SCALE INSECTS ON ORNAMENTAL PLANTS: A BIOLOGICAL CONTROL PERSPECTIVE

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Scale insects on ornamental trees and shrubs can cause various types of problems. With their piercing, tubular mouthparts scale insects consume plant sap and can thereby weaken plants when their populations exceed a certain density. Plants weakened by scale infestations are generally more susceptible to attack by other insects and fungal diseases. Moreover, certain scale insects (mealybugs and soft scales) excrete honeydew which supports growth of unsightly sooty molds.

Scale insects are difficult to control, even with insecticides (Wallner 1978; Johnson 1982). Because of the wax covering the insect's body, many insecticides are ineffective. In some cases only the crawler stage may be killed which means an insecticide must be applied at a specific time in the life cycle of the scale insect. Another problem with the use of insecticides is public concern for personal health and environmental quality. Means other than total reliance on insecticides are available for controlling scale insects on ornamental plants. The objective of this paper is to present a perspective on the feasibility of biological control (insect vs. insect) in the management of scale insects on ornamental trees and shrubs.

A population outbreak of scale insects on a tree or shrub may occur as a consequence of the plant being weakened because of its water and nutritional status, climatic conditions, absence of natural enemies, or any combination thereof. The physiological status of the plant and climatic conditions to which the plant is subjected can often be regulated by the arborist but insect natural enemies are not as easily manipulated. A natural enemy in the case of a scale insect could be a predator (ladybird beetle), parasitoid (wasp), or a disease (fungus). Because many ornamental trees and shrubs are naturalized exotics and commonly grown in intensely managed surroundings, natural enemies that should be present are not. In the absence of natural enemies certain scale species can attain extremely dense populations. The practice of biological control, in effect, results in pest control through manipulation of natural enemies.

There are at least three methods by which natural enemies can be manipulated: 1) inportation of exotic species (classical biological control), 2) augmentation of indigenous species; and 3) conservation of indigenous species. The effectiveness of these methods depends upon accurately identifying species (host and natural enemies) and knowledge of various natural enemy life cycles. We shall therefore look briefly at the natural enemies of scale insects before elaborating on the three methods of biological control. Diseases are excluded from the following discussion since they have not generally been as important as parasitoids and predators in biological control of scale insects.

Parasitoids. The most common parasitoids attacking scale insects are minute wasps generally varying from 0.5-2.5 mm in length. These wasps are generally considered to be the most effective of all the natural enemies attacking scale insects.

The general life cycle of a solitary, internal parasitoid is illustrated in Figure 1. The adult female wasp searches for suitable scale insects in which to lay her eggs. Typically one parasitoid develops per host (solitary) but in certain species several individuals may develop from one host (gregarious). The egg is inserted into (or on) the scale insect by means of an ovipositor. The larva which hatches from the egg has the appearance of a small maggot. This larva feeds upon and kills the scale insect. In endoparasitic species the larval wasp feeds from within the body of the scale whereas ectoparasitic species feed attached to the outside of the body (but beneath the scale covering in the case of armored scale insects). The parasitoid larva eventually becomes a pupa and ultimately an adult which will chew its way through the wax cover leaving behind a characteristic hole.

A great number of scale parasitoids belong to the insect family Encyrtidae, a group of wasps consisting of approximately 3500 species worldwide plus hundreds of species not yet identified (Krombein et al., 1979). Table 1 lists some of the major subfamilies and genera comprising the family Encyrtidae; it is evident that individual genera of wasps are usually restricted to certain genera of scale insects, a relationship useful in analyzing the prospects of biological control. Indeed the species of wasps within a single genus are often adapted to particular species of scale insects. Consequently it is important to accurately identify the scale insect in order to associate the appropriate species of parasitoid. Similarly, it is also important to accurately identify the wasp because more than one species of parasitoid wasp may attack a given species of scale insect.

Predators. Certain mites, ladybird beetles, caterpillars, and birds are known to prey on scale insects. The ladybird beetle, *Vedalia cardinalis* is perhaps the most famous of scale predators. The beetle was introduced into North America from Australia in 1888 by Albert Koebele and within a couple of years it had succeeded in reducing the populations of cottony cushion scale *(Icerya purchasi)* on citrus as well as on several ornamental plants. The success of the vedalia beetle in controlling cottony cushion scale was so dramatic that the beetle was widely credited with saving the citrus industry from economic ruin (DeBach, 1964).

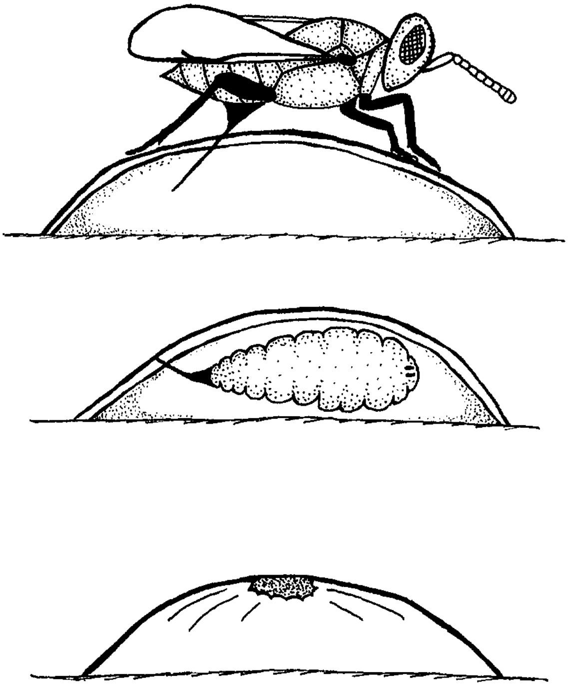

Figure 1. Life cycle of a scale parasitoid (Encyrtidae). Top: female wasp deposits egg in scale. Middle: larval wasp feeds on scale. Bottom: hole in scale indicates that adult wasp has emerged.

Although predators certainly help to reduce scale populations, historically they have not been as successful as parasitoids in biological control projects (DeBach and Rosen, 1976). However, predators can complement the actions of parasitoids. For example, in Israel the predatory mite *Hemisarcoptes* attacks scale insects primarily on the bark of citrus trees whereas the parasitoid wasp *Aphytis* tends to prefer scale insects on leaves. In Canada survival of *Hemisarcoptes* (a predaceous mite) during relatively cold winters is higher than for the parasitoid *Aphytis* (Gerson and Schneider, 1981).

Classical biological control. Likely targets for natural enemy introductions are those insect pests which were themselves introduced — usually by accident. When an insect pest is introduced, most, if not all of its natural enemies are left behind. Therefore the best place to find parasitoids or predators for importation is in the homeland of the insect pest. The deliberate introduction of parasitoids and predators from foreign countries to control insect pests (classical biological control) has occurred regularly and successfully for over a hundred years. The successes as well as some of the failures have been well documented (Clausen, 1978); these case histories of past importations provide a substantial basis for future importations. In the case of scale insects there is good reason to be optimistic about importing natural enemies: scale insects have accounted for more successes in classical biological control than any other group of insects (for examples see Table 2).

Parasitoid species usually consist of races adapted to different climatic conditions and thus it is important to make the importation from a climate similar to that of the intended release site. Once the candidates for importation have been identified and located, quarantine regulations must be followed to avoid accidental introduction of undesirable species, such hyperparasitic wasps (a parasitoid of a parasitoid). After satisfying quarantine regulations the natural enemies are mass reared in an insectary before being released into the fields. Several releases of several thousand individuals may be necessary for successful establishment of the natural enemy (DeBach, 1964; Huffaker and Messenger, 1976).

Augmentation and conservation of natural enemies. From 1890 through the late 1960s roughly 2300 species of predators and parasitoids were introduced for biological control in various regions of the world; of these only 34% have become established (Hall & Ehler, 1979). If the failures would be analyzed carefully some instances may be found where a slight manipulation of the environment could turn failure into success.

Table 1. Major families of scale insects and some associated genera of parasitoid wasps (Encyrtidae). All parasitoid genera listed occur across the U.S. and southern Canada except for *Aneristus* and *Comperiella* which are restricted to the southern U.S.

Families of scale insects	*Subfamilies of wasps and some genera*		
	Aphelininae	*Tetracneminae*	*Encyrtinae*
Mealybugs (Pseudococcidae)		Anagyrus Leptomastix	Pseudaphycus
Soft scales (Coccidae)	Aneristus Coccophagus		Aphycus Blastothrix Metaphycus
Armored scales (Diaspididae)	Aphytis Coccophagoides Prospaltella		Comperiella Habrolepis

Table 2. Successful cases of imported natural enemies providing biological control of scale insects on ornamental plants (from Clausen, 1979).

Scale insect	*Location of scale infestation*	*Natural enemy*	*Source of natural enemy*
oak pit scale	New Zealand	*Habrolepis dalmanni*	United States
European fruit lecanium	British Columbia	*Blastothrix sericea*	Great Britian
cottony cushion scale	California	*Vedalia cardinalis*	Australia
lecanium scale	Canada	*Blastothrix sericea*	Great Britian
olive scale	California	*Aphytis maculicornis*	Iran
		Coccophagoides utilis	Pakistan
Comstock mealybug	United States	*Allotropa burrelli*	Japan
		Pseudaphycus malinus	Japan
San Jose scale	India	*Prospaltella pernicissi*	China, U.S., U.S.S.R.
black scale	United States	*Metaphysuc helvolus*	South Africa
		Metaphycus lounsburyi	South Africa

The same is true for native natural enemies which are not providing effective control. We can manipulate either the natural enemy itself (augmentation) or we may manipulate its environment (conservation).

Natural enemy augmentation includes at least two types of activities: 1) periodic releases of natural enemies, and 2) development of better adapted strains through genetic selection. Both of these activities generally involve mass propagation of natural enemies. If a natural enemy is effective only in certain places, or only during certain seasons, periodic releases at the appropriate place and time may allow for better control; if a natural enemy displays a lack of adaptation, selective breeding for improved strains might enhance its ability to control the scale population. Although augmentation shows great promise for the future (Ridgway and Vinson, 1978), it is presently not a widely used practice in arboriculture.

Localized and sporadic outbreaks of scale populations sometimes result from local environmental conditions which are adverse to existing natural enemies. Air-borne dust and insecticides may be differentially more injurious to parasitoids than they are to scale insects, since the latter are usually protected by their scale-like covering. For instance, an outbreak of pine needle scale occurred at South Lake Tahoe because of high parasitoid mortality from malathion applications for mosquito control (Luck & Dahlsten, 1975). Air-borne dust can abrade the cuticle of adult parasitoids causing them to desiccate; dust can also interfere with host searching behavior. It is not uncommon to find scale outbreaks occurring adjacent to gravel roads and other sources of dust (Edmunds, 1973). Therefore, if it is possible to eliminate or reduce the amount of air-borne dust and insecticides, an aggravated scale problem might be avoided.

Honeydew serves as a food source for adult stages of many natural enemies and it is therefore desirable in small amounts. However, honeydew also attracts ants which are known to guard and protect honeydew secreting scale insects from attack by natural enemies. In such a situation controlling the ants may increase the effectiveness of the natural enemies.

In certain instances a natural enemy may be enhanced by the presence of an alternate host in order to survive periods when the one host is not available. With a thorough knowledge of the natural enemy's biology it may be possible to provide the suitable alternate host by planting a combination of certain plants together.

A Proposed Case for Classical Biological Control: Pit Scales on Oak

Pit scales (family Asterolecaniidae; genus *Asterolecanium*) on oak are part of the many North American scale pests on ornamental plants that have been accidentally introduced. Pit scales are particularly common on species in the white oak group. On close inspection one can see the characteristic pits elicited by this insect on twigs. Oak trees heavily infested with pit scale typically show a proliferation of epicormic twigs and often retain brown leaves over the winter.

Three species of pit scale have been commonly reported from oak: *Asterolecanium minus, A. quercicola,* and *A. variolosum.* Because different populations of pit scale may show variation in morphological characters, identification at the species level is very difficult (Podsaidlo, 1974). For this reason many of the published records of pit scale species are open to question pending further research on this subject.

Pit scales on oak overwinter on the twig as mature females, males being vary rare. Crawlers emerge from underneath the female scale with peak activity in May and a smaller peak occurring in late summer in Oregon. Current year shoots and one-year-old twigs are the preferred feeding sites, although heavy pit scale infestations may also occur on callus tissue surrounding trunk wounds (personal observation). Densities of pit scale can differ strikingly between adjacent trees. At any given site one tree may contain up to ten scale insects per square centimeter while an adjacent tree might be virtually uninfested. Preliminary observations suggest that this patchy distribution might result from individual trees being stressed and thus more susceptible to build-up of pit scale populations. Common causes of stressed oak trees in the urban landscape are soil compaction and alteration of drainage patterns under established trees. An alternative explanation for the patchy distribution of pit scales is that particular scale populations have become adapted to certain genotypes of oak trees (Edmunds and Alstad, 1978).

In researching the feasibility of biological control of pit scales on oak in Oregon we have conducted studies on: 1) distribution and density of pit scales, 2) occurrence of natural enemies of pit scale in Oregon, and 3) available literature concerning parasitoids of pit scale in other parts of the world.

Oak infesting pit scales are thought to be of European or Asian origin. Whatever their origin, pit scales have been carried with oak trees to North and South America, Africa, New Zealand, and Australia. In North America oak pit scales have become well established on both the east and west coasts. Our research indicates that only one parasitoid, *Habrolepis dalmanni,* occurs in Oregon. The rate of parasitization on mixed populations of *Asterolecanium minus* and *A. quercicola* ranges from less than three (generally) up to twenty (rarely) percent. This parasitoid exerts some mortality on pit scale populations but apparently not as effectively as in New Zealand where it was deliberately introduced against *A. variolosum* in the 1920s from the eastern United States (Clausen, 1978). Why *H. dalmanni* is more effective in New Zealand than in the United States is unknown. Assuming the identification of *A. variolosum* was accurate, it might be that *A. variolosum* is a more suitable host for *H. dalmanni* than are *A. minus* and *A. quercicola.*

After establishing which parasitoids are present, the next step is to determine which parasitoids attack oak pit scales in Europe and Asia. At this point one must scrutinize the published host records with great care. For example, *Aphytis variolosum* was originally described and named as a parasitoid of oak pit scale, *Asterolecanium variolosum* (Alam, 1956). If this record was correct, *Aphytis variolosum* would be a likely candidate for importation given the excellent record of other *Aphytis* species in controlling other scale species (DeBach and Rosen, 1976). However, it now appears that this record was in error (Rosen and DeBach, 1979), probably the result of rearing parasitoids from a twig infested with both pit scale and armored scale. In a search through the published records of pit scale parasitoids in Europe and Asia we have had to discount several other records. Thus, parasitoid species of *Mercetiella, Metaphycus (Euaphycus), Asterolecaniobius,* and perhaps other species or races of *Habrolepis* are the only remaining candidates for an importation program. Presently we are investigating the feasibility of acquiring and importing some of these parasitoids.

Conclusions

Scale insects would be a much greater problem were it not for native and introduced natural enemies. When scale problems do arise it is often the inadvertant result of human activities such as accidental introductions of scale pests from other parts of the world. Biological control seeks to control insect pests by restoring or enhancing the actions of natural enemies. The history of biological control demonstrates that manipulation of natural enemies can be an effective means of pest control and that scale insects are especially amenable to this type of control.

If a scale infestation involves a native species such as brown soft scale it may be possible for the arborist to enhance the actions of native parasitoids and predators (i.e. natural enemy conservation). Scale insects having few or no natural enemies, such as pit scales in oak, may ultimately require importation of natural enemies to achieve successful control. Biological control requires an extensive amount of preliminary research but the investment is often rewarded by a control measure which is effective, long lasting, and compatible with environmental concerns.

Acknowledgements. We would like to thank the International Society of Arboriculture for supporting part of our oak pit scale research in Oregon and J. Capizzi and T. Cook for reviewing the manuscript.

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ABSTRACTS

POPOVICH, L. 1983. **Acid rain and forests.** Am. Forests 89(9): 42-44, 50-53.

Acid rain has attained the coveted distinction of becoming not just a political debate but a full-blown cultural phenomenon, a controversy that has forced itself on the nation with an urgency that has surprised all but a few. With its conservative position on acid rain, the Administration is like the little Dutch boy, trying with feeble calls for more research to plug a crumbling dike that is threatening to burst and drown the White House in a flood of evidence implicating acid rain in widespread environmental damage. Contrary to assertions commonly made in the news media and by politicians and other interested observers, the evidence that would link acid-rain damage to forests is inconclusive, at least at this point. While experts and informed observers don't disregard the mounting evidence that implies a causal connection, the scientific consensus today can only say that acid rain creates additional biological stresses, most often in already fragile forest stands, and that it is one of a number of potentially harmful agents which may contribute to increased mortality. In the eyes of science, acid rain is an accomplice to a crime, perhaps an accessory to murder, but probably not the solitary killer it is made out to be.

HENSLEY, D.L., F.D. GIBBONS, H.E. THOMPSON, J. HOFECK, T. LEE, D. SHERLEY, and D. BRUNS. 1983. **Nettle trees on Kansas campus are victims of mysterious decline.** Am. Nurseryman 158(8): 98-99.

Nettle tree (also called hackberry) is normally a sturdy, relatively problem-free tree except for minor problems with witches'-broom, rust and hackberry nipple gall. During the summer of 1983, a condition called "hackberry decline" affected numerous large specimens on the Kansas State University campus. Symptoms included wilting and yellowing of terminal leaves, followed by the eventual death of entire limbs. Partial or total girdling of higher canopy limbs on affected trees were found using an aerial bucket truck. All affected limbs were either partially or fully girdled. This damage was caused by fox squirrels. Why the squirrels favored nettle tree, which is not particularly noted for its sugar content, is still a mystery. The campus will likely trap and move the squirrels to less populated areas.