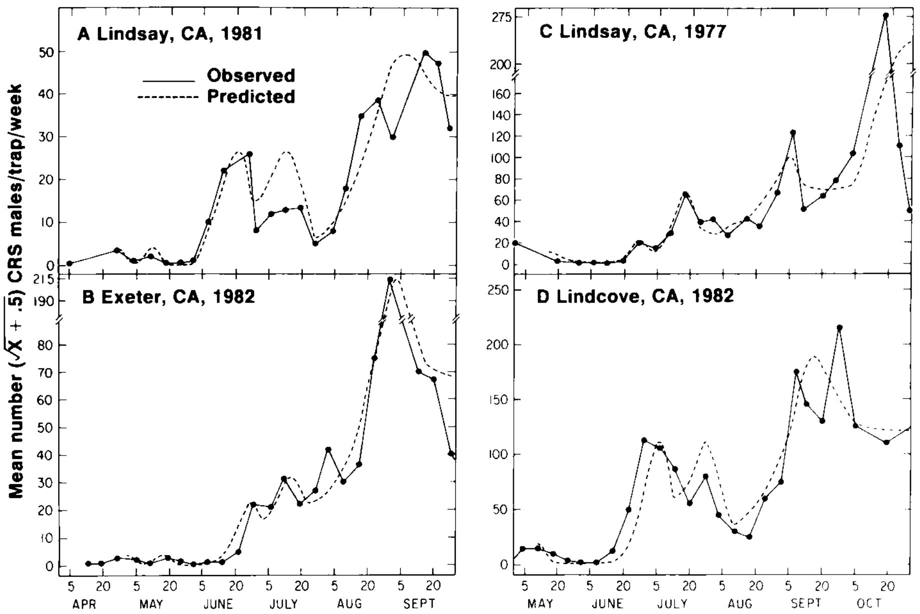

Fig. 1. Field catches of male California red scale in pheromone traps compared with model simulation predictions. Simulations were computed with different model starting dates: A, B, (File REDSCALE1), at first cohort peak; C (REDSCALE2), at second peak; D (REDSCALE3), midway between the two.

37.8°C (100°F) and 11.7°C (53°F). The upper threshold should be treated as an approximation, because no conclusive work has been completed on this estimate.

The average time (in degree-days) that the red scale remains in a life stage is the mean developmental time (DEL) for that stage (table 1). The male life stages between the second stadium and adult have been combined into a single stage, the pupal stage, because of the nature of the available data.

Variability in development times between individuals in a population is represented in the model by K, which is estimated as being equal to $DEL^2/$ (the variance of the development time). Hence, when the variability in development time is small compared with the average development time, K is large. In this manner, K may be considered an inverse measure of the variability in development for a group (cohort) entering a life stage together. All K values used in the model were determined from laboratory temperature cabinet studies conducted at constant temperature and humidity.

In the GPM system, mortality is assigned to a life stage independently of the season through which the simulation is run. Mortality was estimated from data collected from spring red scale populations; the estimates are thus conservative in that they do not take into account mortality during periods of temperature extremes in winter and summer. Each estimate represents the expected percentage of mortality that a cohort of red scale would experience within a given life stage.

Although most life stages suffer significant mortality, the crawler stage experiences the most (22 percent) and the gravid female the least (4 percent). Since the crawler is the smallest life stage and lacks the protective covering of later stages, this high mortality estimate is considered reasonable. In addition to the gravid female's relatively large size, the fact that she seals tightly to the surface on which she is resting following insemination, may contribute to her greater resistance to environmental hazards.

Fecundity rates were estimated from both laboratory and field data, since neither was complete alone. Field studies provided estimates of total crawlers produced per female, because laboratory studies produced unrealistic estimates five to twelve times higher than those from field research. The distribution of crawler production over time was then estimated from laboratory studies and combined with the field data.

The fecundity estimates in the model were the number of offspring produced per female for every degree-day above 53°F. For the five female reproductive stages (ages), these estimates were 0.112, 0.175, 0.056, 0.007 and 0.000 offspring per female, respectively. Young scales were assumed to have a 1:1 female to male sex ratio.

Temperature extremes cause CRS mortality in both winter and summer during an average year in the San Joaquin Valley. In most winters, the majority of survivors are gravid females and second- and third-stage virgin females. Consequently, the population in the spring is composed of two age cohorts: the first develops from surviving gravid females and the second from virgin females. This dual cohort structure persists to some degree in later summer generations. Warm winters may, however, obscure the dual structure by allowing survival of other life stages, resulting in overlapping cohorts.

The adult male has been used in many red scale studies as a population indicator, because it is the life stage most easily monitored and occurs at approximately the same time as the virgin females, which are difficult to sample. The male may be monitored with a pheromone trap containing a sticky card. The date of the spring male flight peak(s) is obtained by changing trap cards once or twice a week, counting the males caught on each card, and plotting card catch over time. This is the date used to initiate the CRS model.

For several reasons (bad weather, pesticides used for citrus thrips or orangeworms, trap cards changed too infrequently), it may be difficult to estimate the date of either of the flight peaks for the two spring cohorts. Thus, three sets of information were developed. The first, REDSCALE1, assumes that the peak flight date for the first spring cohort is known and uses this time as the model starting date (fig. 1a, 1b). REDSCALE2 is similar, but uses the second cohort spring flight peak as the starting point (fig. 1c).

TABLE 1. Developmental and mortality parameters used in the CRS model

Life stage	Developmental time in degree-days$_{53}$ (DEL)	Developmental spread (K)	Nonseasonal mortality (%)
Crawler	5.4	1	22.9
1st stadium	144.5	27	7.0
1st molt	84.6	39	6.0
Female:			
2nd stadium	140.5	16	7.0
2nd molt	192.6	23	8.3
3rd stadium	217.8	15	6.0
Gravid	231.2	21	4.0
Parturient	1009.4	5	12.0
Male:			
2nd stadium	218.2	35	7.0
Pupal*	171.2	17	8.6
Adult	27.0	5	6.7

* Includes all intermediate stages between 2nd stadium and adult.

In situations where the two cohort flight peaks cannot be separated (as when warm winters cause overlap of the two cohorts), REDSCALE3 is used and the model is initiated at the single peak of the spring male flight (fig. 1d). If it is still unclear which is the proper file to use, several simulations may be run and field observations compared with model predictions.

After the spring generation of CRS, all of the files will project a dual cohort population structure. Field studies have, in general, shown a dual structure in summer generations (especially for the second flight), even when the spring cohorts overlap.

High summer temperatures are believed to significantly increase mortality of the younger CRS life stages, especially during the third flight peak in the San Joaquin Valley. However, we have insufficient data to define this relationship quantitatively, and we have not included a model variable for seasonal (heat stress) mortality. As a result, the model overpredicts population levels during the third and fourth (if present) flights. A model scaling factor is imposed midway between the first and second cohort peaks of the second flight to scale down the later flight levels. At present, the model is intended for phenology (timing) prediction, and model density levels should be interpreted with great care.

After the CRS model was built, model output was compared to seven years of male flight data collected by D.S. Moreno, C.E. Kennett, and R.F. Luck from different sites in the San Joaquin Valley (four comparisons are shown in fig. 1). In five out of seven years, both the first and second flights were predicted accurately (within one week of the field surveys) for both cohorts. In the third flight, however, the simulation shows a merging of the two cohorts that was not generally observed in the field. Field surveys of the third flight show either a distinct separation between the two cohorts or an extra peak, especially in years such as 1981 when a relatively cool week was followed by a warm one.

Several factors may be responsible for the observed differences between field counts and model predictions. First, small errors in estimates, in addition to small deviations between model approximations and actual developmental distributions are compounded through several generations, resulting in increasingly larger errors. In addition, the model does not yet include factors accounting for the effect of host plant status (such as nutritional condition of the citrus tree) upon California red scale development and reproduction. Also, temperature records used to drive the model are usually obtained from a single site in the orchard or from a nearby weather station. This single record ignores the variability in CRS development in the field that may occur because of variability in environmental conditions in different parts of the tree or different trees within a grove. Finally, high summer temperatures, which usually occur during the second cohort of the second flight and during the third flight, may contribute to restructuring the cohorts in the field.

The model should be used with some caution. As mentioned, it is constructed to help predict population peaks and aid in understanding CRS phenology through the summer months, not to predict population density. As with any simulation of a complex biological process, it is a simplification of the actual field situation. Detailed field monitoring of California red scale populations will remain the backbone of any CRS management program. The computer model may assist in more efficient timing and interpretation of such field monitoring.

Although now limited to population peak prediction, the CRS model and the GPM system are perceived to be significant contributions to citrus pest population forecasting and management programs. As information from new studies becomes available, the simulation model can be improved with little effort. This information should aid in developing a model that will accurately predict population densities within and between field seasons. As information becomes available for other citrus insect pests, similar models can be created through utilization of the GPM system.

The CRS simulation model is available only to UC campuses, research stations, and farm advisors with access to terminals connected to the UC IPM computer network. Plans are under way to extend access to growers and others by writing versions of the simulation program for microcomputers.

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Predicting CRS infestations by trapping males

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Trapping can improve decision making in CRS control

In some properly managed orchards in southern California, natural enemies reduce California red scale populations to an acceptable economic level, but chemical control is normally required in the desert and San Joaquin Valley areas. We believe annual red scale sprays can be reduced when population densities are properly monitored with CRS pheromone traps. Our objective in this study was to relate year-end scale infestation levels on fruit to pheromone trap catches early in the season in the San Joaquin Valley, using numbers of trapped males as a population density index for CRS.

We gathered data from 1973 to 1983 in 15 San Joaquin Valley navel and Valencia orange orchards in Tulare and Fresno counties. Selected trees were inspected for scale on scaffold branches and twigs and were categorized according to density. Orchards with a light infestation (occasional single scales on twigs or branches) or less were selected for experimentation, because they could be monitored for at least 24 months with little likelihood of requiring scalicide applications.

The flight of the male scale was first monitored with traps baited with live vir-