

BIOLOGICAL CONTROL OF INTRODUCED PESTS OF EUCALYPTUS IN CALIFORNIA

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INTRODUCTION

Implementation of a biological control program against a tree-killing insect presents a number of significant problems. The natural enemies do not act in a remedial fashion; that is, the tree does not necessarily recover from an infestation as a result of natural enemy action and cannot be resampled on a regular basis. Rather, the predators and parasites act to reduce total population size across a broad area, thereby reducing the risk of subsequent infestation of any specific tree. Because there is no remedial action, approaches for colonization and evaluation of natural enemies are unique. The eucalyptus longhorned borer, *Phoracantha semipunctata* F. (Coleoptera: Cerambycidae) was first discovered in California in the mid-1980s. Three braconid parasitoid wasps were collected during a series of exploration and survey trips conducted in Victoria, Australia. The egg parasitoid, *Avetianella longoi* Siscaro (Hymenoptera: Encyrtidae), has been introduced and is now established throughout California. Releases of the larval parasitoids, *Syngaster lepidus* Brullè and *Jarra phoracantha* Austin, Quicke, and Marsh (Hymenoptera: Braconidae), have produced evidence of at least one generation of progeny but no conclusive evidence of establishment. The combination of biological control and cultural management of the trees appears to have reduced the populations of the borer. However, a second borer, *Phoracantha recurva* Newman, was discovered in California in 1995 and has now replaced *P. semipunctata* in the southern part of the state. The egg parasitoid both prefers and is more successful in utilizing *P. semipunctata* than *P. recurva* as a host. Consequently, differential rates of parasitism may be a critical factor in the replacement of one species of borer by another. The larval parasitoids use both borer species with similar success and could provide effective control if problems with their establishment can be overcome. However, recent introductions of eucalyptus foliage and fluid-feeding insects have increased the complexity of the herbivore community and raised the potential for deleterious interactions among pest management tactics, including biological control.

DEVELOPMENT OF EUCALYPTUS BORER PEST MANAGEMENT PROGRAM

Biological control through the introduction and establishment of natural enemies is an effective pest management strategy to control damaging insect pests of a variety of crop plants. It is particularly well suited for control of insects feeding on urban landscape trees and shrubs where alternative strategies, especially the use of insecticides, can have significant non-target impacts on insect and vertebrate communities (Paine *et al.*, 1993). Many of the most successful examples of urban landscape biological control have focused on providing a remedial solution to a damaging insect problem (Gould *et al.*, 1992). That is, for insect herbivores that remove foliage or fluids from the host trees, natural enemies can be released into an environment where they directly reduce the numbers of target insects in established populations colonizing individual trees. The numbers of pest insects on infested trees are reduced to nondamaging levels and the individual trees recover in fitness or value (Hanks *et al.*, 2000).

However, controlling cryptic tree-killing insect pests is much more complicated. Infestations of these insects, particularly borers, are often focused on individual trees having specific characteristics (e.g., moisture stress, disease, or physical injury) rather than distributed across all available hosts, and infestations frequently result in the death of the tree. In these cases, infested trees are often killed before the larvae may be at a suitable or susceptible stage for natural enemies to attack. Consequently, even though natural enemies may reduce population size, they do not provide remedial con-

trol action. Rather, the natural enemies reduce the risk of future colonization. Biological control of tree-killing borers seeks to establish area-wide population reduction through the establishment of parasitoids. This outcome is beneficial to a region as a whole rather than directly providing remedial or curative control on specific trees.

Phoracantha semipunctata F. (Coleoptera: Cerambycidae) is native to Australia, where it occasionally kills severely stressed trees (Duffy, 1963). However, this borer is now found throughout the world where *Eucalyptus* has been planted. It can kill large numbers of trees, particularly in those areas with Mediterranean climates (Paine *et al.*, 1993, 1995, 1997). Both sexes are attracted to stressed, dying, recently killed, or damaged eucalyptus trees by volatile host chemicals (Chararas, 1969; Drinkwater, 1975; Ivory, 1977; Pook and Forrester, 1984; Gonzalez-Tirado, 1987; Hanks *et al.*, 1991, 1998). Males search the bark for receptive females. Mated females lay batches of 10 to 40 eggs in cracks and crevices on the bark or under the loose, exfoliated bark. Neonate larvae bore through the outer bark of the tree and feed within the phloem, cambium, and outer layers of xylem tissues. Larval feeding can effectively girdle and kill living trees (Hanks *et al.*, 1993a). The insects bore deep into the wood at the end of the larval feeding period to construct a pupal cell. Following pupation, adult beetles bore out of their cells and emerge through the outer bark.

Management of the borer in California has focused on host tree preference and host resistance. For example, *Eucalyptus trabutii* Vilmorin and *Eucalyptus camaldulensis* Dehnh. were more attractive to ovipositing females than *Eucalyptus cladocalyx* Fabricius, *Eucalyptus grandis* Hill ex Maiden, or *Eucalyptus tereticornis* Small (Hanks *et al.*, 1993b). In Australia, there were no differences in host attractiveness among host species *Eucalyptus maculata* Hook, *Eucalyptus propinqua* Deane and Maiden, and *Angophora costata* (Gaertner) Britten, but larvae in *E. maculata* were significantly larger than larvae developing in either of the other two tree species (Paine *et al.*, 2000a). Because trees vary in attractiveness to the beetles, it is possible to develop lists of species that are at lower risk of infestation than other species. However, the amount of care a tree of any species receives can directly influence the level of risk. Neonate larvae must tunnel through the living outer bark to reach the cambium. Excessive moisture in the outer bark (>55%) is an effective barrier to larval penetration (Hanks *et al.*, 1991, 1999). Thus, it may be possible to use irrigation management in urban landscapes to maintain bark moisture above the critical threshold and reduce the probability of colonization success.

ESTABLISHING BIOLOGICAL CONTROL

One possible reason that the beetle is not a significant problem in its native range could be the complex of natural enemies that is associated with the insect (Paine *et al.*, 1997, 2001). In California, we have taken two approaches towards biological control. The first has been to introduce and establish an egg parasitoid to reduce the number of colonizing larvae. The parasitoid *Avetianella longoi* Siscaro (Hymenoptera: Encyrtidae) has been introduced from Australia and has had a significant impact on beetle populations throughout the state (Hanks *et al.*, 1995, 1996). Parasitoids were introduced either by placing parasitized host egg masses in the field for wasp emergence or directly releasing adult wasps. Establishment was assessed by placing unparasitized sentinel egg masses at release sites or by collecting naturally laid egg masses, which were used to determine both establishment and efficacy of the parasitoids.

Because the beetle oviposits on the exterior of the bark, the parasitoid reduces the number of larvae hatching from the eggs and entering the tree. Thus the parasitoid reduces potential for girdling and reinforces the effects of maintaining optimal bark moisture through irrigation. While not remedial, the parasitoids and the cultural practices act in concert to reduce the risk of infestation for standing trees.

The second approach to biological control has been to release two species of larval parasitoids in California. The larval parasites may reduce the number of beetle larvae in infested hosts, consequently reducing the number of ovipositing adult beetles seeking new hosts. Numerous releases of the braconid parasitoids *Syngaster lepidus* Brullé and *Jarra phoracantha* Austin, Quicke, and Marsh, two of the more common parasitoid species in Australia (Austin *et al.*, 1994; Austin and Dangerfield 1997), were made in California over the space of 10 years. Studies conducted in Australia suggest that the different species of parasitoids partition the larval resource based, in part, on bark thickness (Paine *et al.*, 2000b; Hanks *et al.*, 2001).

Two release strategies have been used for the larval parasitoids. Adults have been directly released in some areas. In other areas, adults first have been released into field cages containing logs infested with host larvae at the most susceptible stage, with the cages placed in areas of significant beetle activity. The adults were given the opportunity to oviposit on the larvae in the logs before the cages were opened and the adults were allowed to leave the cage. The logs were left in the field in the open cages to allow emergence of any progeny wasps.

Unfortunately it has proven very difficult to monitor and evaluate establishment of the larval parasitoids because of the cryptic life history of the beetle larvae. Sentinel logs containing larvae in suitable stages were placed in the field and monitored for wasp emergence. Bark was stripped from infested trees and checked for wasp cocoons at the end of host larval galleries. Evidence was obtained that suggested that the wasps had undergone at least two generations in the field, but conclusive evidence of permanent establishment is still lacking.

RECENT INTRODUCTION OF OTHER GUILDS OF INSECTS ON *EUCALYPTUS*

Approximately ten years after the introduction of *P. semipunctata*, a second cerambycid species with very similar ecological requirements, *Phoracantha recurva* Newman, was detected in southern California. In the space of four years, *P. recurva* almost completely replaced *P. semipunctata* in southern California, to the extent that *P. semipunctata* is now rarely found in routine surveys. Although there may be many reasons for this species replacement, one of the critical factors may be the difference in the response of the egg parasitoid *A. longoi* to each species (Luhring *et al.*, 2000). Parasitoids locate egg masses of the two borers at the same rate in the field, but the eggs are parasitized at very different rates, with a significantly greater proportion of *P. semipunctata* eggs being parasitized than of *P. recurva* eggs.

The eucalyptus snout beetle, *Gonipterus scutellatus* Gyllenhal (Coleoptera: Curculionidae), was discovered defoliating California eucalyptus trees in March 1994 (Cowles and Downer, 1995). Extensive feeding by this Australian insect can completely defoliate trees and kill branches, whereas intermediate levels of defoliation retard growth and affect tree shape. Fortunately, this weevil was easily and rapidly controlled with the egg parasitoid *Anaphes nitens* (Girault) (Hymenoptera: Mymaridae) following its release in August 1994 and during the summer of 1995 (Hanks *et al.*, 2000).

The eucalyptus tortoise beetle, *Trachymela sloanei* Blackburn (Coleoptera: Chrysomelidae), was first collected in California in March 1998. The adults and larvae of this cryptically colored insect feed on young leaves and tender stems at night. The adults clip off young, tender leaf shoots as they begin to expand, removing the apical shoots as the tree attempts to refoliate. An egg parasitoid, *Enoggera reticulata* Naumann (Hymenoptera: Pteromalidae), was released and evaluations are underway.

In addition to the recently introduced *Eucalyptus* leaf-consuming insects, at least six Australian psyllid species have been introduced into California. Several of these species are under very good biological control (Dahlsten *et al.*, 1998a, b). However, two of the more recently introduced species of lerp psyllids, *Glycaspis brimblecombei* Moore (Heteroptera: Spondyliaspidae) and *Eucalyptolyma*

maideni Froggatt (Heteroptera: Spondyliaspidae), have caused widespread damage and tree mortality to red gum (*E. camaldulensis*) and lemon gum (*Eucalyptus citridora* Hook.) throughout the state. While efforts to introduce natural enemies of these two species are underway, widespread use of systemic insecticides has become commonplace in the urban forests.

INTEGRATION OF BIOLOGICAL CONTROL INTO MANAGEMENT OF GUILDS

While made for the purpose of reducing psyllid-caused tree mortality, insecticide use potentially threatens the successful biological control programs that are in place. In addition, the recommendations for cultural management (e.g., irrigation and fertilizer applications) and planting of less susceptible host species may be incompatible across the guilds of insects now present in the state. Supplemental irrigation may make trees less susceptible to the borers, but may make them more suitable hosts for psyllids. Similarly, tree species not preferred by the borers may be highly preferred by the folivores or the psyllids. The presence of systemic insecticides in honeydew or in nectar may present a significant risk of mortality to parasitoids. These incompatible management approaches must be reconciled. Establishment and incorporation of biological control into management systems under the constraints of trees being killed by other insect species presents a significant challenge.

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