lar spent on the research, a savings in resources of $10.70 to $16.60 is estimated under the model's assumptions. The internal rate of return was determined to be 41.3 percent. In either case, the decision criterion for economic efficiency seems to be more than adequately met.

The total benefits are probably undervalued because they do not include those related to the environment. More astute and careful monitoring of red scale may

lead to more judicious use of chemical controls, which, in turn, could extend the useful life of those chemicals. In addition, worker safety and general environmental conditions may be improved.

Based on this analysis, the funds expended for research on California red scale and the development and subsequent implementation of an effective monitoring program appear to have been well utilized. While the quantifiable bene-

fits will primarily accrue to growers, society may also enjoy several intangible benefits.

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Tracking CRS development by degree-days

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Mature virgin California red scale females possess a sex attractant useful in monitoring CRS populations. After researchers showed that adult red scale males responded positively to sticky card traps baited with caged, live, virgin female scales, the sex pheromone was synthesized. Since then, synthetic sex pheromone traps have become widely used in the detection and management of red scale in citrus integrated pest management programs.

We conducted a study to define California red scale phenology by degree-days (°D) and to determine if male flight patterns accurately reflected the development of CRS generations in the San Joaquin Valley.

Field tests

The study took place in an untreated 2-hectare (5-acre) orchard of mature navel orange trees at the University of California Lindcove Field Station in Tulare County. We selected a block of four adjacent trees with equivalent red scale populations, and followed CRS life stages and their seasonal changes by sampling 300 live scales each from leaves and twigs. Samples were taken every 10 days from January through April, weekly from May through October, and every two weeks in November and December. We ignored the motile first-stage crawlers.

Male CRS flights were monitored from April through September by means of a synthetic sex pheromone trap in each sample tree. The pheromone source was replaced every four weeks. Sticky cards were changed daily when possible but never less frequently than twice weekly.

A hygrothermograph next to the sample trees recorded within-orchard temperatures and relative humidities.

Starting on January 1, we used daily maximum and minimum temperatures to

calculate degree-days above the developmental threshold (t). The threshold, below which no measurable development occurs, was estimated from constant temperature developmental data as 11.6°C (52.9°F).

The thermal constant, K, is the total degree-days required for an organism to complete its development. We estimated K to be 673°D for CRS on grapefruit, and 616.4°D on lemon fruit (using K = T − t(D), where T is temperature, D is total developmental time in days, and t = 11.6°C, the developmental threshold).

CRS phenology

Relative densities (percent) of life stages of the overwintering population (fig. 1) remained unchanged between 0 and 129°D (January to mid-March). All scale stages were present during this period except newly settled crawlers (whitecaps) and pupal and pre-emergent adult male stages. The absence of whitecaps indicates a lack of reproduction by the overwintering gravid females.

After about 129°D, the percentages of first-stadium and molt and second-stadium and molt scales declined (fig. 1a, b), and the percentage of virgin adult females increased (fig. 1c), peaking at 344°D in early May. The first peak of male flight (fig. 1d) coincided with this peak of virgin females. At this time

(344°D), adult virgin females and overwintering gravid females (fig. 1c,e) represented more than 97 percent of the live female red scale population.

A sharp increase in first-stadium scales beginning at 344°D (fig. 1a), indicated the onset of the spring generation arising from overwintering gravid females. This first cohort peaked at 520°D. A second but lesser peak of first-stadium scales occurred at 817°D, and represented offspring of overwintering immature CRS. This second cohort occurred 297°D, or about ½ K, after the first cohort and originated from the small peak of adult females at 722°D (fig. 1e).

Maturation of the spring generation is indicated by serial increases in relative abundances of all stages and a peak in adult male capture. Coincidence between the virgin adult females and the adult male peaks (950°D) (fig. 1c,d) was again observed.

The start of the summer generation is indicated by an increase in whitecaps (first-stadium scales) (fig. 1a) at about 908°D. This increase occurred about 564°D after the start of the spring generation and coincided with an increase in gravid and reproductive (parturient) females (fig 1e). No sequential peaks were observed in the second-stadium and molt and adult virgin females in this scale generation (fig. 1b,c); immature males were

TABLE 1. Duration of developmental stages and total developmental time (°D) in female California red scale at Lindcove Field Station, Tulare County, California during 1980*

	Stage						
	1st†		2nd†		Adult‡		
	°D	Percent§	°D	Percent§	°D	Percent	Total °D
Spring generation	142.2	0.23	186.7	0.31	276.7	0.46	605.6
Autumn generation	132.8	0.23	197.2	0.34	242.8	0.42	572.8

* Degree-days above 11.7°C (53°F) used for ease of calculation.
† Includes stadium and molt stages.
‡ Virgin adult to reproductive adult.
§ Proportion of total developmental time.

TABLE 2. Accumulated degree-days between peaks in relative densities in female stages and between peaks in male capture in California red scale at Lindcove Field Station, Tulare County, California, 1980*

Scale stage	Degree-day accumulation between peaks						
	Overwintered to spring	Spring to summer	Summer to autumn	Spring to autumn	Average	Overwintered to autumn	Average
First (females and males)†	**	722	601	1,323	662	**	—
Second (females)‡	**	††	††	1,339	669.5	**	—
Third (virgin females)	563	††	††	1,158	579	1,721	573.6
Third (adult females)§	761	477	652	1,129	564.5	1,890	630
Adult males	600	††	††	1,156	578	1,756	585.3
Mean	641.3	599.5	626.5	—	610.6	—	596.3

* Degree-days above 11.7°C (53°F).
† Includes first-stadium and first-molt scales.
‡ Includes female second-stadium and second-molt scales.
§ Includes female gravid and reproductive scales.
** Peaks did not occur in overwintered first-stadium females and males or in second-stadium females.
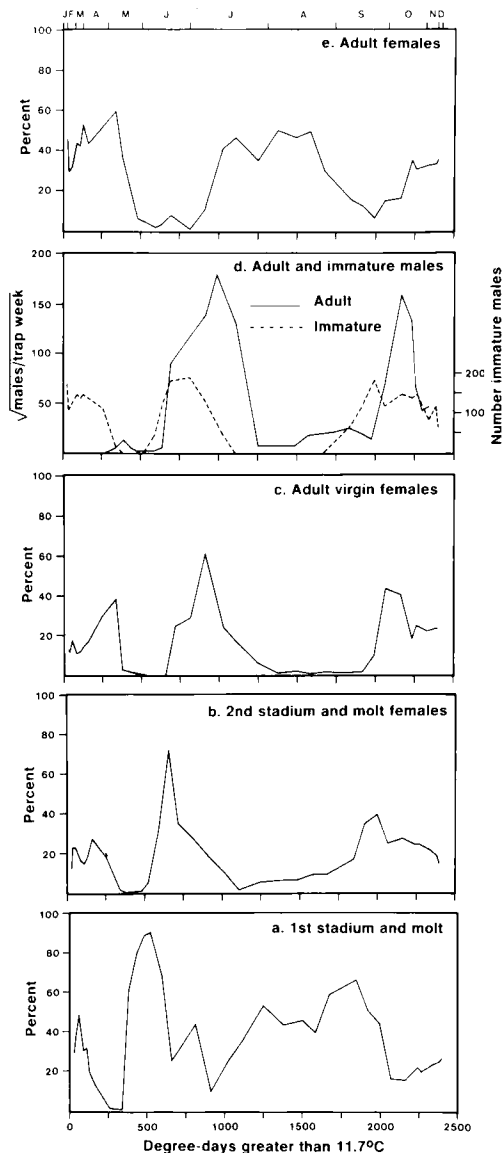†† Peaks did not occur in these stadia during the summer generation.

Fig. 1. Occurrence of California red scale life stages on leaves and twigs and adult male capture levels in navel oranges at Lindcove Field Station, 1980.

stages and all between-peak intervals combined. The average difference between mean °D accumulations and K was −20.1°D.

Conclusions

California red scale development at Lindcove Field Station can be described by degree-days. Total generation time and life stage durations were similar in both the spring and autumn generations. The summer generation did not show increases in the second- and third-stage female and the immature male scale life stages, but the following generation did exhibit these peaks. Life stage peaks in the autumn generation were measured as about two times the generational degree-days from corresponding peaks in the spring generation. Between-peak degree-day accumulations were similar when averaged over three or four generations.

During 1980, red scale generations at Lindcove Field Station were distinct, although the females' extended reproductive period tended to mask this discreteness during the autumn generation. Although the summer generation was poorly defined, values for first-stadium and molt stages between the spring and summer generations were 722°D, indicating the development of a discrete generation. Overall, we reasoned that generation developmental time could be generalized as 611°D when t = 11.6°D (1100°D when t = 53°F). Furthermore, peak-to-peak degree-day values from the autumn generation to the following overwintering generation in the spring approximated values observed during the season.

Virgin adult female and adult male capture peaks coincided in the spring and autumn generations and suggested that male flight patterns accurately reflect development in red scale generations at Lindcove Field Station. Although we lack phenology data for years when adult males showed a midsummer peak, the 1980 data suggest that peaks in female stages could be expected, conditions permitting. Why the older scale stages in the summer generation did not appear at Lindcove is not understood. This absence may explain the variability in adult male capture that has been observed during midsummer in the San Joaquin Valley. Experiments and observations indicate that this anomaly is, in part, related to extreme summer temperatures occurring during the early developmental stages of the summer generation.

generally absent from samples, and adult male capture did not show the expected increase (fig. 1d). First-stadium, first-molt, gravid, and reproductive adult females represented more than 85 percent of the scale population from 1167 to 1556°D, and red scale densities remained very high during this period. Consequently, the scarcity or absence of other stages was not reflected as decreased scale abundance.

The autumn generation, however, displayed sequential progressive peaks in second-stadium and molt females, virgin adult females, immature males, and adult male capture following the sharp rise in first-stadium and molt scales at about 1583°D. This pattern closely resembled that observed for the spring generation. Also, the peaks in virgin adult females (2063°D) and adult male capture (2106°D) coincided (fig. 1c,d). The peak in adult female scales occurred at 2234°D (fig. 1e). A lack of whitecap scales indicated that reproductive females had ceased reproduction in mid-November (2378°D). By this time, the population age structure resembled that of the previous January.

Duration of female CRS developmental stages at Lindcove Field Station (table 1) was measured as the difference in degree-days between the onset of one stadium and that of the next (for example, between the onset of the spring first stadium at 360°D and of the spring second stadium at 502°D, (fig. 1a). The between-generation differences in stage duration were small (less than 6 percent).

Accumulated degree-days between peaks for each red scale female stage and for adult male capture are given in table 2. Average degree-day values observed over three or four peaks differed by less than ±55.6°D from the thermal constant on lemon fruit (range 477 to 761°D). The overall average accumulation was 614.8°D (range 596.3 to 641.3°D) for all