INTEGRATING CLASSICAL BIOLOGICAL CONTROL WITH PLANT HEALTH IN THE URBAN FOREST

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Abstract. Classical biological control is defined as a process of identification and introduction of natural enemies of pest species for the purpose of reducing the population size of the damaging species. Introduction of a parasitic wasp and a predaceous beetle has reduced populations of the ash whitefly by 10,00-fold in landscape trees in California. It is hoped that similar introductions of parasitic wasps to control the eucalyptus longhorned borer will be successful in reducing tree mortality. However, choosing the proper species of *Eucalyptus* for site conditions, proper water management to maintain optimum tree vigor, and proper tree maintenance will reduce the risk of attack by this borer. Plant health care is critical to enhance tree resistance and limit tree susceptibility. The combination of maintaining vigorous tree growth and limiting the number of insect pests in the environment through the action of natural enemies provides a long-term approach to tree protection.

Urban forests are unique environments. They are almost entirely artificial and often contain mixes of both endemic and exotic species with high degrees of spatial and species diversity. The understory of the urban forest may be barren as in the case of a parking lot, composed of a single species at a single height as in a turf landscape, or it may be highly varied in height and rich in diversity as in many backyards. Interspersed among the plants, often at regular spacings, are roads and buildings. In addition, plants are often placed at regular distributions within small areas of the landscape (e.g., street trees of one species within a neighborhood), but in irregular patches when observed from the perspective of the entire landscape ecosystem (e.g. many neighborhoods with different street tree species across a large urban area). There is much more public contact with urban forests than commercial or even recreational forests. Consequently, public perception of insect and disease problems in urban trees is often greater and the thresholds for injury are often lower than they are in other types of forests. Urban forests may also receive more water and nutrients, as well as other forms of maintenance than other types of forests because of their monetary, aesthetic, and environmental value.

Classical biological control is ideally suited for urban forests (7). DeBach (9) defined biological control as "the action of parasites, predators, and pathogens in maintaining another organism's density at a lower average than would occur in their absence." Biological control by predators, parasites, and pathogens is only one of the types of natural control that exist to lower pest densities, but unlike other control factors such as temperature or humidity, natural enemies frequently are responsive to changes in pest numbers. In addition, predators and parasites have the advantage of mobility, they search for their pest insect hosts and feed or lay eggs on them as they are found. When plant-feeding insects are introduced into new areas without their natural enemies, populations often increase to damaging levels. Introduction of natural enemies reestablishes the relationship between the biological control agents and the herbivore that is used for food. Consequently, the pest populations are often dramatically reduced. The process of introducing exotic natural enemies to regulate populations of pest insects is often referred to as classical biological control.

Many of the plant species used in urban forests, particularly in California, are introduced from other areas. Unfortunately, insects that feed on these trees are often also introduced into the area without their natural enemies resulting in aesthetic and economic damage. The use of insecticides is not always the best control strategy because of high levels of public exposure, potential or perceived risk, reduced effectiveness or resistance, frequent need for repeated applications, limited availability of materials, and high costs for effective coverage of large mature trees. However, identification, introduction, and establishment of natural enemies can provide self-sustaining and permanent regulation of pest populations for a relatively low initial cost.

Biological control is both compatible and complementary to good tree care practices. Many insect pest problems can be reduced by maintaining vigorously growing trees. Healthy and vigorous trees may be more resistant to insect colonization or may be able to compensate for insect feeding and not suffer as much reduced growth as trees in poor health. However, when pest populations are at very high levels, even well maintained trees can be at risk of damage or death. Biological control acts as an important population regulating factor to limit pest numbers. Establishment of large numbers of healthy trees in urban forests through proper tree selection and maintenance practices in combination with high levels of pest mortality caused by the natural enemies can reduce the insect problems below the damage thresholds with minimal environmental disturbance.

The relationship between plant health care and biological control to limit insect problems can be demonstrated in two systems in California. In the first example, the role of an introduced parasite and a predator may be more important for reducing the pest populations. In the second example, tree selection and care may be essential elements critical to the overall success of a biological control-based management program.

Ash whitefly

Siphoninus phillyreae, the ash whitefly (Figure 1), was first detected in southern California in the summer of 1988 (2). By 1992, the insect was distributed throughout the state and was also reported in Nevada, Arizona and New Mexico (4). Female whiteflies lay eggs on the underside of leaves of host trees. Nymphal whiteflies feed on plant fluids and excrete large quantities of honeydew. Damage to the plant results from both removal of nutrients by the feeding whiteflies and limited photosynthesis because the black sooty mold growing on the honeydew blocks light penetration. Whitefly developmental time is 28 days at 25°C (16) and there are multiple overlapping generations resulting in densities of the immature stages on leaves approaching $31/cm^2$ by midsummer (12). Trees suffer premature defoliation and both fruit size and crop yield can be reduced.

Figure 1. The ash whitefly adult and immature stages on the under side of ash foliage.

The ash whitefly rapidly became a significant pest in the urban landscape of California not only because of high population densities, but also because of the large number of host species in the urban forests of California. Development of the immatures was successful on as many as 55 species in 13 plant families (2, K. Arakawa pers. comm.). Although the whitefly could develop on all these hosts, there were differences in preference and survivorship of nymphs. The most commonly infested landscape trees were *Fraxinus* sp., *Pyrus* sp., and *Punica granatum*; laboratory tests of ovipositional preference demonstrated that ash and pear were preferred by females over other hosts including *Prunus persica* or *Citrus sinensis* (16). Survival of the nymphal stages was higher on the preferred hosts than on any of the other hosts tested, but development rates were not affected by the plant host (16).

Information on host plant susceptibility and suitability is important in order to decide which species, among the range of trees species available, is appropriate to fit the site and will also avoid potential insect (or disease) problems. However, once a tree has been established, other measures must be explored to reduce insect-caused damage. There was no evidence that the whitefly exhibited a preference for either vigorous or stressed trees. Proper tree care that alleviated stressful growing conditions could improve the ability of the tree to withstand the insect feeding injury, but all trees regardless of vigor could be attacked by the ash whitefly. Insecticides proved to be ineffective at controlling whitefly populations on trees for more than two weeks, and unless all hosts in an area were treated, there was continual reinfestation that rendered insecticide applications both useless and a waste of money (T. D. P. unpublished data). Biological control was the permanent and cost effective solution to the ash whitefly problem.

A population of a tiny parasitic wasp, *Encarsia partenopea* (Figure 2), from Israel was first released into southern California in the fall of 1989. Further releases were made throughout much of the state during the subsequent two years (4). In addition to establishment of the parasitic wasp, a predaceous beetle from Israel, *Clitostethus arcuatus*, was also established in 1990 (3). Laboratory studies have indicated that survival of the beetle may be better at cooler temperatures (3), which support field observations that the predator appears to have established in relatively cool coastal locations. The beetle has also established populations in warm inland valleys, probably in suitable cool microhabitats within the warmer areas.

In carefully monitored studies of field populations of both the parasite and the whitefly host, Gould et al. (12) demonstrated a three to four order of magnitude reduction in whitefly populations that could be directly attributable to the action of the parasite. The authors also demonstrated that the parasites were excellent colonizers and could locate infestations of the whitefly up to 10 km away from the nearest parasite release location within 60 days. This ability to disperse and locate pest infestations illustrates another great benefit of biological control in urban forests; even if trees of the same species are unevenly distributed throughout the landscape, the natural enemies are adapted to search for potential hosts.

Eucalyptus longhorned borer

The eucalyptus longhorned borer (Figure 3), *Phoracantha semipunctata*, was introduced into southern California some time prior to 1985 (19). The beetle colonizes trees in the genus *Eucalyptus*, which were initially brought from Australia into

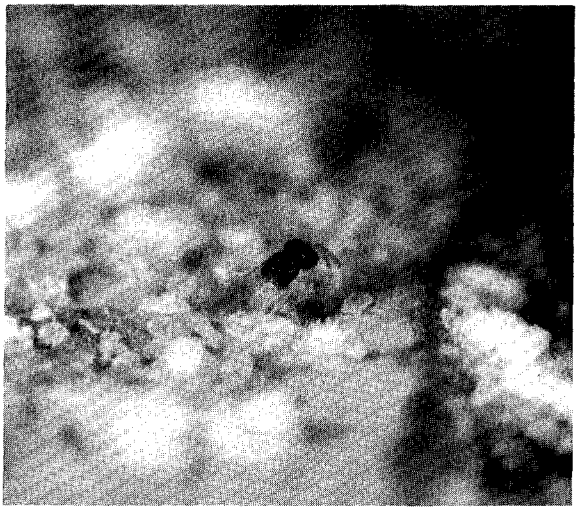

Figure 2. *Encarsia partenopea* lays eggs within the body of the host whitefly nymph, the egg hatches, and the wasp larvae consume the whitefly.

California as fast-growing timber species about 100 years ago. Because the trees were initially imported as seed, their pest insect complex was not brought with them. In Australia, the beetle normally colonizes dying trees and broken branches of *Eucalyptus* and is not considered to be a problem except during periods of prolonged drought or following forest fires. However, in most other parts of the world where both *Eucalyptus* and the beetle are introduced, the insect can be devastating, causing up to 90% mortality of plan-

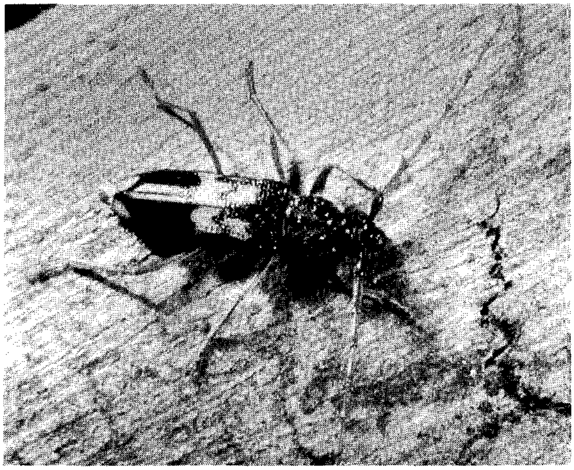

Figure 3. *Phoracantha semipunctata* adult beetles may range in size from 2-4 cm.

tation-grown trees (6, 10, 15, 11).

Female *P. semipunctata* lay up to 40 eggs in batches on the bark of host trees (13). Following egg hatch, the first instar larvae feed for a short distance just under the bark surface before turning inward to construct feeding galleries in the phloem and inner bark at the xylem interface. The tree is quickly girdled and killed by the tunneling action of the larvae. Upon completion of feeding, the larvae construct pupation chambers in the wood where they complete development to the adult stage. Total development from egg to adult may be completed in about 3 months and adults may live for one month (13).

Because insecticides cannot protect living trees from the beetle (1), tree care and biological control offer the best management program. Tree care can be divided into two aspects of protection. The first aspect is to select the proper species for planting at any site. Many of the species planted in California are adapted to the relatively uniform annual rainfall pattern characteristic of eastern Australia which sharply contrasts with the distinct short wet and long dry seasons of California. These trees are capable of growing under California conditions, but may experience periods of prolonged stress. Evaluations of plantations and naturalized plantings for up to five years have revealed that the beetle prefers some *Eucalyptus* species over others for colonization (Table 1). *Eucalyptus globulus*, *E. nitens*, *E. saligna*, *E. viminalis*, and *E. diversicolor* had much lower survival than *E. robusta*, *E. camaldulensis*, or *E. cladocalyx* when all were planted in the same plantation. Approximately 90% of the *Eucalyptus* in naturalized or old established plantings on Santa Catalina Island off the southern California coast are *E. cladocalyx*. However, only one *E. cladocalyx* tree has been killed by the beetle over the last two years. During the same period, all *E. polyanthemos* have been killed. *Eucalyptus globulus* have been killed in areas where they received no supplemental irrigation, but the mortality in watered sites was much lower.

Good tree management to limit tree stress is the second critical aspect of tree care. The strong relationship between stress, particularly moisture stress, and *Eucalyptus* susceptibility to the borer has been addressed by many workers throughout the world (6, 10, 15). Hanks et al. (14) demonstrated that water stressed trees were more attractive to beetles for oviposition than nonstressed trees. They also demonstrated that the high bark moisture content of well hydrated trees was responsible for mortality of the young larvae rather than the flow of phenolic resin as had been suggested by earlier observations (20, 5). Thus, maintaining tree vigor is critical to enhancing resistance to the borer. This is particularly important for trees that have been established in maintained landscapes. These trees appear to be at greater risk of beetle attack if they suffer acute water stress than are trees that have been established in areas receiving less care and which have become adapted to chronic water stress. It is likely that the chronically water stressed trees have developed deeper root systems to satisfy their water requirements, whereas regularly watered trees have developed shallow surface root systems and large canopies. Consequently, these shallow-rooted trees will suffer acute water stress when the irrigation is disrupted. However, if proper arboricultural practices are maintained (e. g. pruning in the fall and winter when the beetle is inactive) and tree susceptibility is limited through proper water management, the risk of beetle infestation will be reduced.

Reduction of individual tree risk can be complemented by practices that result in an overall reduction in beetle populations. A regular sanitation program that insures prompt removal and com-

Table 1. Relative susceptibility of common *Eucalyptus* sp. in California. Different growing conditions may alter the susceptibility of any tree so that an individual of a relatively susceptible species maintained in vigorous condition may be at lower risk than a highly stressed individual of a relatively resistant species.

Resistant species	Susceptible species
E. robusta	*E. saligna*
E. sideroxylon	*E. globulus*
E. camaldulensis	*E. nitens*
E. cladocalyx	*E. viminalis*
E. trabutii	*E. diversicolor*

plete destruction of beetle-infested wood will reduce the number of adult beetles searching for new hosts. A classical biological control program will also reduce beetle populations. Natural enemies of the borer from Australia have been released in California. An unnamed species in the genus *Avetianella* parasitizes the eggs of the beetle, laying as many as four eggs inside each beetle egg. This parasite develops in 16 days at 25°C and the adults live 25-30 days. In addition to the egg parasite, other species of parasitic wasps that attack the larval stages of the beetle have been released. Two *Doryctes* spp. are small gregarious larval parasites while *Syngaster lepidus* (Figure 4) and *Callibracon capitator* are large solitary larval parasites. Although the release phase of the biological control program is in its beginning stages, it is hoped that the combination of parasites that utilize different life stages of the beetle, and potentially different sizes of larvae, will effectively reduce the number of adult beetles available to lay eggs on new trees. The natural enemies will not eradicate the pest, and there will always be some susceptible trees in managed or unmanaged urban forests. However, the combination of proper care and biological control should greatly reduce the amount of risk to individual trees.

Figure 4. Adult parasites of eucalyptus longhorned borer larvae lay eggs through the tree bark with long ovipositors onto the larvae mining beneath.

Plant health and biological control

The two examples presented are model systems that can be followed for integration of plant health care and classical biological control of exotic insect pests. However, biological control can also be an important pest management strategy for control of endemic insect pests. Tree care practices that conserve natural enemies help to maintain a level of control. Augmentation of natural enemies through release of individuals from commercial sources has proven effective for control of some insect and mite species (8). Development of careful monitoring procedures to determine the size of the pest population or the level of aesthetic injury and use of compatible management strategies lie at the heart of a successful integrated pest management program (17, 18). The key elements for urban forests are preventative rather than remedial. These include selection of the proper tree species for the site, selection of individual specimens that are from high quality nursery stock, and use of proper planting, pruning, irrigation, and fertilization practices to maintain the trees in a vigorous condition. Biological control has a role in this preventative management program because natural enemies are part of the environment and will respond to increasing pest populations and regulate their numbers.

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Résumé. Le contrôle biologique classique est défini comme le processus d'identification et d'introduction des ennemis naturels d'une espèce de parasite dans le but de réduire la taille de la population de l'espèce dommageable. L'introduction d'une guêpe parasite et d'un coléoptère prédateur a réduit les populations de mouches blanches frêne de l'ordre de 10000 fois dans les arbres ornementaux de la Californie. Il est espéré que des introductions similaires de guêpes parasites pour contrôler le perceur longicorne de l'eucalyptus seront couronnées de succès dans la réduction de la mortalité des arbres. Les soins pour la santé de l'arbre sont critiques pour rehausser la résistance et la limite de susceptibilité de l'arbre. La combinaison entre le maintien d'une croissance vigoureuse de l'arbre et la limitation du nombre d'insectes parasites dans l'environnement via l'action des ennemis naturels procure une protection à l'arbre par une approche à long terme.

Zusammenfassung. Klassische biologische Kontrolle wird definiert als ein Prozeß der Identifizierurig und Einführung natürlicher Feinde von Schädlinger mit dem Ziel, die Population der Schädlinge zu reduzieren. Die Einführung einer parasitären Wespe und eines räuberischen Käfers reduzierte die Population der weißen Eschenfliege auf kalifornischen Landschaftsbäumen das 10,000 fache. Man hofft, daß ein ähnlicher Einsatz von parasitären Wespen zur Kontrolle des langhörnigen Eukalyptusbohrers bei der Reduzierung der Baumsterblichkeit beitragen wird. Der Pflanzengesundheitsdienst ist entscheidend, um die Widerstandsfähigkeit der Bäume zu steigern, und die Anfälligkeit zu reducieren. Die Verknüpfung von der Erhaltung eines gesonden Baumwachstums einerseits und der Beschlänkung der Anzahl von Schädlingsinsekten durch die Aktion natürlicher Feinde andererseits ebnet langfristig den Zugang zum Baumschütz.