A COST/BENEFIT ANALYSIS OF THE ASH WHITEFLY BIOLOGICAL CONTROL PROGRAM IN CALIFORNIA

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Abstract. The ash whitefly (*Siphoninus phillyreae*) was first identified in California during 1988 and caused widespread defoliation to its primary hosts, ash (*Fraxinus* species) and ornamental pear (*Pyrus* species) trees. The ash whitefly caused higher levels of damage to trees in regions with hotter summers and lower damage to trees in regions with cooler summers. In 1990 a parasitic wasp, *Encarsia inaron (=partenopea)*, was released into urban communities in California to control the ash whitefly infestation. By 1992 the wasp had reduced ash whitefly populations to undetectable levels and preserved the aesthetic benefits of the affected trees. The loss in aesthetic benefits due to ash whitefly damage was estimated using a standard tree appraisal technique, the Trunk Formula Method. The benefits were estimated as the change in the average appraised value of a susceptible tree due to ash whitefly damage times the number of each affected tree species for each region. The total benefits of the biological control program range from $324 million at wholesale values to $412 million at retail. The direct costs of the program were just over $1.2 million. The net benefits are between $323 million and $411 million. The respective benefit to cost ratios are $270:1 and $344:1.

Introduction

The ash whitefly *(Siphoninus phillyreae)* was first identified in Los Angeles County during the summer of 1988. By 1990 it had spread throughout much of California and caused severe defoliation to its primary hosts, ash (*Fraxinus* species) and ornamental pear (*Pyrus* species) trees. In 1990, a parasitic wasp, *Encarsia inaron (=partenopea),* was imported and released into the urban environment to control the ash whitefly infestation. The parasitic wasp reduced ash whitefly populations within two years of its release to levels difficult to detect even with vigorous monitoring efforts (6, 9). The control of the ash whitefly resulted in the preservation of the aesthetic beauty of ash and ornamental pear trees in urban landscapes. This paper estimates the economic benefits and costs of preserving the aesthetic beauty of urban street trees from the ash whitefly biological control program.

Previous research has shown that healthy street trees significantly contribute to the aesthetic beauty of urban areas and that people will demand pest control to protect the aesthetic beauty of street trees with levels of defoliation as small as 5 per cent (10,5). Therefore, the preservation of a tree's aesthetic beauty by controlling pest infestations can result in substantial benefits to the community. In addition, it has been shown that healthy trees significantly contribute to property values and that defoliated trees cause property values to decrease (4).

In the case of the ash whitefly, the economic benefits are estimated as differences in the appraised values of the primary host trees with and without defoliation due to the ash whitefly. Implementation of a widely used landscape tree appraisal technique, the Trunk Formula Method, developed by the Council of Landscape and Tree Appraisers (CLTA), provided estimates of these appraised values for each primary host (2). Similar tree valuing methods have been employed to measure the economic damage to trees as a result of the Oakland fire (8).

Background

The first ash whitefly infestations were recorded in Los Angeles County during the summer of 1988. By 1990 the ash whitefly had spread to 28 other counties in California, parts of Arizona and New Mexico, and had reached outbreak populations in most urban centers. In total, 46 counties in California have reported ash whitefly populations.

The ash whitefly is a pest which primarily attacks urban trees. The primary urban hosts are ash (*Fraxinus* species) and ornamental and flowering pear (*Pyrus* species). These tree species make up 17% of the urban forest based on selected street tree inventories (7). Other hosts include crab apple (*Malus* species), pomegranate (*Punica* species), crape myrtle (*Lagerstroemia* species), and hawthorn (*Crataegus* species) trees among others. Complete lists of all tree species infested by the ash whitefly have been previously published (3, 11). All other hosts suffered little to no damage and comprised only 4% of the total street tree populations (7).

Feeding by whitefly nymphs and adults resulted in chlorosis, or yellowing, of leaves. A honeydew excreted by the whitefly caused sooty black mold to form on the leaves. The chlorosis and sooty black mold together led to substantial defoliation of the host trees. There were a few reported instances of trees dying from the ash whitefly infestation (3), but in general the infestation had not led to tree mortality. Chemical insecticides were not a cost effective control of this pest because the whitefly multiplies rapidly during warm summer months. Susceptible trees would usually be reinfested within 2 to 3 weeks and would require additional chemical treatments (7).

The extent of urban tree damage caused by ash whitefly infestations varied geographically. Consequently, the state was divided into three regions; high damage, low damage and no damage (11; 7). The high damage region includes counties in California where there are relatively cool winters and hot summers. Defoliation of ash and ornamental pear trees in the high damage region reached 70% - 90% during peak infestations.

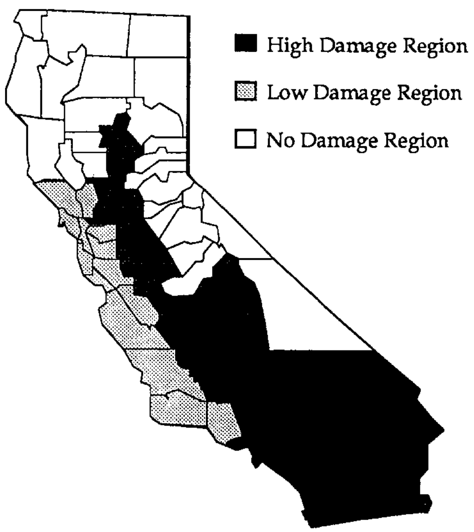

Figure 1. Extent of Ash Whitefly Damage by Region.

Counties in the low damage region have lower temperature variations with milder winters and cooler summers than in the high damage region. The ash whitefly caused 40-50% defoliation of susceptible trees in this region (7). The remaining counties in California have climates too cold to support the ash whitefly and consequently suffered no damage.

During 1989 scientists with the California Department of Food and Agriculture (CDFA) and researchers at the University of California, Riverside (UCR) obtained a small stingless parasitic wasp, *Encarsia inaron (=partenopea)*, from researchers in Israel and Italy. The wasp was reared in CDFA and UCR greenhouses and released throughout neighborhoods in California starting in 1990 (9). Two years after the parasite was released, ash whitefly densities were reduced to numbers difficult to detect even with rigorous monitoring efforts (6, 9). Since 1992 no further releases of the parasitic wasp have been made and ash whitefly populations remain at undetectable levels (6,9). As a result, the ash whitefly biological pest control program is permanently preserving the aesthetic beauty of the host trees.

Methodology

The primary benefit from the ash whitefly biological control program is in the preservation of the aesthetic beauty of the urban forest. The average benefit per host tree equals its change in appraised value (CAV) due to ash whitefly damage. This change is equal to the difference in the hosts' average appraised value as a healthy tree less the average appraised value after ash whitefly defoliation. This benefit is calculated as a one-time change at the level of defoliation that is achieved when the ash whitefly populations are at their greatest. The total benefits are equal to the average benefit per host tree, times the number of host trees in both the high and low damage regions.

The estimation of a tree's appraised value is based on the Trunk Formula Method which is used when appraising landscape trees too large to be replaced with nursery stock (4). The appraised value is:

(1) *Appraised Value* = Condition Factor x Location Factor x [Replacement Cost + (Trunk $Area_a$ - Trunk $Area_r$) x Basic Price x Species Factor]

where:

Condition Factor = Percentage adjustment based on the plant's health and any structural defects.

Location Factor = Percentage adjustment based on where (street, yard, park, highway, etc.) the tree is planted in the urban landscape.

Replacement Cost = Cost (retail or wholesale) to buy and install the largest normally available transplantable tree in the region.

Basic Price = Cost (retail or wholesale) per unit trunk area of a replacement tree measured at the height prescribed by the American Nursery standards. In this analysis the replacement tree is the largest normally available transplantable tree.

Trunk $Area_a$ = Trunk Area in square inches of a cross section of the tree being appraised at a height 4.5 ft.

Trunk $Area_r$ = Trunk Area in square inches of a cross section of the largest normally available transplantable tree at a height of 6 to 12 inches.

Species Factor = Percentage adjustment based on the species of tree being appraised.

Table 1. Data for calculating appraised value of primary host trees.

	Ash		Ornamental Pear	
	Wholesale	Retail	Wholesale	Retail
Condition Factor with no AWF damage	71%	71%	71%	71%
Condition Factor with AWF damage:				
High Damage Region	56.5%	56.5%	56.5%	56.5%
Low Damage Region	64%	64%	64%	64%
Location Factor	60%	60%	60%	60%
Replacement Costs	$70	$88	$70	$94
Trunk $Area_a$	169 in^2	169 in^2	87 in^2	87 in^2
Trunk $Area_r$	2 in^2	2 in^2	2 in^2	2 in^2
Trunk $Area_a$-Trunk $Area_r$	167 in^2	167 in^2	85 in^2	85 in^2
Basic Price	$35	$44	$35	$47
Species Factor	50%	50%	70%	70%

The condition factor adjusted the appraised value for each tree in each region with and without defoliation due to the ash whitefly. The condition factor was calculated based on the condition rating which is determined by the sum of the rating scores in 5 categories including roots, trunk, scaffold branches, smaller branches/twigs, and foliage (4). Each category is ranked on a scale of 0 - 5 with a total of 25 points possible. The total number of points given to a tree determines the value assigned to the condition factor. The condition rating of 19 points for healthy ash and ornamental pear trees corresponds to an average condition factor of 71% (4, 8). Using 19 points as the average for street trees, each of the 5 categories has an average rating of approximately 4 points. A rating of 4 indicates that there are no apparent problems present.

The condition rating depended on the level of defoliation caused by the ash whitefly. In the high damage area, where there was 70-90% defoliation, the rating for foliage went from 4 for healthy trees to 0.5 for extremely defoliated trees. As a result, the total condition rating decreased from 19 points to 15.5 and the corresponding condition factor from 71% to 56.5% (Table 1). In the low damage region,

Table 2. Data used to calculate the change in appraised value (CAV) per tree due to defoliation by Ash Whitefly.

	Ash		Ornamental Pear	
	Wholesale	Retail	Wholesale	Retail
Appraised Value with no adjustment for condition factors	$1,801	$2,264	$1,299	$1,744
Appraised Value using condition factor for no AWF Damage	1,279	1,607	922	1,238
Appraised Value using condition factors for AWF Damage:				
High Damage Region	1,017	1,279	734	985
Low Damage Region	1,152	1,449	831	1,116
Change in Appraised Value:				
High Damage Region	261	328	188	253
Low Damage Region	126	158	91	122

where there was 40-50% defoliation, the rating for foliage decreased from 4 to 2. The 2 indicates that there are major problems in the appearance of the foliage. The total condition rating decreased from 19 points to 17 and the corresponding condition factor from 71% to 64% (Table 1).

The location factor adjustment was 60% for street trees (Table 1). The average location factor for street trees was obtained from an appraisal of the value of the urban forest in Oakland, California (8). The average wholesale and retail replacement costs of trees with installation were obtained from 8 retailers and wholesalers throughout the state of California (Table 1).

Benefits were calculated at both wholesale and retail prices because cities could pay the wholesale price or the retail price depending on the number of trees purchased and the source of the trees. The wholesale costs represents a lower bound to the estimated benefits and the retail costs an upper bound.

Replacement costs were obtained for a 15 gallon (57 liter) container grown plant with a 1.5 inch (3.75 cm) diameter at one foot, the largest normally available transplantable tree. The average trunk area of the trees being appraised was calculated from measurements of the circumference of over 100 ash and ornamental pear trees from several different locations in Davis, CA, at a height of 4.5 ft. (1.4 meters). The species adjustment of 50% for ash trees and 70% for ornamental pear trees came from the "Species Classification and Group Assignment" handbook published by the Western Chapter of the International Society of Arboriculture.

The change in aesthetic values is:

(2) CAV_{ijp} = Appraised Value without defoliation - Appraised Value with defoliation where i is equal to the geographical region, j is equal to ash or ornamental pear tree and p is equal to the wholesale price or retail price of the respective replacement tree.

The total benefits (B) of preserving the aesthetic qualities of ash and pear trees is:

(3) $B_p = \Sigma_i \Sigma_j CAV_{ijp} T_{ij}$

where T is equal to the total number of each primary host tree in each region.

The total estimated benefits is the sum of the aesthetic value change for each species over each region. The total street tree populations were extrapolated from street tree inventories of 14 cities throughout California (7). The inventories only included data on street tree populations planted and maintained by a public agency and did not include trees in other public areas (e.g. parks, golf courses and freeways) or trees on private property.

The average per hectare tree density for each species equals the number of each tree species divided by the total land area of the cities which provided tree inventories. The total number of ash and pear trees throughout California was then estimated by multiplying the average street tree density per hectare by the total land area of all urbanized centers in each affected region. The urban land areas of the affected regions were obtained from the United States 1990 Census Data on Urbanized Areas.

The costs of the ash whitefly biological control program were provided by the California Department of Food and Agriculture and the University of California, Riverside. The costs included salaries of employees hired for the ash whitefly project and the time that permanent employees of CDFA and UCR spent working on this project, their travel expenses to collect and import the parasitic wasp, materials to rear the wasp in greenhouses, and travel expenses to release the wasp at selected sites and monitor its spread. These costs do not include any overhead expenses for administration or depreciation of buildings. Furthermore, the long-term research expenses previously incurred to identify the parasite are not included.

Table 3. Summary of tree value benefits associated with the Ash Whitefly control program.

		Summary of Benefits			
		Average CAV per Tree		Total Benefits (may not equal due to rounding)	
	Number of Trees	Wholesale	Retail	Wholesale	Retail
High Damage Region					
Ash Trees	974,848	$261	$328	$254,541,345	$319,994,833
Pear Trees	262,894	$188	$253	$49,511,617	$66,487,029
Total Trees :	1,237,742	$246	$312	$304,052,962	$386,481,862
Low Damage Region					
Ash Trees	101,914	$126	$158	$12,846,573	$16,149,978
Pear Trees	79,987	$ 91	$122	$7,272,353	$9,765,732
Total Trees :	181,901	$111	$142	$20,118,926	$25,915,709
Total Regions					
Ash Trees	1,076,762	$248	$312	$267,387,918	$336,144,811
Pear Trees	342,881	$166	$222	$56,783,971	$76,252,760
Total Trees :	1,419,643	$228	$290	$324,171,888	$412,397,571

Results

The change in appraised value (equation 2) was calculated from the data in Table 1. The appraised value of an ash tree with no ash whitefly damage is between $1,279 dollars at wholesale prices and $1,607 at retail prices and between $922 and $1,238 respectively for an ornamental pear (Table 2). Even though ornamental pear trees have a larger species factor adjustment, ash trees are appraised at about $360 more per tree due to their larger size.

In the high damage region, the appraised value of an ash tree decreased by $261 at wholesale prices and $328 at retail prices due to ash whitefly defoliation (Table 2). The appraised value of pear trees decreased by about $75 less than for ash trees due to the lower base value of the pear trees (Table 2).

As expected, in the low damage region the decrease in the appraised value of the susceptible hosts was much lower than in the high damage region. The appraised value of ash trees decreased by $126 at wholesale prices and $158 using retail prices. The appraised value of pear trees decreased by about $35 less than for ash trees.

The change in appraised value per tree per region was multiplied by the number of trees to estimated the total benefits of the ash whitefly biological control program. As stated earlier, ash and ornamental pear trees represent a significant part of the urban landscape, comprising 17% of all street trees. Ash trees are more prevalent in the high damage region than the low damage

Table 4. Summary of Ash Whitefly biological control program costs.

Ash Whitefly Biological Control Program Costs	
Item	Costs ($)
Salary	772,492
Collection and Importation of Parasite	4,000
Rearing and Monitoring Costs	457,850
Total Costs	1,224,352

region and make up 15% of all trees for the high damage region and 3.3% for the low damage region. There are fewer ornamental pear trees in both the high damage (4.1% of all trees) and low damage (2.6%) regions.

The average street tree densities were 86 ash trees per square kilometer for the high damage region and 20 ash trees per square kilometer for the low damage region, 23 ornamental pear trees per square kilometer for the high damage region and 16 ornamental pear trees per square kilometer for the low damage region. The total square kilometers of urban centers in the high damage region (11,364 km^2) were twice the total square kilometers for the low damage region (5,065 km^2) In all, there were an estimated 974,848 ash trees and 262,894 pear trees in the high damage region, and 101,914 ash trees and 79,987 ornamental pear trees in the low damage region. The estimated total number of primary host street trees equaled 1,419,643 (Table 3).

Total estimated benefits from the biological control program range between $324 million at wholesale and $412 million at retail replacement costs (Table 3). Over three quarters of the economic benefits are from preserving the scenic beauty of ash trees in the high damage region and ash trees in both regions combined account for over 80% of total benefits. Ornamental pear trees in the high damage region account for 16.6% of the total economic benefits while pear trees in the low damage region account for only an additional 2.4%.

The total benefits from the biological control program from preserving the aesthetic value of street trees were between $255 million at wholesale and $320 million at retail prices for ash trees and between $50 million and $66 million for ornamental pear trees in the high damage region (Table 3). In the low damage region the total benefits are substantially lower and range from $13 million to $16 million for ash trees and $7 million to $10 million for ornamental pear trees.

As stated earlier, these benefits represent a one-time change in the aesthetic beauty of the host trees that is achieved when the ash whitefly populations are at their greatest in early fall. Defoliation levels might be lower during earlier parts of the year. Also, this does not reflect that over time the defoliation will lead to tree death and the need to remove and replant new trees. If the long-term effects were also included, the estimated benefits would be greater.

The direct costs of the ash whitefly biological control program totaled $1,224,324 (Table 4). The net benefits (total benefits less total costs) were between $322,947,536 at wholesale values and $411,173,219 at retail values.The rate of return for each dollar spent to import, rear, release and monitor the parasitic wasp was between $265 and $337. If the overhead costs of the biological control program and the long-term research costs were also included, total costs would be higher and the rate of return would be lower.

Conclusions

The successful introduction of a natural enemy, *Encarsia inaron (=partenopea)*, resulted in the permanent control of the ash whitefly and protection of the aesthetic beauty of urban trees. The economic benefits from avoiding aesthetic damage to ash and ornamental pear trees planted as street trees in urban areas of California are between $324 million and $412 million. It should be emphasized that these benefits are for street trees only. Due to data limitations, the aesthetic benefits for trees on other public areas (golf courses, parks, freeways, etc.) and on private property were not included. Consequently, the economic benefits presented here may be regarded as a minimum value which would increase with the inclusion of additional trees. The benefits were not equally distributed throughout the state. The greatest impact was to ash trees in the high damage region.

The direct cost of the project totaled $1.2 million. The net benefits from the *Encarsia inaron* releases were between $323 million at wholesale replacement costs and $411 million at retail tree replacement costs. The respective benefit to cost ratios are $265:1 and $337:1. This analysis demonstrates that significant economic benefits can be realized from successful biological control programs aimed at preserving the aesthetic beauty of the urban forest.

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Résumé. La mouche blanche du frêne a été identifiée pour la première fois en Californie en 1988 et a défolié sur un vaste territoire ses hôtes primaires, le frêne et les poiriers ornementaux. En 1990, une guêpe-parasite, *Encarsia inaron (=partenopea)*, a été lâchée dans les zones urbaines de Californie pour contrôler l'infestation de la mouche blanche du frêne. Depuis 1992, la guêpe-parasite a réduit de facon permanente les populations de mouche blanche et permis de préserver les bénéfices esthétiques des arbres affectés. Les pertes en bénéfices esthétiques imputables aux dommages par la mouche blanche ont été évalués. Les bénéfices globaux du programme de contrôle biologique se situent entre 324 millions de dollars (valeur en gros) et 412 millions de dollars (valeur au détail). Les coûts directs du programme se sont chiffrés à seulement 1,2 millions de dollars.

Zussammenfassung. Die Weiße Fliege der Esche wurde in Kalifornien zum ersten Mal 1988 identifiziert und verursachte eine weitverbreitete Entalubung auf ihren Hauptwirten, den Eschen und blüheden Birnen. 1990 wurde eine parasitische Wespe, *Encarsia inaron (=partenopea)*, in einigen Städten von Kalifornien freigesetzt, um die Ausdehnung der Weißen Fliege zu knotrollieren. 1992 hatte die Wespe die Population der Weißen Fliege vollständig reduziert und konnte so den ästhetischen Wert der betroffenen Bäume erhalten. Der Verlust an ästhetischen Werten während des starken Befalls wurde geschätzt. Die Vorteile des biologische Kontrollprogramms rangierten von $324 Millionen im Gesamtwert bis $412 Millionen im einzelnen. Die direkten Kosten des Programms lagen bei $1,2 Millionen.