Seasonal Occurrence, Phenological Indicators and Mortality Factors Affecting Five Scale Insect Species (Hemiptera:Diaspididae, Coccidae) in the Urban Landscape Setting[1]

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Abstract Proper timing of pesticide applications is paramount when attempting to control scale insects (Hemiptera: Diaspididae, Coccidae) that are important pests of landscape plantings. Use of degree-days and phenological indicators can better time the applications and reduce the number of treatments. Seasonal appearance of five species of scale insects in the urban landscape along with flowering phenology of 40 plant species were systematically monitored during 1997, 1998, 1999 and 2000 in Athens, GA. Degree-day calculations for predicting first-generation crawler emergence were attained by two methods: use of standard-base or an experimentally determined base temperature. Predictions using a standard temperature resulted in high year-to-year variance. Use of a model-derived base temperature reduced the variance for degree-days needed for first crawler emergence. Mean base temperatures for European fruit lecanium, Indian wax scale, obscure scale, euonymus scale, and tea scale were, respectively, 12.78, 12.78, 5.0, 3.89, and 5.0°C. The range in degree-days required for first crawler emergence of each species using first the experimentally derived base, or the standard base temperature of 10.56 were 1184 to 1296 or 1064 to 1622 for European fruit lecanium; 846 to 1014 or 1150 to 1380 for Indian wax scale; 1246 to 1268 or 515 to 566 for obscure scale; 1366 to 1492 or 313 to 597 for euonymus scale; and 526 to 1502 or 202 to 776 for tea scale. Natural enemy complexes observed in association with each of the scale species are discussed.

Key Words Degree-days, calendar dates, linear regression model, ornamentals, urban landscape, scale insects

Scale insects (Hemiptera: Coccoidea) occur throughout the world with 13 families present in North America. The most common families that are encountered are the Coccidae (soft scales), Diaspididae (armored scales), and the Pseudococcidae (mealybugs) (Ben Dov 1992). Many other families of scale insects are relatively common but are often overlooked due to their cryptic coloration and sessile life stages (Dreistadt 1994). Scale insects are pests in a variety of settings including forests, greenhouses, nurseries, orchards, and urban landscapes. Damage is expressed when scale insects extract nutrients from the host plant and when they affect the appear-

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ance of the host plant, rendering it unsaleable. Indirect damage can also be seen in the production of honeydew by scales that promotes growth of sooty mold (Williams and Kosztarab 1972). Sooty mold reduces the aesthetic value of the plant and may decrease overall photosynthetic productivity. Economic losses from scale insects reach an estimated $500 million annually in the U.S. (Kosztarab 1996).

Scale insects commonly found in the urban landscape in Athens, GA, are: tea scale (*Fiornia theae* Green (Hemiptera: Diaspididae) on hollies and camellia; Indian wax scale (*Ceroplastes ceriferus* (F.) (Coccidae) on a wide host range; euonymus scale (*Unaspis euonymi* (Comstock) (Diaspididae) on euonymus; obscure scale (*Melanaspis obscura* (Comstock) (Diaspididae) on oak trees; and the European fruit lecanium (*Parthenolecanium corni* (Bouche) (Coccidae) on oaks, maples and wax myrtle. When these insects become a problem, most growers either prune out the infested material or apply pesticides. Natural enemies and other life-history information are often not incorporated into management strategy. For example, the European fruit lecanium can reach high numbers, but the population is generally kept at low levels with natural enemies (Kosztarab 1996). Currently, natural enemy complexes are known for few scale insects, and much of the data are regional.

Previous research has evaluated life-history attributes of some scale insects, identified phenological indicators, and developed growing degree-day models for male flights and crawler emergence. The use of phenological indicators involves predictable effects of climate on the seasonal timing of biological events such as flowering or insect emergence (Huberman 1941, Tauber et al. 1986). Degree-day accumulations can be correlated with seasonal activity of some pests and often provide more accurate timing than relying on calendar dates (Raupp et al. 1992). The calculation of degree-days gives growers a better idea of when to scout for pests and to spray insecticides for control of the susceptible crawler life stage. Scale insects for which degree-day information is available include: obscure scale [*Melanaspis obscura* (Comstock)] (Potter et al. 1989, Hendricks and Williams 1991, Mussey and Potter 1997), walnut scale [*Quadraspidiotus juglans-regiae* (Comstock)] (Gordon and Potter 1988 Mussey and Potter 1997), olive scale [*Parlatoria oleae* (Colvee)] (Nestel et al. 1995), California red scale [*Aonidiella aurantii* (Maskell)] (Murdoch 1994), white peach scale (*Pseudaulcaspis pentagona* Targioni-Tozzetti) (Murdoch 1994), San Jose scale [*Quadraspidiotus perniciosus* (Comstock)] (McClain et al. 1990, Rock and McClain 1990), pine needle scale [*Chionaspis pinifoliae* (Fitch)] (Mussey and Potter 1997), juniper scale [*Carulaspis juniperi* (Bouche)] (Mussey and Potter 1997), euonymus scale [*Unapsis euonymi* (Comstock)] (Mussey and Potter 1997), calico scale [(*Eulecanium cerasorum* (Cockerell)] (Mussey and Potter 1997), cottony maple leaf scale [*Pulvinaria acericola* (Walsh and Riley)] (Mussey and Potter 1997), cottony maple leaf scale [*Pulvinaria acericola* (Walsh and Riley)] (Mussey and Potter 1997), and oystershell scale [*Lepidosaphes ulmi* (Linnaeus)] (Katsayonnas and Stathas 1995, Mussey and Potter 1997).

Our research describes the bionomics of five scale insects abundant in the urban landscape in the southeastern U.S. Insects investigated included European fruit lecanium, (*P. corni*), on pin oak (*Quercus palustris* Muenchh.), red maple (*Acer rubrum* L.), and willow oak (*Q. phellos* L.); Indian wax scale, (*C. ceriferus*), on burford holly (*Ilex cornuta* 'Burfordi' De France); euonymus scale, (*U. euonymi*), occurring on golden euonymus (*Euonymus japonicus* L.); tea scale, (*F. theae*), on burford holly (*I. cornuta* 'Burfordi' De France) and camellia (*Camellia japonica* L.); and obscure scale, (*M. obscura*), on pin oak (*Q. palustris*) and willow oak (*Q. phellos*).

Materials and Methods

Study sites. Four research sites in Athens, GA, were established for the European fruit lecanium, Indian wax scale, and tea scale. Three sites were chosen for euonymus scale and two sites for obscure scale. Research sites for European fruit lecanium included 7 pin oaks bordering buildings on University of Georgia campus, six willow oaks bordering an apartment complex, three pin oaks bordering Sandy Creek Nature Center facilities, red maples bordering buildings on University of Georgia campus. Research sites for Indian wax scale included 3 burford hollies bordering the Biological Sciences Building on the University of Georgia campus, 8 burford hollies in the front of a local restaurant, 6 burford hollies bordering a local church, 22 burford hollies in a landscaping around a local business. Sites chosen for obscure scale included: 7 pin oaks bordering buildings on the University of Georgia campus and 14 pin oaks planted in the landscape around a local business. Study sites for euonymus scale on the cultivar "Silver King" were 8 euonymus planted in the landscape of a local church, 4 euonymus bordering a local business, and 6 euonymus at a local residence. Study sites for tea scale included 4 *Camellia japonica* shrubs planted on the University of Georgia campus, 8 burford hollies bordering buildings of University of Georgia, 4 burford hollies bordering a local church and 22 burford hollies used in the landscape around a local business.

Monitoring of flowering plants. Forty species were monitored for four growing seasons from February 1997 to July 2000. Plants were inspected twice per week from late winter to early summer. Indicator plants were chosen based on ease of identification by the laymen. Only mature plants (large enough to flower) that represented a range of blooming times were chosen. The different blooming times were used to help pinpoint emergence times for different scale insects occurring in the landscape plants of Georgia. To reduce bias from variation in microclimate, each plant species was monitored at four different sites. Recorded data included, first bloom, 50% bloom and full bloom. First bloom was defined as the date at which the plant produced its first bloom. Fifty percent bloom and full bloom were determined by evaluating four randomly selected limbs for each plant and counting the number of reproductive structures. Average data and range for each phenological event of each plant species were determined from the four sites within each year. Average dates and ranges for each blooming event were calculated across the 4-yr study.

Monitoring of insects. Scale insect populations were monitored concurrently with flowering plants. Samples of live plant material were taken once every 2 wks from mid-February to the end of September during 1997, 1998, 1999 and 2000. Samples were transported to the laboratory, placed in 18-cm diam Petri dishes, and observed for the adult male, crawler and parasitoid emergence. Additional live material was collected weekly and placed in parasitoid emergence containers and monitored for parasitoid emergence. Parasitoid emergence containers were 1.89-L cardboard containers with a glass vial attached to the side of the container. Field observations of scale populations and potential natural enemies were made twice per week per site. Crawlers were collected either on double-sided sticky tape placed near adult females or by using an aspirator. After counting crawlers, sticky tape was removed and replaced with a fresh sticky tape, and live collected crawlers (from aspirator) were returned to portions of the host plant. Collected natural enemies were identified in the laboratory or were sent to appropriate taxonomists for identification.

Site temperatures and degree-day accumulations. Temperature readings were obtained at each study site for each scale species using a Hobo™ monitor (Onset Computer Corporation, Pocasset MA) from 1 January to 31 December of each year (1997, 1998, 1999 and 2000) for European fruit lecanium, Indian wax scale, euonymus scale, and tea scale. Temperature readings were taken from 1 January 1999 through December 2000 for obscure scale. Temperature data were entered into a computer program (Degree-day Utility, Higley et al. 1986), and degree days were calculated using 10.56°C as the base temperature and 32.22°C as the upper threshold using the single sine method. The threshold temperatures of using 10.56 and 32.22°C were arbitrarily chosen based on previous use of these temperatures in calculating growing degree days for scale insects in California. Live samples of scales were collected at monthly intervals (November through February) for 2 yrs and placed in incubators (Percival Co., Perry, IA) at each of the following temperatures to attain a model for the developmental time of first-instar emergence: 15, 18, 21, 27 and 30°C ± 1°C. Samples were checked twice per week for crawler emergence. The reciprocal of development time was regressed on temperature using a linear least squares technique (Steel and Torrie 1960). Temperature thresholds for crawler emergence were determined by extrapolation of the regression line to the abscissa. Data were entered into the formula $DD = K_t = (T - T_0)*D_t$, where T = tested temperature, T_0 = base temperature, and D_t = mean developmental time to a particular stage of development at temperature T. Degree-days were then recalculated through the degree-day utility program using the base temperatures attained from the model. Results from using the model temperatures were compared to that of field-collected data using the set standard-base temperature of 10.56°C.

Results

European fruit lecanium, *Parthenolecanium corni*. One generation occurred in 1997 and 2000; two generations occurred were observed in 1998, 1999 with second-generation crawlers emerging in early autumn. Calendar dates and degree-days were recorded for the crawler emergence time periods for each site (Table 1). Average calendar date for first crawler emergence at the four sites ranged from 23 May to 15 June. Each first emergence spanned an average of 10 days. Degree-days calculated from the field using 10.56°C as the base temperature varied from year to year with 1997 having a mean of 1100, 1998 having a mean of 1382, 1999 having a mean of 1150, and 2000 having a mean of 1582 degree-days to first crawler emergence. Results from the linear regression model yielded a base temperature of 12.78°C. Recalculation of degree-days using this new base temperature yielded the following results: 1997 with a mean of 1203, 1998 with a mean of 1198, 1999 with a mean of 1263, and 2000 with a mean of 1209 degree-days to first emergence.

The only plant species that corresponded with first crawler emergence as a potential indicator plant was oak leaf hydrangea. In 1997, 1999, and 2000 oak leaf hydrangea was in full bloom when crawlers were emerging. In 1998, the oak leaf hydrangea had completed blooming 1 wk prior to crawler emergence.

Both parasitoids and predators were collected from the European fruit lecanium. Parasitoids included: *Blastothrix claripennis* Compere (Hymenoptera: Encyrtidae), *B. longipennis* Howard (Hymenoptera: Encyrtidae) and *Metaphycus* sp. (Hymenoptera: Encyrtidae). Predators included the predatory fungus weevil, *Anthribus nebulosus* West (Coleoptera: Anthribidae); a lady beetle, *Hyperaspis* sp. (Coleoptera: Coccinellidae); the convergent lady beetle, *Hippodamia convergens* Guérin-Méneville (Co-

Table 1. Calendar dates and degree-days to first crawler emergence for lecanium (*P. corni*)

Year	Site	Date emergence	DD Range 10.56°C	DD Mean 10.56°C	DD Range 12.78°C	DD Mean 12.78°C
1997	(1)	5/26-6/5	1030-1140	1084	1178-1216	1189
	(2)	5/30-6/11	1054-1194	1130	1198-1232	1215
	(3)	5/26-6/6	1015-1112	1064	1168-1220	1184
	(4)	5/31-6/13	1077-1215	1148	1202-1250	1229
1998	(1)	6/2-6/13	1181-1424	1366	1178-1221	1196
	(2)	6/12-6/22	1348-1511	1428	1192-1228	1215
	(3)	6/2-6/12	1164-1368	1264	1172-1202	1184
	(4)	6/15-6/21	1458-1562	1510	1249-1290	1263
1999	(1)	5/23-6/2	1016-1210	1100	1184-1215	1192
	(2)	6/12-6/22	1058-1193	1128	1189-1224	1206
	(3)	5/31-6/4	1142-1205	1177	1272-1315	1296
	(4)	5/30-6/4	1151-1223	1188	1290-1342	1328
2000	(1)	6/3-6/11	1422-1596	1482	1184-1220	1199
	(2)	6/5-6/13	1426-1558	1487	1186-1216	1212
	(3)	6/10-6/18	1542-1702	1622	1252-1290	1269
	(4)	6/3-6/12	1428-1610	1523	1218-1242	1225

leoptera: Coccinellidae); twicestabbed lady beetle [*Chilocorus stigma* (Say)]; the green lacewing, *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae); phytoseiid mites (Acarina: Phytoseiidae); cheyletid mites (Acarina: Cheyletidae); acrobat ants, *Crematogaster* sp. (Hymenoptera: Formicidae); bowl and doily spiders, *Frontinella pyramitela* (Walckener) (Araneae: Linyphiidae), and a clubionid spider, *Trachelas tranquillus* (Hentz) (Araneae: Clubionidae).

Indian wax scale, *Ceroplastes ceriferus*. One generation occurred in 1997, 1998, and 2000. A second generation was recorded in 1998. Dates for first crawler emergence (Table 2) were fairly uniform with 1997 ranging from 2 June to 15 June, 1998 from 5 June to 14 June, 1999 from 30 May to 2 June, and 2000 from 27 May to June 5. Degree-day calculations using field-collected data (Table 3) yielded results with a wide range of variance from 1087 to 1485 and a mean of 1308 over the 4 yrs. Use of the linear regression model yielded a base temperature of 12.78°C instead of the 10.56°C that was used in the field data. Recalculation of the degree-days using the new base temperature yielded the following degree-day calculations to first crawler emergence: 843 in 1997, 930 in 1998, 910 in 1999, and 896 in 2000. The only phenological indicator that corresponded with first crawler emergence of Indian wax scale was *Yucca filamentosa* L.

Natural enemies that were recorded for Indian wax scale include a parasitoid,

Table 2. Calendar dates and degree-days to first crawler emergence for Indian wax scale (*C. ceriferus*)

Year	Site	Date emergence	DD Range 10.56°C	DD Mean 10.56°C	DD Range 12.78°C	DD Mean 12.78°C
1997	(1)	6/8-6/12	1168-1238	1206	838-872	852
	(2)	6/9-6/15	1154-1231	1197	832-864	846
	(3)	6/2-6/7	1087-1212	1150	818-854	831
	(4)	6/4-6/9	1120-1187	1152	826-856	838
1998	(1)	6/4-6/8	1238-1302	1273	848-923	909
	(2)	6/5-6/10	1245-1385	1309	898-968	946
	(3)	6/12-6/14	1242-1320	1282	882-934	912
	(4)	6/10-6/14	1424-1485	1453	948-1086	1014
1999	(1)	5/30-6/4	1321-1445	1392	904-948	928
	(2)	5/31-6/2	1326-1400	1372	852-922	886
	(3)	6/1-6/2	1346-1364	1355	822-876	848
	(4)	5/30-6/2	1334-1412	1380	862-942	914
2000	(1)	5/27-6/2	1258-1393	1324	848-928	888
	(2)	5/30-6/3	1302-1400	1346	874-952	910
	(3)	5/31-6/5	1315-1401	1344	884-926	906
	(4)	5/27-6/1	1280-1408	1342	874-912	902

Table 3. Calendar dates and degree-days to first crawler emergence for obscure scale (*M. obscura*)

Year	Site	Date emergence	DD Range 10.56°C	DD Mean 10.56°C	DD Range 5°C	DD Mean 5°C
1999	(1)	4/17-4/20	531-559	544	1228-1272	1246
	(2)	4/19-4/23	538-598	566	1244-1290	1265
	(3)	4/18-4/21	535-570	551	1235-1282	1253
2000	(1)	4/10-4/13	505-541	523	1256-1296	1268
	(2)	4/11-4/17	485-545	515	1238-1287	1259
	(3)	4/9-4/13	492-535	522	1258-1290	1268

Metaphycus sp. (Hymenoptera: Encyrtidae); the green lacewing, *Chrysoperla carnea* (Neuroptera: Chrysopidae); the convergent lady beetle, *Hippodamia convergens* (Coleoptera: Coccinellidae); the bowl and doily spider, *Frontinella pyramitela* (Araneae: Linyphiidae); and an agelenid spider *Agenelopsis* sp. (Araneae: Agelenidae).

Obscure scale, *Melanaspis obscura*. Only one generation per year of obscure scale occurred in the Athens, GA. Calendar dates (Table 3) for first crawler emergence was uniform over the 2 yrs, ranging from 17 April through 23 April in 1999 and from 9 April to 17 April in 2000. Degree-day accumulations from field-collected data (using the standard of 10.56°C) rendered similarly uniform results: degree-days to first emergence with a mean of 555 in 1999 and a mean of 525 in 2000. The linear regression model yielded a new base temperature of 5.0°C. Recalculating the degree-days using this new base temperature yielded the following degree-day accumulations: 1254 in 1999 and 1261 in 2000.

Phenological indicators that corresponded with first crawler emergence were honeysuckle in early bloom and Florida dogwood in full bloom. Natural enemies for obscure scale that were found in Athens, GA, included an aphelenid parasitoid, *Coccophagoides fuscipennis* (Girault) (Hymenoptera: Aphelenidae); the encyrtid parasitoid, *Aphytis* sp. (Hymenoptera: Encyrtidae); an encyrtid parasitoid, *Metaphycus* sp. (Hymenoptera: Encyrtidae); a predatorymite, *Hemisarcoptes malus* (Shimer) (Acarina: Hemisarcoptidae); a predatory mite, *Cheyletia* sp. (Acarina: Cheyletidae); a predatory mite, *Anystis* sp. (Acarnia: Anystidae); and a pink headed fungus, *Nectria diploa* (Berk. & Curt.).

Euonymus scale, *Unaspis euonymi*. Four generations per year were observed for euonymus scale in all 4 yrs (Table 4). Dates for first crawler emergence for euonymus scale ranged from 16 April to 23 April in 1997, 26 April to 2 May in 1998, 25 March to 1 April in 1999, and 6 March to 11 March in 2000. The mean number of degree-days using a base temperature of 10.56°C to first crawler emergence was 585 in 1997, 503 in 1998, 386 in 1999, and 384 in 2000. Use of the linear regression

Table 4. Calendar dates and degree-days to first crawler emergence for euonymus scale (*U. euonymi*)

Year	Site	Date emergence	DD Range 10.56°C	DD Mean 10.56°C	DD Range 3.89°C	DD Mean 3.89°C
1997	(1)	4/16-4/19	548-577	564	1382-1414	1406
	(2)	4/17-4/21	577-601	586	1392-1434	1421
	(3)	4/18-4/23	571-621	597	1402-1456	1432
1998	(1)	4/28-5/01	478-508	493	1448-1472	1464
	(2)	4/29-5/02	495-524	511	1452-1512	1492
	(3)	4/26-4/30	475-522	497	1432-1487	1468
1999	(1)	3/25-3/28	363-402	384	1372-1398	1388
	(2)	3/23-3/26	360-398	379	1364-1392	1384
	(3)	3/26-4/1	283-412	398	1368-1442	1403
2000	(1)	3/6-3/9	267-312	298	1356-1382	1358
	(2)	3/7-3/11	276-335	322	1364-1402	1372
	(3)	3/6-3/11	269-325	313	1342-1387	1366

model yielded a base temperature of 3.89°C. Recalculation of the degree-days using the model derived base temperature yielded the following numbers of degree-days to first crawler emergence: 1409 in 1997, 1472 in 1998, 1390 in 1999, and 1365 in 2000.

Phenological indicators that corresponded with the first crawler emergence were recorded in each year. In 1997, snowball viburnum was in 50% bloom, and Oregon grape was beginning to bloom. In 1998, Oregon grape was in 50% bloom and snowball viburnum was in 50% bloom. In 1999, red maple was in 50% bloom, Oregon grape was in 50% bloom, black cherry was in 50% bloom, and Florida dogwood was in 50% bloom. In 2000, black cherry was in 50% bloom, and Florida dogwood was in 50% bloom.

Natural enemies that were collected for the euonymus scale were Korean lady beetle, *Chilocorus kuwanae* (Coleoptera: Coccinellidae); the predatory nitidulid, *Cybocephalus* sp. (Coleoptera: Nitidulidae); the convergent lady beetle, *Hippodamia convergens* (Coleoptera: Coccinellidae); and a predatory cheyletid mite, *Cheyletus* sp. (Acarina: Cheyletidae).

Tea scale, *Fiornia theae*. Multiple generations of tea scale occurred in each year of the study. Crawlers first emerged between 22 April and 11 May in 1997, between 17 and 28 April in 1998, between 21 and 28 February in 1999, and between 6 and 12 March in 2000. Degree-day accumulations using the base temperature of 10.56°C yielded results (Table 5) with high variance. In 1997, the degree-days ranged from 612 to 791; in 1998, from 401 to 564; in 1999, from 184 to 201; and in 2000, from 212 to 234. The linear regression model yielded a base temperature of 5.0°C. Recalculation of degree-days using the new base temperature yielded an average of 1449 in 1997, 1442 in 1998, 542 in 1999, and 548 in 2000.

Phenological indicators for first crawler emergence in tea scale were 1997, Chinese wisteria in 50% bloom and honeysuckle beginning to bloom; 1998, Chinese wisteria 50% bloom, tulip poplar beginning to bloom, sugar maple in 50% bloom; 1999, henbit beginning to bloom, common chickweed beginning to bloom; and 2000, honeysuckle beginning to bloom and Chinese wisteria 50% bloom.

Natural enemies that were found attacking or associated with tea scale included a aphelenid parasitoid, *Encarsia* sp. (Hymenoptera: Aphelenidae); a eulophid paraisoid, *Aprostocetus* sp. (Hymenoptera: Eulophidae); the convergent lady beetle, *Hippodamia convergens* (Coleoptera: Coccinellidae); the green lacewing, *Chrysoperla carnea* (Neuroptera: Chrysopidae); the bowl and doily spider, *Frontinella pyramitela* (Araneae: Linyphiidae); and an agelenid spider, *Agelenopsis* sp. (Araneae: Agelenidae).

Other scale species. Other species of scales for which degree-day information and limited life-history data were collected included cottony maple leaf scale [*Pulvinaria acericola* (Walsh & Riley)], cottony camellia scale [*Pulvinaria floccifera* (Westwood)], cottony maple scale [*Pulvinaria innumerabilis* (Rathvon)], tulip tree scale [*Toumeyella liriodendri* (Gmelin)], oak felt scale [Acanthococcus quercus (L.)], and the cottony cushion scale [*Icerya purchasi* (Maskell)]. A population of cottony maple leaf scale on red maple (one site on the University of GA campus) was observed for 1998, 1999, and 2000. Only one generation occurred per year. Dates for crawler emergence ranged from 13 May to 28 May for the 3 yrs. Degree-days ranged from 892 to 1229 using a base temperature of 10.56°C. Phenological indicators were tulip poplar beginning to bloom in each of the 3 yrs and oak leaf hydrangea beginning to bloom in 1998. Natural enemies were not observed.

Two sites were observed over 1997, 1998, and 2000 for the cottony camellia scale.

Table 5. Calendar dates and degree-days to first crawler emergence for tea scale (F. theae)

Year	Site	Date emergence	DD Range 10.56°C	DD Mean 10.56°C	DD Range 5°C	DD Mean 5°C
1997	(1)	4/22-4/29	612-637	624	1287-1342	1328
	(2)	4/25-5/2	624-674	649	1298-1440	1402
	(3)	4/27-5/5	632-715	672	1346-1440	1412
	(4)	5/8-5/11	757-791	776	1458-1512	1498
1998	(1)	4/17-4/22	401-434	421	1364-1438	1417
	(2)	4/19-4/25	418-462	438	1398-1456	1428
	(3)	4/17-4/24	410-498	450	1420-1508	1468
	(4)	4/23-4/28	502-564	533	1482-1522	1502
1999	(1)	2/21-2/26	184-193	188	513-538	526
	(2)	2/24-2/28	192-221	202	540-558	549
	(3)	2/24-2/28	194-218	205	546-562	554
	(4)	2/21-2/25	188-221	202	538-570	549
2000	(1)	3/6-3/9	192-224	211	520-534	528
	(2)	3/7-3/11	202-234	221	546-562	551
	(3)	3/6-3/11	199-224	212	534-552	540
	(4)	3/8-3/12	212-234	222	546-568	554

Sites included a local church (host plant was burford holly) and the Psychology Building at the University of Georgia (host plant was bradford pear). Only one generation occurred per year. Crawlers began to emerge in late June for 1997 and 2000, and in mid June for 1998. The degree-days (using 10.56°C as the base temperature) ranged from 1584 to 1941 in 1997, 1463 to 1649 in 1998 and 1422 to 1637 in 2000. No phenological indicators were found to correspond with first crawler emergence. Natural enemies that were observed included the green lacewing, *Chrysoperla carnea* (Neuroptera: Chrysopidae); the bowl and doily spider, *Frontinella pyramitela* (Araneae: Linyphiidae); and unidentified Clubionid spider (Araneae: Clubionidae); and acrobat ants, *Crematogaster* sp. (Hymenoptera: Formicidae).

The University of Georgia campus was the only site where cottony maple scale (host plant was red oak) was found. The emergence dates for crawlers were determined for 1997, 1998, 1999, and 2000. Only one generation per year occurred at this site. The emergence dates ranged from mid to late May. Degree-days ranges for first crawler emergence ranged from 898 to 1321 using 10.56°C as the base temperature. Phenological indicators for first crawler emergence was tulip poplar beginning to bloom in 1997 and 1998, and tulip poplar at 50% bloom in 1999 and 2000. No natural enemies were observed.

Two sites were found for tulip tree scale in the Athens area; the State Botanical

Gardens and the University of Georgia campus. Populations were univoltine. The calendar dates for crawler emergence ranged from 12 April to 26 April for each of the years. Degree-days (using 10.56°C as the base temperature) ranged from 532 to 616 in 1997, 1999, and 2000. The degree-day data for 1998 ranged from 368 to 388. Phenological indicators in 1997 and 1998 were honeysuckle beginning to bloom and Florida dogwood beginning to bloom, and in 1999 and 2000 snowball viburnum and Florida dogwood at 50% bloom. In 1997 and 1998, carpenter ants (*Camponotus* sp.) were associated with the population of tulip tree scales at the State Botanical Gardens. In 1999 and 2000, acrobat ants (*Crematosgaster* sp.) were associated with this population. No natural enemies were observed for either population during our study.

Cottony cushion scale populations were observed in 1997 at Lake Herrick on the University of Georgia campus (host plant wax myrtle) and at a local bank in Athens (host plant camellia) in 1998. Multiple generations occurred each year. Number of degree-days to first crawler emergence (using 10.56°C as the base temperature) ranged from 598 to 645 in 1997, and from 434 to 452 in 1998. The phenological indicator for 1997 was tulip poplar beginning to bloom and for 1998 Florida dogwood in full bloom. Carpenter ants (*Camponotus* sp.) were associated with the 1997 population, and the vedalia beetle [*Rodolia cardinalis* (Mulsant)] was associated with each population.

The oak felt scale was observed in both the years of 1998 and 1999 on red oak and pin oak. Populations of this scale were univoltine. Dates for first crawler emergence were uniform over both years, occurring within the first 2 wks of April. Degree-days (using 10.56°C as the base temperature) ranged from 285 to 338 in 1998 and from 481 to 521 in 1999. One natural enemy was found, a coccinellid (*Hyperaspis* nr. *bigeminata*). No phenological indicator was recorded for this scale species.

Discussion

The present study investigated the use of degree-days, calendar dates, and phenological indicators for predicting occurrence of scale insects. Use of a standard base temperature and an experimentally-derived lower threshold temperature was compared. In each case, use of the experimentally-derived lower threshold yielded estimations that were less variable than those calculated using a standard-base temperature.

The European fruit lecanium is a cosmopolitan pest of urban landscape deciduous trees throughout the southeaster U.S. although previous works indicate that there generally is only one generation of this scale per year, Kosztarab (1996) reported two generations on peach in Pennsylvania. Our study showed that two generations of this scale may occur in the southeastern U.S. The natural enemies that we collected were similar to those reported previously for this insect (Kosztarab 1996). The predatory fungus weevil, *Anthribus nebulosus* Forster, was not previously known to occur in Georgia. This Eurasian predator of scale insects, introduced into Virginia as a biological control agent (Kostarab and Kozár 1983), previously has been known in the U.S. only from Virginia, Connecticut, Massachusetts, and New York. Northeastern populations are considered adventive (Hoebeke and Wheeler 1991). Dates for the first crawler emergence were uniform, occurring in late May and early and mid June. Previous estimates of 846 to 1,657 GDD (Stewart et al. 2002) for crawler emergence were narrowed to a range of 1172 to 1342 using an experimentally-derived base temperature of 12.78°C.

Indian wax scale is another common scale insect in landscapes throughout the southeaster U.S. Natural enemies included a *Metaphycus* sp., green lacewing larva, convergent and twicestabbed lady beetles. Both bowl and doily spiders and sheet web spiders are common on hollies that maintained populations of Indian wax scale in this study. Scale crawlers were seen trapped in webs of both of these spiders, but we did not determine the impact of spider webs on crawler mortality. Other insects included various members of the Hymenoptera, which might have been collecting honeydew from the Indian wax scale. Crawlers first emerged in late May through mid June. Only one phenological indicator, *Yucca filamentosa,* corresponded to crawler emergence for each of the years.

Obscure scale, a common pest of oaks in the urban landscape, can have severe effects on its hosts. High populations will readily cause limb die-back. Only one generation occurred for each year of this study. The natural enemy complex found in Athens is consistent with previous reports (Stoetzel and Davidson 1971, 1972, Potter et al. 1989, Hendricks and Williams 1992). The pink headed scale fungus was present from late July to early August of 1999 and 2000. This fungus is known to significantly affect populations of obscure scale when present (Stoetzel and Davidson 1971, 1972). Crawlers began to emerge between mid to late April. Hendricks and Williams (1992) forecasted the degree-days for the obscure scale using the model of Potter et al. (1989) of 4.44°C. The data obtained from use of this model yielded accumulated degree days to crawler hatch that ranged from 1,498 to 1,566 for the population of obscure scale in Auburn, AL. These results were similar to that of the obscure scale populations found in Lexington, KY, where accumulated degree-days to crawler emergence ranged from 1,530 to 1,566. Degree-day accumulations for Athens, GA, using a set base temperature of 10.56°C, ranged from 497 to 598. Use of the linear regression model yielded a base temperature of 5°C and a degree-day range from 1248 to 1261.

Our findings provide a better understanding of scale crawler phenology and natural enemy interactions in the urban landscape. Future research may focus on overall importance of natural enemies such as the bowl, doily, and the sheet web spiders in scale pest population dynamics. Quantification of crawler mortality due to incapacitation in spider webs could be important. Further work may also include greater investigation of parasitoid complexes through rearing live samples of scales from different populations. Use of models to calculate the lower threshold for development of scale insects can improve prediction of crawler emergence.

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