

ESTABLISHING AN INTEGRATED PEST CONTROL PROGRAM FOR STREET TREES¹

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This paper describes our methods of developing an integrated control program for the street trees of a community. A step by step process is presented, taken largely from the authors' experiences with two cities in California: Berkeley and San Jose. Combined, the cities together maintain approximately 300,000 street trees of over 100 species, 500 square miles and about one half a million people. The following discussion is probably best understood by assuming the reader is an independent operator or already the manager of a city street tree system.

Initial contact

The first step is to arrange a meeting with the person who has control over the street tree system. Information has to be obtained about the entire tree maintenance program; specifically, what has been done before and what is being done now. For cities without detailed records, extrapolations from previous budget expenses, preferably on a monthly or a more regular basis, can help. Knowing how the budgeting is determined can provide a view of the hierarchy, areas of responsibility and an overview of the decision making process. Thus, direct questions about the process need to be asked, such as, who approves budget expenses? Who manages the field operations? How are complaints handled? Who actually treats the insect population and what methods are currently used? All street tree problems need to be discussed, not just a key insect or an important group of pest problems.

Agreements about the extent of the system also need to be developed. In some cities the street trees may be managed differently than the park trees because different city departments, hence different personnel, are making the deci-

sions. The result of the meeting should be a written statement of cooperation for at least one entire season (not a fiscal year) with some indication of length of time it may take to get a full program operating (possibly 3 to 5 years).

The cooperative agreement should include provision for a summary report at the end of the first season. This report should suggest priority research projects and management techniques which will need to be accounted for in the following season's budget.

Determining the work load

The information needed to determine the work load requires answers to the following questions: How many street trees? How many species? Is there a master list or purchasing list of species? Is there a list of specimen trees? What are the pest problems? How many trees in how many stands are involved with each problem, and how are they currently being managed? The exact pesticides used need to be noted, preferably with dosages and trade names. What kind of equipment is used and how many people are involved? How much is budgeted to currently manage the problems; including personnel, equipment depreciation or rental, and pesticides? (A breakdown into insecticides, fungicides and herbicides is preferable rather than a single category of "pesticides").

Additional questions concerning the position of the street tree management system within the overall political system need to be answered, e.g., if you are talking to park and recreation personnel: what is the intradepartmental structure down to the field people responsible for tree maintenance and what is the supra structure above the departmental level up to elected offi-

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group interested in this system or tree care in general? Answers to these questions during initial interviews, city literature, or access to records and/or personnel with the specific information to provide the necessary details, is needed to develop the work plan agreement and to begin considerations about costs of developing such a program.

The work plan agreement

The actual dynamics of our services and research functions need to be discussed in order to inform the management personnel properly. Starting in the spring we begin regular visits to the area. A weekly check into the city office allows us to pick up notices of complaints from citizens, and other reports about pest problems, accumulated since the last visit. We take each report, go to the field locations specified and examine the situation. A report is filed on each situation. The decision making process used for sorting problems has been reported in a previous publication (Olkowski, 1970).

At the site our inspection begins by observing the tree. First the entire tree is looked over for signs of insect populations, presence of insect and plant damage, discolored areas, or dead or dying parts. Usually prior knowledge indicates or suggests an inspection of leaves, twigs or some other plant part is the place to start looking for an aphid, scale, beetle, caterpillar or other insect population. Once a large population of plant feeding insects (herbivores) is found the species needs to be identified. Not every insect found needs to be identified since most insects are usually under control and produce no problems. For such miscellaneous insects a note as to its general group (i.e., order, super-family, family) can be recorded. If a more thorough search or study is being conducted, all the insects found should be collected.

Is there a tree or parks commission of interested citizens, or a volunteer community

Collecting insects for identification

Two general groups of insects (or arthropods) usually constitute "pests": soft bodied and hard bodied. The soft bodied; aphids, mealybugs,

caterpillars, fly maggots, etc., can be placed in a small vial or jar filled with alcohol and closed with a tight lid or cork. Hard bodied insects, e.g., beetles, must be killed (in a special killing jar or a closed jar placed in the sun), and put into a container for transport and/or mailing.

Through correspondence with specialists, and repeated work with various insects, one discovers the necessary procedures for preparing and preserving different groups. Once the insects have been collected and killed they can be carried or sent to entomology departments, agricultural extension offices or state departments of agriculture. Important information to include is the date, location and host plant (see Oldroyd, 1970).

Do not send or carry live insects around! Such insects can escape and start new problems in areas where their natural enemies do not occur. This caution applies to the shipment of live plant materials. For example, this last year in the early spring, as part of one of our projects in California, we ordered some bare root birch trees (*Betula papyrifera*) from an Ohio nursery. The plants arrived, were potted and a little later they leafed out. We soon found some of the leaves were being badly crinkled and knotted into gall-like growths. Large groups of wax producing aphids were responsible. Upon identification, this species, *Hamamelistes spinosus*, proved to be unknown in California. We quickly destroyed all populations, notified the state quarantine office, confined all plant material in cages and began a careful daily monitoring program until satisfied no aphids had survived. We also notified all entomologists in the vicinity to look for this aphid on birch trees in the area. Fortunately we prevented the introduction of a new pest insect.

An excellent introduction to the subject of entomophagy, or the study of insect eating is provided by van den Bosch and Messenger 1973, DeBach 1974, and Swan, 1964. Some earlier books e.g., Essig (1931), Sweetman (1936, 1958) and Clausen (1956) (as well as two extensive articles by Douthett (1964), and Hagen and Franz (1973) can help to develop a historical context for the science of biological control. The comprehensive volume prepared by DeBach (1964)

provides for the basic theory and critical information needed to function in the field. Clausen's (1940) classic work on Entomophagous Insects provides basic biological information about parasitic and predatory insects. Huffaker (1971) edited a volume with important theoretical papers but also with new developments for different crop ecosystems, and new discoveries and methods for the field as a whole. Askew (1971) also presents information about the life histories of parasitic and predaceous insects within an excellent book covering the whole field of parasitic insects along with many clarifying diagrams and clear drawings. Other books and articles that should also prove useful include: Stary (1970), Malyshev (1968), Balduf (1935), Evans and Eberhard (1970) and Hagen (1962). These books have numerous photographs and references to other works for more detailed information. Correspondence with biological control specialists can also provide more help concerning specific problems.

We have been specializing in aphid natural enemies and have learned to recognize their major predators: ladybird beetles (family Coccinellidae: order Coleoptera), hover flies (family Syrphidae: order Diptera) and lacewings (Chrysopidae and Hemerobiidae: order Neuroptera); and their major parasites, miniwasps of the familiar Aphidiidae and Aphelinidae (order Hymenoptera). In California where we work, many aphid species have populations which are usually excessive because their parasites have not invaded the new area along with their host aphids. Thus we are constantly inspecting aphid populations, looking for the characteristic "mummies", or dead discolored aphid skins that have a parasitic "miniwasp" inside. We also take aphids and dissect them to find the immature parasite form inside. When a particular aphid population has been treated regularly for many years we need to leave a stand of trees totally unmanaged for a season to discover what kind of natural enemies are present and how much pest reduction is occurring as a consequence.

Monitoring

We use the word monitoring to mean the regu-

lar repeated inspection of a pest population. With big trees this may require a hydraulic lift, ladders, or tree climbing, to make an adequate inspection. When one first decides to monitor a problem and has selected the tree for inspection it is necessary to make counts of pests and their natural enemies on different parts of the tree. Once the distribution of the animals within the tree is known you can make judgment about which portion is representative of the entire tree. Thus, eventually, one can save considerable time and effort by not sampling the entire tree each time, confining observations to a representative area.

To take a representative and quantitative sample a decision must be made about how much area is needed for a sample. An example from our work with leaf feeding aphids may help clarify at this point. If at first we count 10 leaves and get a total of 50 aphids (5 aphids/leaf), and then count another 10 leaves, we can compare the 10 leaf count with the 20 leaf count. If the 20 leaf count provides a similar average aphid per leaf count (e.g., 20 leaves with a 100 aphid total = 5 aphids/leaf) then the 10 leaf count will provide the same average and should be the desired sample size. If the counts are very dissimilar then count 30 leaves and make a similar comparison. This procedure can provide a sampling routine for the plant feeding insect. A similar procedure also needs to be developed for the natural enemies. The different stages of the particular predators and parasites need to be identified and some assessment of how helpful these are, e.g., how many lady beetle larvae are there to how many aphids? Is the herbivore population increasing or decreasing? Are the carnivore populations increasing or decreasing?

Another question of importance is: does the aphid population with this many natural enemies exceed aesthetic injury levels? To answer this question one needs to assess the population sizes of herbivores and the amount of plant damage—light, medium and heavy assessments will do until greater detail is needed. Thus to do a proper job of monitoring a pest situation one needs to follow a population for a period of time in different areas, on different plants and under different climatic circumstances. The goal

throughout such a monitoring program is to be able to say that a certain number of herbivores, with a certain number of beneficial insects present, on a specific variety of plant is or isn't going to be causing intolerable damage.

The establishment of an injury level on a particular pest is a critical procedure for predictive purposes but is particularly useful in timing pesticide applications. An excellent example has been worked out for the California oakworm *Phryganidia californica* on native California live oaks (Pinnock and Milstead 1971). This injury level is determined by counting the number of 3rd instar larvae on 25 twigs. More than 25 larvae will insure that the tree will be defoliated. For holly oaks, *Quercus illex*, the level is different but the procedure is the same.

Recommendations

Our work plan agreement says that with each report on a problem we inspect, we will make a recommendation. Often we report: "Don't do anything, we are monitoring the situation." Sometimes we say there is a need for education and indicate what we will do, or have already done, e.g., provide a handout sheet, an article, a discussion in person or by phone with the individual concerned, or we organize a lecture with a movie for the community group concerned. Our reports have the following categories below which we fill in the specifics: name of city, date, how complaint originated, nature of the problem, location(s), our recommendations (short-term and long-term) and who submitted the report.

When we recommend use of an insecticide we specify the material, dosage and which plants to be sprayed. We have often recommended cultural controls such as pruning because we have noticed that certain aphids like the inner canopy growth and their populations can be considerably reduced by elimination of this preferred habitat.

After a season of monitoring and experience with the street tree ecosystem we develop a priority list of problems. This list is based on the number of trees involved, degree of damage and the number of complaints. We start our biologi-

cal control research on the most important problems moving on to the lesser problems when these are resolved.

The importation process

Our special service and research function is the importation of natural enemies of introduced pests. This is the basic reason why we are attached to a laboratory with a quarantine facility. Such a facility is charged by the State and Federal government (through appropriate agreements) with the responsibility for the introduction of particular parasites and predators of pest insects. The steps in this process will be reviewed to illustrate the nature of this work; from the beginning when a pest problem is first observed in the field, to the end when it is under permanent biological control (see van den Bosch and Messenger 1973 for a more thorough coverage).

Proper Identification: Here we lean heavily on other specialists. Some of the basics of this step have already been outlined. Various members of our laboratory specialize in particular groups of beneficial insects. Frequently we can also make great use of the information about certain agricultural insects and situations, extrapolating to the street tree ecosystem.

Pest Assessment: Once a pest population is observed to be above aesthetic and/or economic injury levels we need to determine if this is a regular occurrence. If this situation occurs each year and is not an irregular perturbation in a long-term cycle we have the first indication that the insect is exotic to the ecosystem in which it is now regularly found.

Original Home: The original area in which the insect evolved and from which it escaped needs to be located. The assumption here is that in its native area the insect is under control by its natural enemies. Sometimes this problem is not easily solved. In such cases library searches for records of previous studies that mention parasites, predators and pathogens need to be conducted. Records of climatically similar areas are scrutinized for indications that useful natural enemies may exist there. Once potential sources for natural enemies are located, correspondence

with specialists, museums and entomology departments, are initiated to obtain additional information. Sometimes someone from our laboratory may be passing through the particular area in question and will make collections for us. A most critical consideration in all importations is to fit the parasite and pest population together, taking into consideration the differences in climate between areas for potential parasites, predators and the host. The possibility of a successful colonization project is no doubt related to how similar are the foreign source area and the future colonization and/or target host's area (see Messenger, 1971).

Permits: The next step in the process, once a particular parasite or predator appears to be a reasonable choice for introduction, is to apply for permits for permission to import it. Once permission is obtained the necessary mailing labels are given to the foreign explorers.

Training Foreign Explorers: Training of the foreign explorer is necessary since specific procedures, equipment and collecting processes need to be followed. All available pertinent information and a process for communication throughout the field excursion need to be arranged. Ideally, foreign explorers should be able to rear parasitic or predaceous material during their travels because excellent natural enemies are frequently rare and difficult to find. Packaging and mailing procedures also need to be discussed. We make every effort to get early collections from the field as they are usually free of hyperparasites (or secondary parasites).

Establishing Laboratory Cultures: Sufficient plant material upon which the herbivore can be raised must be obtained and prepared so as to provide adequate host material in time to raise the natural enemies shipped in from the foreign explorer. Mass production rearing procedures need to be developed for natural enemies that will be mass produced after passing through quarantine prior to colonization. One of the major problems to be surmounted at this stage is the difficulty of producing herbivore material free of local parasites, predators and pathogens.

Prepare Quarantine Personnel: When final plans have been developed, the person responsi-

ble for quarantine operations needs to be thoroughly informed regarding the project. Targeted natural enemies, all preparations and timing should be discussed. Copies of all pertinent literature and descriptions should be provided. During subsequent weeks continued arrangements and happenings should be reported.

Preparing Field Locations: Three major requirements for an adequate field location are needed: 1) a sufficient number of host trees, 2) high populations of herbivore populations and 3) assurances that the area will not be subject to pesticide applications for an extended period of time.

The first requirement will insure adequate field populations of herbivores because sufficient plant material will be available. Usually other considerations determine how many trees can remain untreated and are outside the scope of this paper. However, the fact that one of our introduction projects, against two aphids (*Myzocallis castanicola* and *Tuberculooides annulatus*) on the English Oak (*Quercus robur*), was successful for at least three parasites on a total of six trees (4 of which were large—over 30 feet), indicates how little host material is needed.

Monitoring of potential field colonization sites needs to be started to fulfill the other two major requirements. Monitoring of early and late populations should be conducted to allow for all contingencies.

The assurances that the treatments in the area will be suspended must also be directed toward closely interrelated control operations in the same area, such as pesticide fogging for mosquito control.

Receipt of Exotic Natural Enemies: Packages opened in quarantine are inspected to evaluate emergence in transit and shipping conditions. Remaining material is allowed to emerge and hyperparasites are removed, killed, labeled and stored. All other materials are burned or sterilized within the quarantine rooms (for a description on this area see van den Bosch and Messenger, 1973). After mating, parasites and predators are reared through one generation and are then

released for colonization. Some parasitic insects do not need mating as the female can produce young without the presence of males, thus are easier to rear (e.g., the aphelinid *Mesidiopsis subflavescens*).

Colonization—Once released from quarantine a decision needs to be made: Should one directly release this first generation, mass produce and then release, or test the quarantine releases for host specificity? The decision is resolved based on theoretical knowledge and previous experience with the particular natural enemy concerned. Upon arrival at the colonization site the largest pest populations should be selected that are not subject to high populations of competing predators. After release at the site monitoring begins with the objective of making recoveries of the natural enemies just released. After recoveries are made an evaluation of the effects of the introduced natural enemy upon the herbivore needs to be made. Frequently these later functions, recovery and evaluation, may take a number of years. With one of our successful introductions, *Trioxys hortorum* on the elm aphid *Tinocallis platani*, only during the third season were parasite mummies first discovered.

This entire process is set in motion for each herbivore species on the priority list until effective biological control is achieved. Obviously, the process needs a biological control laboratory with a quarantine area, protocol, and appropriate specialists. Unfortunately there are only 5 of these laboratories in the United States. Such laboratories are needed in each state, with adequate staffing to carry on campaigns against horticultural, architectural, silvicultural and agricultural pest problems. The fact that 95% of the pest problems in the world still remain unapproached from a biological control viewpoint, indicates that entomologists, field insect managers and the general public do not yet appreciate the importance of this method of insect population management.

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