Use of Biologically Based Methods to Control Pest Plants: Issues Related to Federal Research, Regulation, and Implementation

Elizabeth A. Chornesky
3425 Patterson St. NW., Wash., DC 20015
and
Cynthia M. Palmer

[Ms. Palmer and Dr. Chornesky were with the Congressional Office of Technology Assessment until the agency was closed by Congress on Sept. 30, 1995. Ms. Palmer is currently employed by the Office of Environment, Safety and Health, U.S. Dept. of Energy. The views expressed by the authors in this article do not necessarily represent the views of the U.S. Dept. of Energy.]

Introduction

New species constantly flow into the country, yet, once here, few are ever eradicated. The result is continued growth in the number of harmful non-indigenous species in the United States (U.S. Congress 1993). Every year these interlopers exact costs of millions of dollars from U.S. agriculture, forestry, and other sectors. Some endanger human health. Others have severe ecological repercussions for native species and ecosystems. Such non-indigenous plants, animals, and diseases parasitize, kill, consume, compete with, or destroy the habitats of native plants and animals.

Paradoxically, certain non-indigenous species can actually suppress harmful pest organisms. Researchers, farmers and land managers have sought to take advantage of this quality by intentionally introducing non-indigenous species as biological control agents. A number of U.S. growers, including large companies like Gallo and Campbell, now routinely release predacious wasps to suppress insect pests (U.S. Congress 1995). And federal and state land managers increasingly are turning to biological control to combat noxious weeds in rangelands and natural areas. These efforts hold promise, but also entail certain ecological risks.

In 1993, the congressional Office of Technology Assessment released a report evaluating the impacts of harmful non-indigenous species in the United States (U.S. Congress 1993). The following year, OTA began addressing how we can control the harmful species that are already here. This new assessment -- *Biologically Based Technologies for Pest Control* -- investigated the potential of methods such as biological control and their place in emerging policies to reduce the nation's reliance on conventional pesticides (U.S. Congress 1995). A major theme of the resulting report is how to enhance the development of effective pesticide alternatives while preventing unintended harmful impacts. This paper discusses some of the study's key findings.

OTA's assessment was requested by three congressional committees (de la Garza et al. 1993; Studds and Saxton 1993; Vento 1993). They asked the agency to investigate not only applications to agriculture, but also the extent to which biologically based methods could be used against pests of natural areas, forests, aquatic habitats, and urban and suburban environments.

Technologies examined by OTA include:

- *biological control* -- the use of natural enemies to suppress pests. Methods include:
  1) the introduction and establishment of new biological control agents;
  2) the repeated augmentation of natural enemy populations; and
  3) the adoption of management practices that enhance the impacts of natural enemies already present in an area
- *microbial pesticides* -- relatively stable formulations of microbes (bacteria, viruses, nematodes, etc.) that suppress pests by secreting toxins, causing diseases, preventing the establishment of other microorganisms, or other mechanisms
- *behavior-modifying chemicals* -- use of pheromones to disrupt insect pest mating or to attract pests to pesticides
- *genetic manipulations of pests* -- the release into pest populations of modified individuals that interfere with the pest's reproduction or impact, and
- *plant immunization* -- non-genetic changes to plants that deter insect pests or reduce susceptibility to diseases.

Forces Shaping Pest Management in the United States

Today, conventional pesticides pervade all aspects of pest management in the United States. U.S. expenditures for pesticides exceeded $8.4 billion in 1993, comprising about one third of the world market (Aspelin 1994). According to data from the U.S. Department of Agriculture, each year more than 900,000 farms use pesticides on approximately 80% of the acreage planted in corn, cotton, soybeans, and potatoes (Vandeman, et al. 1994). In addition, around 351,600 certified commercial applicators apply pesticides to suppress building, home, and landscape pests (Aspelin 1994). And most U.S. homes contain pesticidal products, the majority of which have been used within the past year (Whitmore, R.W., et al. 1993).

Nevertheless, widespread use of pesticides is a relatively recent development. Use of chemical pest control burgeoned after World War II, doubling in the years between 1964 and 1978 alone (Fig. 1) (Aspelin 1994). Rising herbicide use has contributed significantly to the recent growth. Herbicide applications to corn, cotton, and wheat, for example, grew from ten to ninety-five percent of acreage between 1952 and 1980 (Osteen and Szmerda 1989).

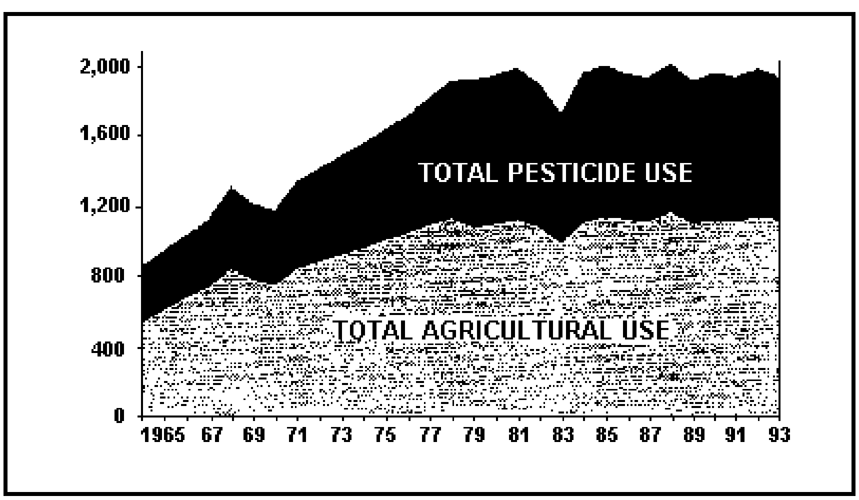

Fig. 1. Growth in U.S. Conventional Pesticide Use, 1964-1993. Note usage is reported in pounds of "active ingredient." Newer pesticides tend to have active ingredients that are more potent or concentrated and can be applied at a lower dosage. Hence, the apparent leveling-off in the 1980s does not necessarily translate into a stabilization of pesticide use according to numbers of acres treated, numbers of products applied, frequency of application, or other relevant measures. Source: U.S. Congress, 1995, based on data from Aspelin, 1994.

Several forces are now changing the nation's pest management practices. Some will tend to limit the numbers of conventional pesticides and their allowed uses. More rigorous federal regulation is directly and indirectly causing companies to withdraw certain pesticides from U.S. markets (EPA 1995; Womach 1994). Many of these are the so-called minor use pesticides where the potential market size is small. New chemicals coming on line are unlikely to offset these pesticide losses: high rates of merger and consolidation within the pesticide industry mean that companies increasingly are seeking to recoup the rising costs of product discovery and development by producing new products for only the largest markets. In addition, strong public opinion about pesticide use and exposure will continue to pressure policymakers in favor of rigorous pesticide screening (U.S. Congress 1995).

At the same time, pest control needs are growing. An increasing number of pests have become resistant to formerly effective chemical controls. As of 1988, at least 18 herbicide resistant weeds had been reported from 31 states, including such well known weeds as cheatgrass (*Bromus tectorum*) (LeBaron and McFarland 1990). At least 183 arthropod pests in the U.S. are resistant to insecticides; 62 of these show resistance to 2 or more of the 3 major categories of insecticides now in use (Georghiou 1995). In addition, the number of non-indigenous pests in the U.S. continues to rise. More than 205 species were newly detected or introduced into the country from 1980 through 1993, and at least 59 of these had the potential to become pests (U.S. Congress 1993). Moreover, experts predict rates of pest entry will increase with globalization of trade and with global warming. Finally, the significance of some long-established species is being reevaluated as natural area managers have begun to understand their harmful effects on native biodiversity.

The growing gap between pests requiring control and available pesticides is generating a need for a greater variety and number of tools and techniques. The importance of this problem has not been lost on national policymakers, who have responded in recent years with a number of initiatives aimed at providing pest management tools and expanding the implementation of integrated pest management (IPM). IPM generally refers to pest management systems that incorporate multiple pest control tools and seek to minimize pesticide inputs. Although specific definitions of IPM vary, originators of the concept and many subsequent promoters maintain that "natural" controls (including biological control) should be maximized, enhanced, and relied upon whenever possible (Cate and Hinckle 1994).

A notable recent action in the executive branch was the Clinton Administration's June 1993 announcement of its intent to reduce the use and risks of pesticides. A major mechanism for achieving this goal is a commitment to expand IPM to 75% of U.S. crop acreage by the year 2000. The biologically based technologies assessed by OTA thus may play an integral role in ongoing efforts to expand IPM.

Current Use of Biologically Based Methods

The extent to which biologically based methods are applied today provides indirect evidence of the methods' feasibility and of users willingness to adopt these approaches. OTA found that current use of these approaches is surprisingly widespread (U.S. Congress 1995).

Although conventional pesticides dominate U.S. pest management, biologically based methods have penetrated most major applications and joined the mainstream (U.S. Congress 1995). At least 28 state departments of agriculture operate their own biological control programs (Fig. 2). The USDA Animal and Health Plant Inspection Service as a matter of policy promotes biological control wherever possible. For control of the gypsy moth, a major forest defoliator found in more than 11 states, the U.S. Forest Service relies primarily on a combination of microbial pesticides and natural enemies. Numerous farmers adjust pesticide selection or spray schedules in order to minimize harmful impacts on pests natural enemies (Vandeman et al. 1994). And several major food processing companies promote biointensive IPM among farmers who supply their produce.

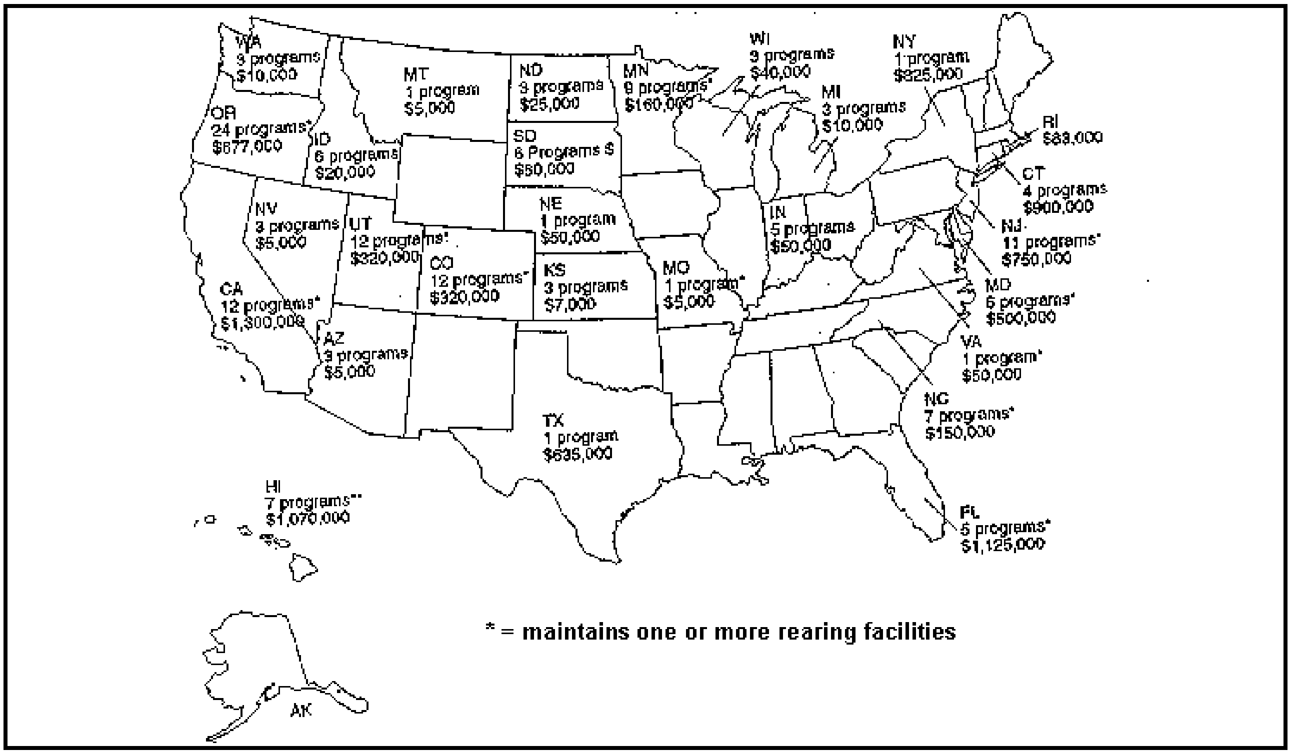

Fig. 2. Biological Control Expenditures and Programs in State Departments of Agriculture (1994). Source: U.S. Congress, 1995.

Biologically based products -- natural enemies, microbial pesticides, and pheromones that are sold commercially -- comprise one of the fastest growing sectors of the pesticide industry, with annual U.S. sales of more than $100 million (U.S. Congress 1995). All of the major agrochemical companies have invested to some degree in this area. By far the greatest sales have been of microbial pesticides based on the bacterium *Bacillus thuringiensis* or Bt. A growing array of microbial pesticides is now available to homeowners for control of landscape and household pests.

Current use in the U.S. is patchy, however (U.S. Congress 1995). Most biologically based tools are used against insect pests of arable agriculture, forestry, and aquatic habitats. Use is growing in urban and suburban settings as well. Few biologically based methods are yet available for control of plant pathogens, although a number of new microbial products have been introduced in the past year.

Applications Against Pest Plants

Biologically based methods have been identified or used with varying success against weeds of arable agriculture, rangelands, forests, wildlands, waterways, and other habitats. Differences among habitat types in the diversity of weeds requiring control and the goals of pest management may explain this uneven record. For example, in arable agriculture the need to suppress multiple weeds simultaneously poses a difficult challenge because most biological methods are relatively target specific. Likewise, the partial suppression afforded by certain biological control agents may be more acceptable in rangelands and natural areas where the environmental or economic costs of herbicides are sometimes too high.

None of the biologically based technologies is used to a significant extent against weeds in arable agriculture (Watson 1994). The four attempts to suppress crop weeds by introduction of natural enemies (i.e., classical biological control) have been unsuccessful. Potential microbial pesticides have been explored for 23 crop weeds and effective agents found for 13 (Watson 1994).

Experience with the only two microbial pesticides ever marketed for control of crop weeds demonstrates some inherent difficulties in the commercial development and marketing of such products. Devine was registered in 1981 for control of citrus strangler vine (*Morrenia odorata*) and Collego in 1982 for control of northern joint vetch (*Aeschynomene virginica*). Both were very effective but were later withdrawn from commercial sale because they did not generate large enough markets, in part because each controlled only a single weed, whereas farmers usually have to deal with many weeds at once. Devine proved almost too effective, persisting in fields and giving good weed control for more than three or four years at some sites. Related to current efforts by the U.S. Environmental Protection Agency (EPA) to support "biopesticides," that agency and the producer (Abbott Laboratories) initiated a cooperative effort in 1995 to put Devine back on the market (Cibulsky 1995).

More successful has been the use of biological methods to suppress weeds of rangelands, pastures, and waterways. Natural enemies have been introduced against 40 U.S. weeds (Watson 1994). They have yielded some level of control for 18 and excellent control in 7 of these cases. Examples include the weeds musk thistle (*Carduus nutans*) and skeletonweed (*Chondrilla juncea*). Plant diseases have been evaluated as potential microbial pesticides for five weeds of pastures, rangelands, and forests, but none has been developed into a commercial product (Watson 1994).

Several state and local programs propagate and distribute weed natural enemies to spread and enhance their effects. The Oregon Department of Agriculture's weed program has introduced 42 natural enemies of 20 target pest plants since it began in the 1970s. Program staff collect and transfer biological control agents across weed-infested areas to maximize the agents impacts. In Montana, county extension agents cooperate with high schools and 4-H clubs in a similar program giving students hands-on experience in biological control (Pearson 1994). At least seven commercial suppliers now harvest weed control agents from the field for sale to ranchers, land managers, and others (Hunter 1994).

In aquatic habitats, grass carp (*Ctenopharyngodon idella*) and a few other fishes have been stocked in more than 35 states for control of aquatic weeds (Kuris 1994). However, fish introductions for weed control have been widely criticized because of the fishes harmful impacts on aquatic habitats (U.S. Congress 1993, 1995). Classical biological control programs have yielded some suppression of three important aquatic weeds -- alligator weed (*Alternanthera philoxeroides*), water hyacinth (*Eichornia crassipes*), and water lettuce (*Pistia stratiotes*). Researchers have identified fungi as potential microbial pesticides for two aquatic weeds, but neither has been developed commercially (Watson 1994).

Only few classical biological control programs have specifically targeted weeds of natural areas and wildlands. Examples include purple loosestrife (*Lythrum salicaria*), melaleuca (*Melaleuca quinquenervia*), and banana polka (*Passiflora mollissima*) (Randall and Pitcairn 1994). Pest control in natural areas and wildlands has usually piggybacked on programs aimed at pests of agriculture, rangelands, navigable waterways, or other areas; such programs tend to be better-supported.

Summary of Current Use

Adoption of biologically based methods has occurred most frequently where conventional pesticides are:

(1) unavailable because of pest resistance or small market size;
(2) unacceptable, such as in environmentally sensitive habitats or where human contact is high; or
(3) economically infeasible, because the costs of pesticide use are high relative to the economic value of the resource, such as in rangeland management (U.S. Congress 1995).

Adoption is less common where effective and acceptable pesticides exist, or where numerous pests require simultaneous control (U.S. Congress 1995). This is because biologically based methods do not generally compare favorably when measured against the performance standards set by conventional pesticides. Most have a narrower target range, act more slowly, provide a less efficient level of pest suppression, and, if sold commercially, have shorter field persistence and briefer shelf life. Interestingly, most of these same attributes mean biologically based methods are less likely to harm natural enemies already present in an area. Thus, they become significant advantages in pest management systems that seek to reduce pesticide inputs and enhance naturally occurring biological control.

Limited availability of biological methods and of information resources also contribute to their uneven adoption (U.S. Congress 1995). Considerably more research effort focuses on identification of biologically based methods than on adaptation of methods to field use. Several prominent areas would benefit from increased attention, including:

- Greater focus on integrating biological methods into pest control systems (e.g., developing appropriate information about compatibility with conventional pesticides);
- Determining the appropriate scale of use (e.g., experts disagree as to whether a site by site or an areawide approach works best for augmentative releases of natural enemies or for pheromone applications); and
- Developing the necessary methods to enable large-scale production, distribution, and application of natural enemies and microbial pesticides.

A considerable amount of ongoing research, especially in the private sector, has a different focus: genetic engineering of natural enemies and microbial pesticides. The goal for microbial pesticides is to enhance their target range, lethality, and field persistence Ñ in other words, to bring their performance more in line with that of conventional pesticides.

Risks and Regulations

In looking ahead to expanded use of biologically based methods, it is important to ask what risks the technologies will pose. The significance of any such risks will depend on how well the regulatory system prevents the high impacts from occurring.

A general problem of the regulatory system has been inconsistent record-keeping and the infrequency of monitoring for non-target impacts after permitting (U.S. Congress 1995). While no glaring permitting errors came to OTA’s attention during the assessment, these difficulties ultimately will make it hard for regulators to identify and learn from past mistakes. This issue may take on greater significance as applications of biologically based methods grow. This section outlines the types of risks that are of particular concern and how the current regulatory system deals with these risks.

The Risks of Biologically Based Methods

Biologically based methods generally compare favorably to conventional pesticides from the perspective of public health and environmental impacts (U.S. Congress 1995). Also, rates of resistance development appear to be significantly slower. Like most things, however, the technologies are not risk-free. Some potential impacts have been better documented than others. Allergic reactions among insectary workers to fungal pathogens and insect eggs and wastes are the best understood human health impacts.

Of perhaps greater public concern are the potential harmful effects on non-target native species and ecosystems. Certain prominent ecologists and entomologists -- including Dan Simberloff (Florida State University), Jeffrey Lockwood (University of Wyoming), and Frank Howarth (Bishop Museum, Hawaii) -- have focused attention on the risks of classical biological control in particular. A significant problem in evaluating and addressing these risks is that some of the most likely ecological effects have probably gone unnoticed because of a chronic lack of monitoring (U.S. Congress 1995).

The best-documented environmental impacts involve predation on non-target species by vertebrates released for biological control. Well known examples include the effects of mongooses (*Herpestes auropunctatus*) on island bird faunas, and declines in native fishes due to releases of mosquito fish (*Gambusia* spp.) in aquatic ecosystems (Simberloff and Stiling 1994).

Similar concerns have been raised about the impacts of introduced insect parasites and predators (Simberloff and Stiling 1994). Recent evidence suggests that the tachinid fly *Compsilura cocinnata*, introduced to control the gypsy moth (*Lymantria dispar*) in 1906, may suppress populations of a number of native butterflies (Boettner and Elkinton 1995).

A few documented cases exist where phytophagous (plant eating) biological control agents affect non-target native plant species. The cactus moth (*Cactoblastis cactorum*), initially released onto several Caribbean islands, spread to Florida where it has caused the decline of rare cacti (*Opuntia spinosissima*) (Randall and Pitcairn 1994; Simberloff and Stiling 1994).

Some evidence suggests that certain introduced natural enemies may adversely affect native natural enemy populations by outcompeting them. For example, in some areas, the

European lady beetle (*Coccinella septempunctata*) appears to be displacing native lady beetles (Kareiva 1994).

Microbial pesticides based on Bt can affect non-target butterflies and moths. Some researchers, however, believe these effects are temporary because the bacteria do not persist in the field (U.S. Congress 1995).

Control of native pests with biological methods, especially biological control, raises special concerns because the full ecological role of the pest may not be well understood. Native plants that may be a pest in one context, such as snakeweed (*Heilipodus ventralis*), may be an important source of forage and support numerous other native species in another (U.S. Congress 1995).

Certain scientists believe that introduction of a natural enemy produces conditions that facilitate rapid evolution of changes in important characteristics of the biological control agent, such as host range (e.g., Simberloff and Stiling 1994). If true, this could make exact determination of the agent's full impacts prior to release virtually impossible (Kauffman and Nechols 1992).

Collection of natural enemies from free-living populations for commercial distribution and sale has raised concerns about depletion of free-living populations. The potential consequences include regional impairment of pest suppression and interference with publicly supported control programs. This last issue has been raised specifically regarding collection of natural enemies that have been introduced at public expense to suppress noxious weeds on state and federal lands.

The Federal Regulatory System

No federal statute directly addresses biologically based approaches (U.S. Congress 1995). Primary responsibility for regulation of biological control falls to the USDA Animal and Plant Health Inspection Service (APHIS) under its plant protection statutes. The EPA deals with microbial pesticides and pheromones under its pesticide statute -- the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). No Federal agency deals in a comprehensive way with vertebrate introductions for biological control; this area is primarily under state purview (U.S. Congress 1993). The discussion that follows focuses on the roles of APHIS and EPA.

APHIS -- Past oversight of biological control introductions by APHIS was incomplete, poorly documented, and non-transparent for those seeking permits (U.S. Congress 1995). The agency has taken some promising initiatives in recent years, but the system still has several flaws. Some of the permitting requirements are too demanding, and others too lax. Considerations regarding impacts of biological control on threatened and endangered species are not always raised at an early enough stage in the agency's decision-making. And no consistent or clear cut mechanism exists for APHIS to expedite permits for those biological control agents known to pose minimal risk.

Some of these problems derive from a lack of clear statutory guidance on how to balance the risks and benefits of biological control. In 1995 the agency tried to resolve this matter: The agency issued and then withdrew a proposed rule for regulating introductions of non-indigenous organisms (U.S. Congress 1995). Public response to the proposed regulation was almost uniformly negative -- biological control researchers, practitioners, and marketers considered it burdensome and unworkable.

EPA -- In 1994, EPA separated out its review of biologically based products from that of conventional pesticides, placing non-chemical approaches within a new regulatory division called the Biopesticides and Pollution Prevention Division (BPPD). This division has become an active participant in the Clinton Administration's policy initiative to reduce the nation's reliance on conventional pesticides.

To enhance the development of pesticide alternatives, BPPD has streamlined the data requirements for microbial pesticides and pheromones and has provided more user-friendly services to those seeking to register new products. Critics charge that the agency needs to pay closer attention to impacts on non-target organisms and ecosystems. Such issues may come into sharper focus as more genetically engineered microbes Ñ and the potentially heightened risks they pose due to enhanced host range, lethality, or persistence Ñ make their way through the pipeline (U.S. Congress 1995).

Role of the Federal Government in Research and Implementation

The federal government plays a large role in the research, development, and implementation of biologically based pest control. At least 11 agencies are involved and annual expenditures exceed $210 million (Table 1). Some of the government's successes have been great, such as elimination of the screwworm (*Cochliomyia hominovorax*) from North America using the sterile insect approach, and economic control of 11 insect pests and three weeds using classical biological control. Nevertheless, despite the size of federal efforts, biological methods do not always move smoothly from research into providing on-the-ground solutions to pest problems.

Table 1.
Biologically Based Pest Control: Funding for Research and Pest Control Programs (1994, in millions of dollars).
Source: U.S. Congress, 1995

Agency	Research	Pest Control Programs[a]
Agricultural Research Service (ARS)	104	na[b]
Cooperative State Research, Education and Extension Services (CSREES)[c]	12	na
Animal and Plant Health Inspection Service (APHIS)	12[d]	69.7[e]
Forest Service	5	11
U.S. Environmental Protection Agency (EPA)	1	na
U.S. Army Corps of Engineers	1.4	na
U.S. Department of the Interior	1	0.3
States	29[f]	9.4[g]
Total Public Spending	165	90

[a] Column does not include technology transfer functions of ARS or CSREES or classical biological control research programs in which researchers introduce a biological control agent.

[b] na = data not available.

[c] Numbers only cover biological control work and not microbial pesticides or other biologically based methods.

[d] APHIS/PPQ Biological Control Operations program only.

[e] All APHIS programs having a major focus on biologically based methods.

[f] Includes state matching funds distributed through CSREES. Not included is the significant, but unquantified direct state funding of research at Land Grant Universities.

[g] Covers state biological control programs only.

To some extent this results from a gap between the research and its use -- referred to by some long time observers as the "valley of death." This was the single most prominent problem identified during the OTA assessment (U.S. Congress 1995). It results from a lack of institutional coordination at several levels within and among federal departments. Much of the basic research on biologically based methods never makes it into the field, because no agency has consistently taken responsibility to translate the work of scientists into practicable applications for farmers and other users.

Federally supported research does not always provide a good match to national priorities. For example, OTA found no clear mechanism to match the research to known impending losses of pesticides through the reregistration process or the development of pest resistance. Yet, it is under precisely these circumstances that biologically based methods are most likely to be adopted. Another example is the allocation of research resources to different pest types. Although herbicides make up the single largest category of pesticide use in the United States (57%), only 15% of federal research on biological methods addresses weeds (Fig. 3).

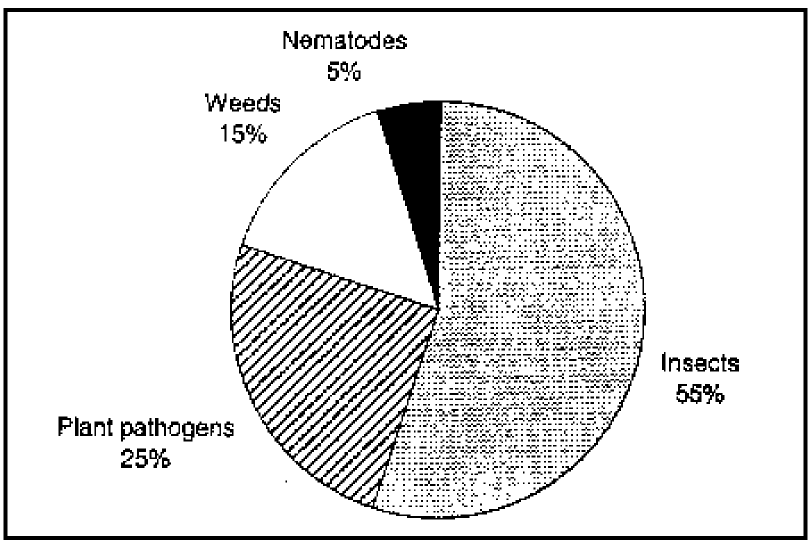

Fig. 3. Distribution of Federal Research on Biologically Based Methods According to Pest Type (1994). Figure does not include data from EPA or APHIS because research and development activities could not be identified according to pest type. Source: U.S. Congress 1995.

The various problems with coordination and prioritization have sometimes delayed the development of appropriate management tools for national programs to control emerging pest threats. Although federal researchers were warning of the impending threat posed by the silverleaf whitefly (*Bemisia argentifoli*) as early as the mid-1980s, USDA agencies were unable to mobilize a coordinated response until 1991. This agricultural pest eventually exacted costs exceeding $300 million in the California Imperial Valley from 1991 through 1994.

Typically, USDA initiates pest control programs when a pest climbs to the top of the political agenda and the urgency to find solutions is great. Such conditions may not be conducive to carefully conceived and executed biological control programs. For example, to date APHIS has introduced 24 species and over 100 geographic strains of potential control agents against the Russian wheat aphid (*Diuraphis noxia*) -- a pest that has caused more than $850 million in losses since it arrived in the U.S. in the 1980s. But the agency has had difficulty documenting the biological control agents establishment or impact, in part because of poor attention to taxonomic identification before release and inadequate post-release monitoring (U.S. Congress 1995).

Such issues may take on greater significance to those involved in control of pest plants if and when the federal role in weed control grows. Weed programs currently comprise a small proportion of overall pest control efforts. Certain weed control programs -- such as the Army Corps work on aquatic weeds and the Agricultural Research Service's rangeland weed efforts in California -- encountered difficulty during the last round of federal budget proposals (U.S. Congress 1995). Conversely, the Department of the Interior currently is attempting to raise the profile of noxious weed issues through several well-publicized national weed summits and increased agency coordination (**see Jackson and Schneider article in this Proceedings**). These varying trends make it difficult to predict the level of future federal involvement.

Conclusion

Today, there are good reasons to take a careful look at pesticide alternatives like biologically based methods. The technical and policy forces shaping the future of pest management in the United States are increasingly driving us away from reliance on conventional pesticide-based approaches. OTA found that biological control, microbial pesticides, and the other methods have joined the mainstream. Their use, although widespread, remains uneven.

The possible ecological risks of these technologies are important but still poorly documented. It is going to be very difficult for the regulatory agencies to adequately address these risks without better evidence of their significance. This problem would be best addressed by combined efforts of the regulatory and research communities to increase accountability and record-keeping of permitting decisions, to monitor higher risk applications, and to conduct research on potential ecological impacts.

Federally supported research often fails to translate initial research findings into field-ready pest control solutions. This problem is particularly significant for control of pest plants. For example, past efforts by university and federal researchers have frequently stopped once a promising microbial strain has been identified with the expectation that it will be picked up by the private sector. But the private sector is unlikely to take on this role, often because no readily marketable product is yet in sight.

In general, research on control of pest plants had been driven by the interests of agriculture and range management. Nevertheless, USDA has given relatively low priority to the development of biologically based methods for weed control. This reflects the agencys' historical emphasis on insect pests and also a perceived low applicability of such methods to weeds of arable agriculture. Perhaps the greatest federal interest in control of pest plants lies in the Department of the Interior and its current noxious weed initiatives. However, the department's ability to conduct related research will be limited because its research arm, the National Biological Service, was recently downsized and merged with another agency.

For the foreseeable future, the public sector will need to play a major role in the development and implementation of biologically based pest control. Given the significant institutional and other complexities, Congress and government agencies will need strong and consistent encouragement to direct resources toward solving the important national problems created by pest plants.

Acknowledgments

Literally hundreds of people contributed to the OTA assessment of biologically based pest control. We are deeply grateful to the other members of the project staff Ñ John Longbrake and Christine Taverna Ñ who made it possible to complete the report with grace and good humor under the most trying working conditions. We also appreciate the significant contributions made by various members of the Advisory Panel and workshops, by background paper contractors, and by staff from numerous federal agencies. This paper is based on work conducted by the congressional Office of Technology Assessment. Congress closed the agency in late 1995. Copies of the 209-page report can still be obtained by contacting the National Research Council Board on Agriculture or the Government Printing Office. The text is also available over the internet through the OTA website at Princeton:

(http://www.wws.princeton.edu/~ota/).

Literature Cited

Aspelin, A.L. 1994. Pesticide Industry Sales and Usage: 1992 and 1993 Market Estimates. U.S. Environmental Protection Agency, 733-K-94-001, Washington, D.C.

Boettner, G.H. and J.S. Elkinton. 1995. Fly in the Butterfly, Shoo Fly, Shoo: When Biocontrol Meets Biodiversity. Proceedings of the 9th Annual Meeting of the Society for Conservation Biology.

Cate, J.R. and M.K. Hinckle. 1994. Integrated Pest Management: The Path of a Paradigm. National Audubon Society, Weadon Printing, Inc., Alexandria, Va.

Cibulsky, R., Manager, Licensing/Business Development, Abbott Laboratories. 1995. Personal communication to the U.S. Congress, Office of Technology Assessment.

de la Garza, E., P. Roberts, R. Smith, C. Stenholm. 1993. Letter from the House Committee on Agriculture to Senator Kennedy, Chairman of the Technology Assessment Board, U.S. Congress, Office of Technology Assessment.

Georghiou, G. (University of California at Riverside). 1995. Insecticide Resistance in the United States. Unpublished contractor report prepared for the U.S. Congress, Office of Technology Assessment.

Hunter, C.D. 1994. Suppliers of Beneficial Organisms in North America. California Environmental Protection Agency, Sacramento, CA.

Kareiva, P., Professor, University of Washington. 1994. Personal communication to the U.S. Congress, Office of Technology Assessment.

Kauffman, W.C. and J.R. Nechols (eds.). 1992. Selection Criteria and Ecological Consequences of Importing Natural Enemies. Thomas Say Publications in Entomology No. 1. Entomological Society of America, Lanham, Md. 117 pp.

Kuris, A. (University of California at Santa Barbara). 1994. A Review of Biologically Based Technologies for Pest Control in Aquatic Habitats. Unpublished contractor report prepared for the U.S. Congress, Office of Technology Assessment.

Lebaron, H.M. and J. McFarland. 1990. Herbicide Resistance in Weeds and Crops: An Overview and Prognosis. In, M.B. Green, H.M. Lebaron, and W.K. Moberg (eds.), Managing Resistance to Agrochemicals: From Fundamental Research to Practical Strategies. American Chemical Society, Washington, D.C.

Osteen, C.D. and P.I. Szmerda. 1989. Agricultural Pesticide Use Trends and Policy Issues. U.S. Department of Agriculture, Economic Research Service, AER-622, Washington, D.C.

Pearson, W., County Extension Agent, Columbus, MT. 1994. Personal Communication to the U.S. Congress, Office of Technology Assessment.

Randall, J. (The Nature Conservancy, Davis, CA) and M. Pitcairn (California Department of Food and Agriculture). 1994. Biologically Based Technologies for Pest Control in Natural Areas and other Wildlands. Unpublished contractor report prepared for the U.S. Congress, Office of Technology Assessment.

Simberloff, D. (Florida State University) and P. Stiling (University of Southern Florida). 1994. Biological Pest Control: Potential Hazards. Unpublished contractor report prepared for the U.S. Congress, Office of Technology Assessment.

Studds, G. and J. Saxton. 1993. Letter from the House Committee on Merchant Marine and Fisheries to Senator Kennedy, Chairman of the Technology Assessment Board, U.S. Congress, Office of Technology Assessment.

U.S. Congress, Office of Technology Assessment. 1993. Harmful Non-Indigenous Species in the United States. Government Printing Office, Washington, D.C. 391 pp.

U.S. Congress, Office of Technology Assessment. 1995. Biologically Based Technologies for Pest Control. Government Printing Office, Washington, D.C. 204 pp.

U.S. Environmental Protection Agency. 1995. Annual Report for 1994. 735-R-95-001, Washington, D.C.

Vandeman, A., et al. 1994. Adoption of Integrated Pest Management in U.S. Agriculture. U.S. Department of Agriculture, Economic Research Service, Bulletin No. 707, Washington, D.C.

Vento, B. 1993. Letter from the House Committee on Natural Resources Subcommittee on Forests, National Parks, and Public Lands to Senator Kennedy, Chairman of the Technology Assessment Board, U.S. Congress, Office of Technology Assessment.

Watson, A.K. (McGill University). 1994. Biologically Based Technologies for Pest Control: Agricultural Weeds. Unpublished contractor report prepared for the U.S. Congress, Office of Technology Assessment.

Whitmore, R.W., et al. 1993. National Home and Garden Pesticide Use Survey. In, K.D. Racke and A.R. Leslie (eds.), Pesticides in Urban Environments. American Chemical Society, Washington, D.C.

Womach, J. 1994. CRS Issue Brief: Pesticide Policy Issues in the 103rd Congress. U.S. Congress, Congressional Research Service, IB93082, Washington, D.C.