IAEA-314-D4-97CT02288
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WORKING MATERIAL

Use of nuclear techniques in biological control: Managing pests, facilitating trade and protecting the environment

Report of a Consultants Group Meeting held in Vienna, Austria, 14 - 18 April 1997

Reproduced by the IAEA
Vienna, Austria, 1999

CONTENTS

USE OF NUCLEAR TECHNIQUES IN BIOLOGICAL CONTROL: MANAGING PESTS, FACILITATING TRADE AND PROTECTING THE ENVIRONMENT

INTRODUCTION

Agricultural production is adversely affected by many pests, including arthropods and weeds, which traditionally have been controlled with a heavy emphasis on chemical pesticides. Production is affected in the field, prior to harvest, and after harvest. In-field losses and post-harvest losses on the order of 30 - 40% are common (Oerke *et al.* 1994). Quarantine regulations also account for indirect losses by preventing the interstate and international shipment of products that exceed allowed standards for the presence of pests. Resistance to many pesticides also has been documented, leading to increased use rates, which in turn can exacerbate the adverse effects of pesticides on the environment.

For these reasons, improved methods of pest control are being developed, with an emphasis on the need for biointensive or ecologically-based pest management strategies (Benbrook 1996, Natl. Res. Council 1996). Biological control offers one of the most promising, environmentally sound, and sustainable approaches for control of arthropod pests and weeds.

Globally, biological control has been an accepted method of pest management for over 100 years. It has been used traditionally in agriculture, forestry and rangeland areas and for medical and veterinary pests, but has great potential for management of other pests (e.g. in urban, interiorscape and environmental areas). Conservationists are "turning to biological control to help save biodiversity" (OTA 1995). In fact, public support for biological control as the preferred method of managing non-indigenous and indigenous pests is increasing in many countries (Leppla and Delfosse 1995, NAPPO 1994, OTA 1995), but is not without risks and challenges (Howarth 1991). However, the risks of population-level effects to non-target species from use of specific natural enemies in biological control programmes are historically very low (Bennett 1990, Kauffman and Nechols 1992, OTA 1995, Wapshere *et al.* 1989).

There is tremendous potential for solving pest management problems for the public good, through research, implementation and technology transfer of all four types of biological control (See Table 1 in Working Paper by Delfosse). Classical and augmentative biological control offer significant opportunities for increasing nuclear techniques, but certain gaps in knowledge and practice exist. There are significant opportunities for increasing use of classical and augmentative biological control through nuclear techniques for production and release of biological control agents. Increasing application of nuclear techniques in classical and augmentative biological control will facilitate international trade by contributing to availability of pest-free commodities and pest-free shipments of biological control agents. It can also enable sustainable environmental stewardship by increasing availability and application of safe natural enemies at affordable costs, and reducing application of high-risk pesticides.

BACKGROUND

Maximizing biological control strategies

Classical and augmentative biological control are potentially very important vis-à-vis nuclear technologies. Classical or inoculative biological control is currently the most practised of the four types. It involves introduction of non-indigenous natural enemies of pests, usually from the home range of the pests, into the country where the pest is troublesome. Usually the natural enemy is selected from the suite of parasites, predators and diseases that co-evolved with the pest, but sometimes the original host is a species closely related to the pest. One of the most important aspects of classical biological control is that relatively small numbers of agents are released ("inoculated"), and the agents generally spread on their own after establishment. The natural biotic potential of the agents allows numbers to build up to levels damaging to the target pest, and it is generally not necessary to make repeated releases once the agent is established. Post-establishment redistribution by humans can often help spread the agents faster (particularly when the distribution of the pest is very wide or when ecological barriers exist to natural spread), but is not always necessary. Nuclear techniques have not been used with classical biological control, but significant opportunities exist to help clarify questions of host-specificity of biological control agents for weeds through use of sterilized or substerile F-1 immatures (see below).

Augmentative or inundative biological control involves use of indigenous or non-indigenous natural enemies against indigenous or non-indigenous pests. As with classical biological control, augmentative biological control most often uses natural enemies that have co-evolved with their hosts, but sometimes natural enemies from closely related hosts are used. Unlike classical biological control, augmentative biological control agents generally do not establish, often because of adverse eco-climatical factors in the introduced area, and are released in very large numbers, often several times each season. Strategic continued preventative releases are sometimes needed in the same season. Releases are timed, when possible, to overwhelm the most susceptible stage(s) of the pest. Some beneficial uses of nuclear techniques have been developed for augmentative biological control, but many more (see below) are possible.

Advances and challenges in augmentative biological control

Commercial production of predators and parasitoids originated from a need to control pests, including pests introduced from other areas without their natural enemies. For example, in 1959 *Aphytis melinus* was introduced into California with the expectation of becoming established as part of a classical biological control programme against citrus red scale. This parasitoid did not overwinter so seasonal releases were required to control citrus red scale. As a result of this need, commercial production was established in California. Today, seven insectaries produce over 1.5 billion *A. melinus* for augmentative release each year, which manages citrus red scale without the use of insecticides, saving California growers millions of dollars annually. Secondary pests, or pests resistant to chemical pesticides, and regulations restricting the use of certain chemicals also contributed to the need to develop a commercial augmentative industry.

The commercial natural enemy industry is still a niche market with less than 3% of the pest control sales world wide (Leppla 1997). Constraints on biological control have kept the market share small, but specific successes give promise for future growth (see Working Paper by Penn, Appendix 2). Additional natural enemies are needed for multi-pest complexes. Better data are needed on how augmentative biological control agents can be used more extensively in IPM and area-wide pest management.

Challenges facing augmentative biological control include cost of production, quality control and quality assurance, shipping and regulations. These same concerns apply to industry and governmental agencies. For example, the cost of production may be increased due to short shelf life, unstable markets, high labor demands, natural and artificial diet problems, and other issues, such as disease and contamination.

Availability of inexpensive quality control techniques (including assays for components in production systems) would help companies provide consistent, high quality products in sufficient numbers for cost-effective pest management (Penn, 1997). Shipping conditions may contribute to mortality of biological control agents. Possible trade barriers related to shipping include the potential of accidental pest hitchhikers or deliberate inclusion of a live food source in the shipments. The possibility exists that the live food source may be from pesticide resistant strains. Procedures and protocols for end users to conduct quality assurance, and customer education for proper handling and release of biological control agents, and monitoring results, are necessary to assure successful pest management (Penn, 1997).

Properly timed distribution of the appropriate stage of the predator or parasitoid is a crucial component for success to achieve pest suppression with natural enemies. The lack of equipment to accomplish this task increases the cost and may reduce the effectiveness of the intended programme. Providing irradiated host/prey released in the field at the time of introduction of specific natural enemies would provide greater flexibility of timing the release and allow for development of the natural enemy so that the most effective stage is present for optimum pest suppression.

Lack of enabling regulations for biological control is the most important single barrier to greater implementation of biological control globally. Appropriate regulations are needed that facilitate the importation and use of natural enemies. In many countries, "gatekeeper" regulations place barriers in the way of efficient introduction of agents (Delfosse, 1996).

Constraints to increased production and use of augmentative biological control agents where nuclear techniques might be helpful

While improvement is needed in a number of areas relating to the production and use of natural enemies (as mentioned above), ionizing radiation may be most helpful in facilitating production and use of natural enemies in three areas: (1) improvements in rearing media (either artificial diets or natural hosts/prey); (2) shipping-related issues, including the provision of natural prey to be used as food during shipment, and amelioration of concerns relating to the incidental presence of hitchhiking pests; and (3) provision of supplemental food or hosts in the field, to increase the initial survival and buildup of released natural enemies.

RECOMMENDATIONS

High-priority should be given to the use of nuclear techniques to improve production, shipping and implementation of biological control agents. Other high priority applications of nuclear techniques for biological control of weeds and programmes that extend the utilization of existing SIT programmes are identified in Appendix 3.

1. Immediate efforts should be taken to establish a CRP on use of nuclear techniques for improved augmentative biological control.

2. Ensure that ionizing radiation sources are widely available or obtained for the use of the commercial biological control industry and CRP partners.

3. Studies should be conducted to address the following production-oriented (P), trade-oriented (T) and future (F) research activities:

   P1 Determine the possibility of using ionizing radiation (gamma, x-ray or electron beam) to improve the suitability of natural or factitious hosts/prey for use in parasitoid/predator mass-rearing.

   P2 Determine the efficacy of ionizing radiation for use in sterilizing artificial media for parasitoid/predator mass-rearing. Dose-effect studies should be performed to determine irradiation effects on microbial load, and to evaluate any adverse effects on the nutritional quality of the diet.

   T1 Determine the feasibility of using ionizing radiation needed to reproductively sterilize hosts or prey used as food to be shipped with biological control agents.

   T2 Determine the benefit of using irradiated hosts/prey as supplemental hosts/food for field populations of natural enemies. Laboratory tests on effects of radiation on parasitization or feeding should be performed, and field tests on application rates for irradiated hosts/prey should be conducted.

   F1 Evaluate use of ionizing radiation to produce sterile and/or substerile F-1 weed biological control agents. Use these reproductively inactivated agents to safely evaluate their impacts on potential non-target hosts in the pre-release evaluation phase.

   F2 Increase pest suppression by combining released augmentative natural enemies and sterile insects in IPM and AWPM programmes.

   F3 Integrate F-1 sterility and augmentative releases of predators and parasitoids in AWPM programmes.

   F4 Utilize by-products from SIT mass-rearing facilities in augmentative biological control programmes.

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Appendix 2: Working Papers

DEVELOPMENT AND INTEGRATION OF ALTERNATIVE MANAGEMENT STRATEGIES USING INHERITED STERILITY AND NATURAL ENEMIES TO CONTROL LEPIDOPTERAN PESTS

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Lepidopteran pests such as corn earworm, *Helicoverpa zea*, fall armyworm, *Spodoptera frugiperda*, beet armyworm, *Spodoptera exigua*, and diamondback moth, *Plutella xylostella*, are often the most destructive pests of field crops in the United States. Insecticide resistance, increasing concern over pesticide pollution, and the desire to effectively manage lepidopteran pests on an area-wide basis have motivated scientists to identify and develop new pest management tactics that are compatible with current IPM practices. IPM-based systems, including genetic methods and biological control, offer the best long-term solutions to pesticide reduction and the management of destructive agricultural pests. F_1 sterility has emerged as a promising control strategy for lepidopteran pests.

The potential for using F_1 sterility as a component of regional management of lepidopteran pests has been suggested by Knipling (1970) and LaChance (1985), and numerous laboratory and cage studies on pests around the world have supported these ideas (LaChance 1985, Anonymous 1993). The successful application of the F_1 sterility principle to a wild population of *Helicoverpa zea* (Boddie) during a recent pilot test encouraged further development of this pest control strategy (Carpenter & Gross 1993). However, the high cost of rearing lepidopterans, relative to the cost of rearing dipterans, has moderated researchers' enthusiasm concerning the use of F_1 sterility for the control of lepidopteran pests. Nevertheless, Carpenter and Gross (1993) revealed that even a low irradiated : wild insect ratio could significantly reduce the seasonal increase of *H. zea*. In addition, population models (Knipling 1992, Carpenter 1993) have suggested that F_1 sterility would be more efficient if combined with other pest control strategies. Therefore, recent studies have investigated the potential of integrating F_1 sterility and parasitoids for increased efficiency in suppression of pest populations.

Mannion et al. (1994 & 1995) studied the compatibility of F_1 sterility in *H. zea* and the tachinid parasitoid, *Archytas marmoratus* (Townsend). They found these two control strategies to be compatible, and suggested that combining the two strategies may be useful for managing early season populations of *H. zea*. However, caution should be exercised in the extrapolation of these results to other lepidopteran pests, such as *S. exigua*. Parasitoid/host relationships are highly variable as a result of the various reproductive strategies of both host and parasitoid species. For example, *H. zea* females lay individual eggs spaced some distance apart to reduce mortality from larval cannibalism. Alternatively, *S. exigua* females lay eggs in masses and larvae feed gregariously, in a patch, during their first two instars. Also, *A. marmoratus* larviposits many maggots in the vicinity of late instar *H. zea*, whereas a common parasitoid for *S. exigua, Cotesia marginiventris* (Cresson), stings individual, early instars.

The beet armyworm, *Spodoptera exigua* (Hübner), is a serious pest in cotton in the southeastern United States, especially during outbreak conditions (Smith & Freeman 1994). Although many factors have contributed to the outbreaks of *S. exigua* in cotton, an unusually high level of resistance to some pesticides is implicated (Sprenkel & Austin 1994). Alternative management strategies, such as conservation of natural enemies (Ruberson et al. 1994), mating disruption with synthetic pheromone (Wakamura & Takai 1992), and inherited sterility, are being studied for their potential role in an integrated pest management program for *S. exigua*.

Carpenter et al. (1996a) performed laboratory and greenhouse studies in which the research objectives were as follows: (1) to compare the acceptability and suitability of progeny from irradiated (100 Gy) and nonirradiated *S. exigua* males mated with nonirradiated females as hosts for *C. marginiventris*, and (2) to relate these findings to the potential of combining the F_1 sterility technique with resident or released *C. marginiventris* for managing populations of *S. exigua*. Results from these studies revealed that progeny of irradiated male and nonirradiated female *S. exigua* were acceptable and suitable hosts for *C. marginiventris* development. Female *C. marginiventris* showed no oviposition preference for *S. exigua* progeny from females paired with either irradiated or nonirradiated males. Fully successful integration of F_1 sterility and parasitoids into a pest management approach can occur only if parasitoid strategies do not negatively impact irradiated insects and their progenymore than those of the wild population, and if F_1 sterility does not negatively impact the efficacy of parasitoids. F_1 sterility and *C. marginiventris* appear to be compatible tactics that potentially could be integrated into a preventative pest management program for *S. exigua*.

The compatibility of these two strategies is congruent with the findings of Mannion et al. (1994, 1995). Carpenter (1993) suggested several scenarios in which the integration of compatible strategies such as F_1 sterility and parasitoids might be used to control lepidopteran pest populations. For example, sterile *S. exigua* larvae could be field reared on early season host plants or nursery crops. *Cotesia marginiventris* (native and/or released) could use these sterile larvae as hosts and, thereby, increase the parasitoid's early season population. Other natural enemies of *S. exigua* may also use these sterile hosts. Larvae that escaped the natural enemies would produce sterile adult *S. exigua* that would reduce the reproductive potential of the next generation of *S. exigua*.

Cotesia marginiventris is considered the dominant parasitoid of *S. exigua* in the eastern half of the United States (Tingle et al. 1978, Ruberson et al. 1994). This parasitoid is part of a large natural enemy complex that has the capacity to suppress *S. exigua* populations in cotton. However, *S. exigua* can become a serious pest of cotton, especially when the natural enemy complex has been disrupted (Ruberson et al. 1994). When *S. exigua* populations escalate, growers often are reluctant to postpone insecticide applications until the natural enemy complex has brought the *S. exigua* population under control. Pedigo (1995) suggested that the development of new integrated pest management programs should provide a special focus on the identification of preventative tactics. Ruberson (1994) emphasized the usefulness of conserving natural enemies for effective suppression of *S. exigua*. Because F_1 sterility and *C. marginiventris* are compatible and may provide synergistic effects, further studies are warranted to test the practicality and efficacy of integrating these two tactics for controlling *S. exigua*.

The results of Carpenter et al. (1996a), and data from recent studies and population models (Carpenter et al. 1996b) suggest that the full potential of inherited sterility as an area-wide control strategy for lepidopteran pests may be realized only when inherited sterility is integrated with other suppression methods such as the use of parasitoids.

The employment of an integrated management approach for lepidopteran pests will no doubt require consideration of numerous economic, ecological, behavioral and logistical factors. Currently, that knowledge is incomplete. However, population models may provide some insight into how different control strategies could be combined for greatest efficiency. Although the effectiveness of inherited sterility continues to increase as the ratio of irradiated to nonirradiated insects increases, the efficiency decreases quickly once a 10:1 ratio has been obtained. A similar loss of efficiency occurs in the parasite release technique when the parasite to host ratio increases above 5:1 (Carpenter 1993). According to these models, the economic benefit of combining inherited sterility and parasite release techniques would be greatest when the ratio of irradiated to nonirradiated is $<$10:1 and the ratio of parasite to host is $<$5:1.

Models developed by Knipling (1992) depicting different integration scenarios suggest that combining inundative releases of parasitoids with sterile insects will yield both additive and synergistic effects. Although the parasite and the sterile insect techniques have different modes of action, the effectiveness of the sterile insect technique increases the ratio of adult parasites to adult hosts, and the effectiveness of the parasites increases the ratio of sterile to fertile insects. Greater suppression could be expected if parasite releases were combined with the inherited sterility technique (Carpenter 1993). Not only is inherited sterility more effective than full sterility in reducing population increases, the inherited sterility technique produces sterile F_1 larvae that would provide an increased number of hosts for the parasites. Therefore, the number of parasites produced should increase even if the rate of parasitism remained the same (host density independent), and whether or not additional parasites were released.

Fully successful integration of inherited sterility and parasites into a management approach can occur only if parasite strategies do not negatively impact irradiated insects and their progeny more than that of the wild population, and if inherited sterility does not negatively impact the efficacy of parasites. Results from these studies indicate that parasites and inherited sterility are compatible control strategies.

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Review Paper For: FAO/IAEA Consultants Group Meeting on *Use of Nuclear Techniques for the Production and Augmentative Releases of Biological Control Agents of Insect Pests*, 14-18 April 1997, Vienna, Austria 11

International Issues in Relation to Biological Control Regulation, Coordination and Accountability

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Biological control has been an accepted and effective method of pest management for over 100 years. Several recent reports from the Office of Technology Assessment, the National Research Council of the National Academy of Sciences, the U.S. Department of Agriculture and others have advised increasing research and development of biologically-based technologies (BBTs) for pest management. In addition, several reports have identified elements of regulation, coordination, and accountability that should be in place for a biological control program to be highly successful. This report summarizes perspectives on regulation, coordination and accountability that were presented in key documents important to the future of biological control, particularly Carruthers and Petroff (1997), Delfosse *et al.* (1996*a,b*), NRC (1996) and OTA (1995).

INTRODUCTION

Globally, biological control (Table 1) has been an accepted method of pest management for over 100 years. It has been used traditionally in agriculture, forestry and rangeland areas and for medical and veterinary pests, but has great potential for management of other pests (e.g., in urban, interiorscape and environmental areas). Conservationists are "turning to biological control to help save biodiversity" (OTA 1995). In fact, public support for biological control as the preferred method of managing nonindigenous and indigenous pests is increasing in many countries (NAPPO 1994, OTA 1995, Leppla and Delfosse 1995), but is not without risks and challenges (Howarth 1991). However, the risks of population-level effects to non-target species from use of specific natural enemies in biological control programs are historically very low (Bennett 1990, Kauffman and Nechols 1992, OTA 1995, Wapshere *et al.* 1989).

Table 1. The four types of biological control (modified from Wapshere *et al.* 1989).

Type: CHARACTERIZATION	Description and Examples
Classical or inoculative: ECOLOGICAL	Nonindigenous natural enemies against (usually) nonindigenous pests; e.g., *Puccinia chondrillina* rust against *Chondrilla juncea* (skeleton weed)
Augmentative or inundative: TECHNOLOGICAL	Indigenous or nonindigenous natural enemies against indigenous or nonindigenous pests; e.g., *Trichogramma* wasps against eggs of pest Lepidoptera
Conservation of natural enemies: ECOLOGICAL	Enhancing or protecting indigenous natural enemies (usually); e.g., eliminating use of pesticides in rice to favor spiders, planting shelter belts to encourage predators, providing a missing resource, etc.
Broad spectrum: TECHNOLOGICAL	Polyphagous natural enemies used specifically; e.g., confining goats on blackberry, sheep on leafy spurge, grass carp in canals or ponds, etc.

There is tremendous potential for solving pest management problems for the public good through research, implementation and technology transfer of all four types of biological control. However, gaps have recently been pointed out in regulation, coordination and accountability of biological control that prevent it from being used to maximum advantage. Unless these gaps are filled, increased implementation of nuclear techniques for the production and augmentative releases of biological control agents will be delayed.

COORDINATION OF USDA BIOLOGICAL CONTROL ACTIVITIES

Many reports identified the lack of coordination, cooperation and facilitation of biological control as critical needs (Cook and Granados 1991, Delfosse 1991, Ehler 1990, ESCOP 1989, Gabriel and Cook 1990, Granados *et al.* 1991, Leppla *et al.* 1995, Mendelsohn *et al.* 1993, Moran 1992, McDonald 1991, 1992, 1993, 1994, Metterhouse 1985, Mullin and Fugere 1996, OTA 1993, 1995, Tauber *et al.* 1985, Thomas 1987).

Several gaps clearly exist in coordination of biological control. Among the most important are economic constraints; it is difficult to coordinate biological control if key groups compete for a shrinking share of limited resources. "Lack of necessary coordination ... was the most prominent problem identified by every workshop and advisory panel" convened by OTA (1995), and earlier by the Experiment Station Committee on Organization and Policy (ESCOP 1989). Ehler (1990) pointed out that better coordination would increase potential for biological control success, and would reduce the costs and risks. It would also reduce duplication of effort. Leadership in coordination of biological control efforts is needed.

OTA (1995) found that States provide matching research funds for SAES through CSREES, directly fund experiment stations and land grand universities, and operate quarantine and insect rearing facilities. Twenty-eight States have their own research and implementation programs for biological control. Twenty-two States have cooperative programs with APHIS and ARS, but there is little coordination among or between States and the Federal government. OTA (1995) concluded that "the harshest critics say that the necessary [biological control] coordination is virtually nonexistent today." OTA's interviews with scientists highlighted the worry that the "poor coordination of biological control programs among government agencies can result in replication of effort" and other problems. Increased coordination "would increase the potential for success and reduce the costs and risks." OTA (1995) stated that, despite the expenditure of over $130 million each year by 11 federal agencies, "this expenditure appears to be largely uncoordinated and to lack adequate prioritization." Implementation is less than ideal because "no federal research agency takes responsibility for this function." Past coordination activities have been unsuccessful "because the coordinating committees and institutes have had inadequate institutional status, authority, and funding." Noxious weeds are spreading up to 4,000 acres per day, and land managers favor biological control of weeds, but resources are not available for weeds, and "no federal research agency has yet made a large effort in this area."

There have been some attempts at Biological Control Coordination. The Experiment Station Committee on Organization and Policy (ESCOP), representing the State agricultural experiment stations of the land-grant university system, established a Working Group on Biological Control in 1985 and sponsored a national symposium, *New Directions in Biological Control*, in 1989. This group stated (ESCOP 1989)

> A coordinated, national scientific initiative is needed to maximize our understanding and use of biological control ... . Because there is currently no formal organization to coordinate the efforts of university scientists, government agencies, and industry, these sectors have often developed independent and conflicting agendas. By coordinating efforts toward a common goal, we can minimize duplication, foster cooperation, and focus effort on important problems. Researchers should be included in the development of guidelines and regulations overseeing environmentally safe use of biological control agents.

In 1990, APHIS established NBCI following five years of internal discussion. NBCI has provided a degree of biological control coordination. For example, NBCI: initiated development of the *National Biological Control Information Center* (a combination of NBCI and the ARS *Biological Control Documentation Center* information activities); established a bulletin board system and the first *World Wide Web Internet Home Page* for biological control; completed limited funding initiatives discussed below; instituted a *Customer Advisory Group* with rotating 3-year terms that has involved 25 of the key biological control workers in the U.S.

since 1990; and provided technical advice and coordination for many biological control and IPM programs; and other activities. Coordination from NBCI has been sought by other Federal agencies and international groups, and recently NBCI has been charged with preparing a strategic plan to coordinate APHIS' programs.

OTA (1995) emphasized that NBCI was "a response to a perceived need to increase the prominence of and coordinate biological control within APHIS, between APHIS and the other USDA agencies, and between APHIS and organizations outside the government." In 1992 APHIS elevated NBCI to the Office of the Administrator, the highest administrative position that biological control has ever reached in any country. NBCI's mission has remained to "promote, facilitate and provide leadership for biological control." However, by establishing NBCI, APHIS created "considerable institutional conflicts within USDA" OTA (1995). OTA found reviews of NBCI's impacts to be "mixed," and stated:

> NBCI is effective at outreach beyond the beltway and is highly respected by scientists in state government, universities and other institutions. However, the institute's highly regarded staff and expertise are not always paid attention to within APHIS. For example, efforts by [NBCI] to involve stakeholders in the development of biological control regulations were not incorporated into the broader proposed rule that APHIS issued for nonindigenous species. Moreover, the institute has not been incorporated into the working group representing various agencies in the USDA IPM Initiative. This oversight is unfortunate because it perpetuates the historical separation of biological control and IPM pest control disciplines.

An Interagency Biological Control Coordinating Committee (*IBC³*) was established in 1990 by USDA. The purpose of *IBC³* was to increase interagency cooperation in developing and implementing biological control, recommending policy, developing a federal and state framework to achieve mutual goals in biological control, providing leadership in biological control within USDA, proposing uniform departmental policy in such matters, reviewing and coordinating biological control programs nationwide, developing joint funding initiatives and protocols, setting priorities for target pest selection, coordinating foreign exploration and collection, and reporting these activities to the USDA Agency Administrators.

In 1994, *IBC³* designed the *National Biological Control Program* (*NBCP*) that linked the existing infrastructure of the five USDA agencies and partner State institutions to mobilize limited resources to accelerate the development and implementation of biological control technologies. Additional funding of $20 million per year was requested to initiate this effort. The goal was to "improve the capacity for farmers, foresters, and homeowners to solve pest problems in ways that enhance the sustainability and competitiveness of American agriculture and forestry." OTA (1995) noted that *IBC³*, unlike NBCI, "never had any direct funding."

There are several options for increasing biological control coordination. The visions of biological control coordination, cooperation and facilitation have yet to reach full inter-agency implementation. The ESCOP Biological Control Working Group has established linkages, raised visibility of biological control, provided budget inputs and planned workshops. The roles, responsibilities and organizational placement of NBCI are being re-examined. Federal agencies received minimal funding from the *NBCP*. *IBC³* no longer meets due to lack of funding and agency commitment to this effort.

Thus, although considerable groundwork has been laid over a decade for biological control coordination in the United States; the needs, issues and challenges have been discussed widely at many meetings and in the literature; and there is generally strong support for the effort from the States, the private sector, scientific and environmental communities, appropriate political support, funding and organizational placement for national biological control coordination and cooperation is yet to be realized.

OTA pointed out that both NBCI and *IBC³* were designed to increase coordination of biological control, but "neither fulfills it perfectly-the institute because it is located within an operations agency and lacks funds and authority; the committee because it has largely ceased to function." OTA (1995) suggested five options for Congress to improve biological control coordination:

Option. *Congress could select either the NBCI, IBC[3], or a new unit (perhaps incorporating both organizations) as the institutional site for national coordination of biological control. Selection of NBCI would requite its elevation to a higher level within USDA, because its current position makes it accountable to the priorities of one agency (APHIS). Selection of IBC[3] would require revitalizing the now inactive committee. Specific coordinating responsibilities and appropriations would need to be assigned to whatever organization is selected.*

Option. *Alternatively, Congress could create a centralized agency responsible for all federal activities related to biological control. This option seems only remotely feasible today, because biological control programs are dispersed throughout at least eight agencies, in many cases related directly to their pest control responsibilities.*

Option. *Congress could strengthen and stabilize the new biological control program within the National Research Initiative, and also make provisions so that CSREES could fund some projects of long duration rather than the five-year grants the agency says are mandated by current law. Note that the National Research Initiative program on biological control has not received strong support from the current Congress and might be eliminated in fiscal year 1996.*

Option. *Should Congress choose to fund the USDA IPM Initiative, it could stipulate that the designated organization for coordinating biological control be a participant. Even without designating a coordinating organization, Congress could require that the NBCI be involved in the Initiative to help integrate biological control and IPM programs (see also chapter 3 for discussion of problems related to a lack of coordination between biological control and IPM).*

Option. *Congress could direct USDA to maintain a consistent and comprehensive database on biological control introductions. Several different institutional sites might be possible. Previous attempts at developing such a database in the ARS suffered from erratic support. The history of poor documentation and recordkeeping by the APHIS regulatory unit that permits biological control introductions (see chapter 4) makes it seem an equally problematic site at this time; although whatever data are developed by APHIS via the permitting process should be incorporated into the biological control database. Other possibilities include the National Agricultural Library or the National Germplasm Program. Development of a biological control database could occur even if no coordinating structure for biological control is designated.*

OTA (1995) noted that a major problem was that "National goal-setting mechanisms lack funding authority and therefore have little direct influence over the research agenda." This results in a scattered effort, with the consequence "that some of the research components necessary to enable the practical uses of [biologically based technologies] BBTs are not addressed." And "it is clear that not enough attention has been given to the essential research to take BBTs out of the hands of scientists and into those of farmers and other users." OTA also highlighted that "Despite clear-cut institutional responsibilities, ARS has not always delivered solutions that are field-ready to APHIS; as a result, APHIS has developed its own research capabilities ... ."

Facilitation of development of commercial biological control is hindered by lack of access to information about BBTs that are ready for technology transfer, according to OTA; four options were offered (note that the OTA references to ARS in the following options refer equally well to all federally funded research programs across agencies):

Option. *Congress could instruct ARS to make all discoveries related to development and commercialization of certain BBTs public property (i.e., not allow ARS scientists to patent their discoveries). Areas of particular significance to industry are the development of artificial diets for natural enemies and of new pheromone formulations. The ARS scientists involved might need additional incentives to continue research in these areas. This approach would not be desirable for microbial pesticides, however, because larger companies view the licensing arrangement as vital protection of intellectual property.*

Option. *Congress could instruct ARS to encourage the development of CRADAs even with companies that cannot provide funding for the research. The agency would need to provide internal incentives and support for scientists that engaged in such projects.*

Option. *Through its oversight functions, Congress could encourage ARS to communicate discoveries of relevant technologies and opportunities for collaborative ventures more effectively to all members of the BBT industry. Better communication, perhaps via joint conferences or meetings, might have the additional benefit of better informing ARS scientists of the potential end uses of their discoveries (see chapter 5).*

Option. *Congress created [IR-4] to support research that develops data for registration of minor use pesticides. Since the scope of IR-4 was expanded in 1982 to cover "biorational" pesticides, only a small part of the program's funding has gone towards work on BBTs (see chapter 5). Congress could specify that a larger portion of the IR-4 program funds should be designated to help meet the data requirements for registration of microbial pesticides and pheromone-based products.*

REGULATION OF BIOLOGICAL CONTROL

The need for reasonable regulations and procedures to provide oversight for importation, interstate movement and release to the environment of biological control agents has been identified for many years by several independent groups in the United States (Charudattan and Browning 1992, Cook and Granados 1991, Coulson *et al.* 1991, Glenister 1991, Granados *et al.* 1991, Marrone and Sandmeier 1991, Mullin and Fugere 1996, National Research Council 1996, OTA 1995, Shantharam and Foudlin 1991, Tolin 1991). Regulations should be strategic in nature; science-based, consistent, easily understood and transparent; effective, responsive, flexible and dynamic; and should meet domestic and international needs (Medley and McCammon 1995). A conflict-resolution procedure is needed, and leadership is essential to involve all partners early in discussions of programs and agents to ensure that resources are not committed to programs that are unlikely to be implemented (Delfosse 1996). Agency responsibilities need to be established, and fixed times for regulatory decisions should be established (OTA 1995). A regulatory roadmap is needed; "if you don't know where you are going, any road will take you there" (Below 1987). "A sound, but scientifically sensible, regulatory system is essential for making biological control work" (Tolin 1991).

There is a strong view that biological control agents should be regulated differently from chemical pesticides; in particular, regulations and procedures should be product-oriented, rather than process-oriented, and there should be a shift from a chemical paradigm back to a biological paradigm (Chabot 1991, Cook and Granados 1991, Glenister 1991). Separate registration packages for each strain or strain combination will not work for future needs. The overlapping responsibilities of APHIS (under the *Federal Plant Pest Act, FPPA*) and the EPA (under the *Federal Insecticide, Fungicide and Rodenticide Act; FIFRA*) "pose unnecessary barriers to registration of biological-control [sic] organisms."

Regulations that facilitate interstate movement of biological control agents are also needed. The private sector considers federal regulation of the natural enemy-producing industry "to be among their greatest challenges and wish to participate in the development of any new rules" (OTA 1995). Clear, consistent and concise regulations for field testing and registration of commercial biological control agents are needed (Granados *et al.* 1991, Marrone and Sandmeier 1991). State legislation should be consistent with federal regulation (Marrone and Sandmeier 1991).

Many groups have addressed risk in biological control (Cate and Maddox 1994, Charudattan and Browning 1992, Coulson and Soper 1989, Granados *et al.* 1991, Howarth 1991, McDonald 1993, Osburn and Nicholas 1992, OTA 1995, Shantharam and Foudlin 1991, Wapshere *et al.* 1989). Biological control is not risk-free, and it is not a panacea, but regulation of biological control agents should be in proportion to the risk they present in possibly causing *population-level effects* on non-target species. Most reviewers concluded that the main risk from biological control is the *potential* of non-target damage, but that there are few recent examples where this has been documented. Clouding the issue is the paucity of studies that specifically *look* for non-target effects.

OTA (1995) pointed out that BBTs have low risks compared to conventional pesticides, but do have risks that should be examined by long-term, post-release monitoring, and that there are also important economic and environmental risks from *failure* to control pests. Thus, not providing cost-effective BBTs due to over-regulation must be avoided.

Charudattan and Browning (1992) and Dunn and Martin (1993) stressed the importance and need to promote the dialogue regarding critical issues affecting research, development and implementation of biological control. Increased and continual dialogue between regulators, biological control researchers, and environmental groups is required throughout the entire regulatory process. Scientists have technical expertise to contribute to the regulatory process and are concerned about safety issues; they should be directly involved in regulatory actions.

Risk-benefit analyses should be used when appropriate in pre-decisional analyses (Dunn and Martin 1993). Unfortunately, it appears the more we know about an organism under regulatory scrutiny, the higher the presumed risk (Charudattan and Browning 1992). The risks inherent in biological control are not properly taken into account by current regulations (Cate and Maddox 1994), and risks from biological control and biotechnology are often inappropriately linked (Shantharam and Foudlin 1991). This linkage tends to overestimate the risks due to introduction of unmodified agents, and can raise unreasonable fears of the potential for biological control agents to produce *population-level effects* on non-target species. This can lead to over-regulation and under-use of biological control.

Risk assessments should include components of risks from continuing the use of alternatives (e.g., chemical pesticides), which are well known and documented. The presumption of maximum risk may represent a legal safety net, but it is not consistent with more than 100 years of biological control history in the United States (Charudattan and Browning 1992).

Releases of exotic arthropod parasites and predators of arthropod pests seldom represent a significant threat to endangered species or other non-target organisms because: (1) emphasis is generally placed on rather host-specific natural enemies to begin with; (2) generalist natural enemies usually have poor searching abilities and tend to feed preferentially on whatever is abundant; and (3) density-dependent processes nearly always preclude significant attack rates at low host/prey densities (such as those likely to occur in the case of rare or endangered species). Probably the most important cause of animal extinction is habitat destruction. It seems more likely that extinction or endangerment of a non-target species would occur because of interspecific competition with an exotic invader (consider salt cedar) or pesticide treatments used to suppress it, than by a natural enemy that needs it as host or prey to survive.

Legner (1986) and Coulson and Soper (1989) reviewed the risks associated with biological control, and concluded: (1) arthropod parasites and predators of insects and other arthropods present the lowest environmental risk of all categories of biological control agents; and (2) as a consequence of biological control programs, over 600 insect parasites and predators have been imported into the continental United States, of which more than 200 have become established. Of these, only two species (both hymenopterous secondary parasites introduced in the early 1900s when biological control was in its infancy) are believed to have had detrimental effects, and these are of little importance. Current protocols would not allow for the introduction of such species.

Regulation of biological control require different types of information and understanding than that for chemical pesticides. For example, biological control agents employ a series of steps to locate and affect their hosts. If the sequence is disrupted, the agent typically does not accept the host for sustenance or reproduction. Habitat is another factor that affects the interaction of agents and potential host targets. If a potential non-target host is located in areas (habitats) where natural enemies do not exist (spatial or temporal separation) no attack can occur. This is important as laboratory (physiological) host range studies do not typically take such factors into consideration. Regulations must allow biological control practitioners to evaluate host-specificity using both physiological and ecological characters.

Host-specificity is seldom an all-or-nothing phenomenon. Thus attack of a host without reproduction of the natural enemy will cause little harm. The ultimate question is what will be the ecological host range leading to a population level impact on a non-target species be in the field environment? To that end, the Audubon Society promotes increased monitoring of biological control agents following field release. They state (Cate and Maddox 1994) "There is virtually no evidence of harmful outcomes from scientifically conducted biological control projects, but there is also little information available, and the consensus is that monitoring should be part of most projects." In addition, they suggest monitoring some of the 1,000 species of non-indigenous organisms established in the United States since European colonization to see how host ranges may have evolved.

Evaluation of risk associated with biological control is more complicated than using the standard ***risk = (hazard x exposure)*** formula, particularly for biological agents that can establish and spread. Generalist agents that affect many species, however, clearly pose more risk than host-specific agents. McDonald (1993) cited the role of familiarity and knowledge in shaping perceptions of potential risks and benefits. Risk-based decisions, however, are necessary and some risk is acceptable. Attempts to estimate risk and assess benefits should be scientifically-based and should use existing data bases even independent of actual host range testing. Known phylogenetic, ecological, and biological relationships are often quite indicative of the host range of related groups and can be used to help estimate risk of a potential non-indigenous biological control agent.

Proper use of biological control agents is a bona fide concern. However, Audubon states (Cate and Maddox 1994) "There are concerns that existing regulatory statutes for control of plant pests (particularly agricultural crop pests) are inappropriate for effective oversight of agents used to control non-plant pests." Regulatory oversight needs to be consistent with scientific advances, guidelines need to be developed that reflect the scientific nature and biological fundamentals of host-specificity, all biological control agents should be systematically regulated (not some by EPA, some by APHIS, and others not at all). The process should exclude unsafe products and practices while not stifling others unnecessarily. USDA-APHIS currently promotes, conducts, and regulates biological control, which is an obvious conflict-of-interest that the Audubon Society would like corrected (Cate and Maddox 1994). They feel that EPA and USDA should initiate a comprehensive review of biological control regulations with respect to statutory authority. In either case, they believe that neither Agency will have adequate resources to hire the necessary specialists to implement a science-based regulatory process, and thus recommend a peer reviewed process using knowledgeable specialists from a diversity of State and Federal institutions.

The cost of the regulatory process should also be restricted as high costs push biological control technologies into the commercial realm and towards agents with broad host ranges and large commercial markets. Narrow host ranges and many diverse markets may actually be the areas within which biological control agents may be most useful and effective. Whatever regulatory path is selected, it should result in fewer rejections of safe organisms and more disapprovals of deleterious agents.

Finally, a process by which regulators are accessible to customers is needed. Agencies need to define responsibilities for organism groups, define criteria and characteristics for risks and benefits, establish fixed times for regulatory decisions, facilitate access to procedures, and establish a voluntary mechanism to share results of safety testing (Granados *et al.* 1991). Osburn and Nicholas (1992) stated (referring to animal biotechnology) that the public should be represented, and access and participation in debate should be improved. Further, they suggested the following mechanisms for improving access: "1. Legislation regarding public participation in regulations decisions across the board; 2. Publication beyond the *Federal Register*; 3. Improved representation in decision-making processes; 4. Open forums; 5. Research on opening up scientific decision-making processes; and 6. Rebuilding public trust and regulatory transparency." These points apply equally to regulation of biological control.

In summary, all groups expressing a view (researchers, the private sector, environmentalists, regulators, etc.) agree that proper oversight of biological control is essential. These groups even agree in principle on the essential elements of a regulatory system for biological control: science-based, strategic, open, significant public involvement, transparency, flexible, dynamic, and responsive to national and international needs. However, as Australia discovered a decade ago, the challenge is in negotiating the details of the process (Cullen and Delfosse 1985), but the outcome of having reasonable regulations and procedures that enable and facilitate use of biological control agents is well worth the effort (Delfosse 1992 *a,b*). Such negotiations continue in the United States, and progress is being made (Delfosse 1996).

OTA (1995) devoted a large amount of time discussing APHIS' role in regulation of biological control. They concluded that APHIS' past regulation of biological control was "inconsistent and incomplete," or "uneven;" the review of applications for entomophagous agents "has been particularly lax;" and the current biological control regulatory system in APHIS "has a number of important flaws" such as lacking "balance, transparency, and efficiency." OTA stated that APHIS needs to "devise a regulatory framework that ensures environmental safety while encouraging the development and use of BBTs." A well-designed system would "screen out the greater risks from BBTs while facilitating adoption of the vast majority of these technologies." A tiered testing system could streamline data requirements, and requires developing a risk hierarchy. This is difficult, but the extremes could be determined: high risk would include use of most terrestrial vertebrates and generalist predators and plant-attackers; low risk would include host- or habitat-specific parasites, diseases and predators. Risk-benefit analyses should be used to address this issue, and host-specificity testing should be based on science (such as the centrifugal phylogenetic testing procedure, or the relatedness testing procedure). In particular, regulators need to be aware of the difference between the ecological and the physiological host range of biological control agents, and should regulate biological control agents in proportion to the risk they present to causing population-level effects on non-target species. The APHIS TAG has done a good job to the extent of their charge, but this group needs to be updated and expanded.

OTA (1995) stated that APHIS was aware of the need to update its biological control regulations and procedures when it established NBCI. In January 1992, APHIS Administrator Melland formally charged NBCI with reviewing how APHIS regulates biological control. Terms of reference (Mendelsohn *et al.* 1993) were to:

Examine APHIS' biological control regulatory authority, policies and philosophies;

1. Clarify biological control responsibilities of APHIS units;
2. Document the current biological control regulatory system used by the Biological Assessment and Taxonomic Support (BATS) group in the Plant Protection and Quarantine unit;
3. Consult widely with APHIS' customers about the current regulatory system (including implementing guidelines), and suggest a new system (now known as the "Strawman") based on this customer input and using the best available science; and
4. Propose a mechanism to facilitate APHIS' continued involvement with customers to ensure that the regulations and implementing procedures and guidelines are changed as science and societal needs change.

Referring to the *APHIS Biological Control Philosophy*, Administrator Melland stated, "In support of this philosophy, APHIS will develop regulations that facilitate the release of safe biological control agents, while maintaining adequate protection for American agriculture and the environment. The regulations will give clear and appropriate guidance to permit applicants, including specific types of data needed for review and environmental analysis and specific time limits for Agency review. They will be updated as the science progresses."

OTA (1995) suggested three options for Congress with regard to biological control regulation:

Option. *Congress could, through its oversight functions, instruct APHIS to streamline its permitting process and to design a more balanced regulatory system for biological control. Components of these changes might include the following:*

Developing a more even-handed regulation for biological control with broader input from all stakeholders (researchers, natural enemies companies, farmers and other users, wildland managers, state agencies, conservation biologists, etc.).
•Formulating an explicit policy concerning the regulation of nematodes. Although formally within APHIS's jurisdiction, nematode products rarely go through APHIS review. The agency needs to carefully consider whether this leaves any significant risk issues unaddressed. Potential impacts on companies producing nematode-based products must weigh into the development of a more formal policy.
•Instituting a technical advisory group (TAG) to evaluate proposed introductions of unprecedented biological control agents targeted at insect pests (entomophagous agents), and improving the science underlying the regulatory decisionmaking for these agents by developing appropriate host-specificity testing protocols. The different standards of review for biological control agents targeting plant and insect pests are based on historical concerns about agricultural crop protection and ignore our scientific understanding of the importance of native biodiversity and the value to agriculture of conserving native natural enemies. Enhanced review of entomophagous species may provoke objection from entomologists who are not used to this level of scrutiny.
•Developing mechanisms through which to include input from a cross section of nongovernmental organizations, including those concerned with environmental risk and conservation issues, in APHIS's decisions about biological control agents. The Federal Advisory Committee Act allows membership on advisory committee by nonfederal agencies so long as the committees adhere to certain procedural requirements. If APHIS chooses not to expand TAG membership, other channels may be available for nonfederal input.
•Requiring post-release monitoring of the non-target impacts from the highest risk introductions as a condition of the permitting process. The challenge is to develop a mechanism for funding such research, so as not to place undue burdens on a low-profit industry that produces a valuable set of low-risk pest control tools.
•Maintaining clearer records of permitted releases, the basis for these decisions, and any subsequent impacts, to improve future decisionmaking. According to APHIS, some of these changes are already in progress; these efforts deserve support and encouragement.
•Convening a panel of scientific experts to evaluate APHIS's past regulatory precedents as a basis for future permitting decisions. This review could help APHIS identify some of the high-risk releases and facilitate agency streamlining of other permitting activities.

Option. *An opportunity to address some of the flaws in APHIS's regulatory system may present itself in the agency's efforts to consolidate all of its plant protection statutes into a single package.*

Option. *Congress could pass a new law embracing uses of natural enemies and microbial pesticides that would give more similar coverage to these two categories, but OTA does not find sufficient justification for this option. EPA, FDA, and APHIS all have expertise in different areas, which corresponds at least roughly with their current regulatory responsibilities. It is important, for example, that EPA continue toxicity studies on certain microbial products; the other agencies are unequipped to take over that function. Certainly regulatory gaps exist, but these can be addressed within the current institut9ional framework (see previous options).*

Quality and purity of commercial biological control agents was raised as a concern by OTA (1995), who made the following recommendation:

Option. *The quality and purity of natural enemies products is thought to vary. Some scientists have suggested that APHIS should regulate this area to improve the consistency of product performance. However, APHIS currently lacks jurisdiction to issue such standards. Industry organizations such as the Association of Natural Bio-Control Producers and the International Organization for Biological Control, and the industry is moving toward voluntary standards. Congress could instruct APHIS to work with the natural enemies industry to develop such standards and to future assist in these efforts by providing access to the scientific resources of USDA.*

Markets for BBTs could be increased by the following option (OTA 1995):

Option. *Congress could provide market opportunities for the natural enemies industry by contracting out the production of biological control agents used in federal pest control programs conducted by APHIS and the land management agencies. These agents are currently produced by federal laboratories.*

The outcome of the process of working with customers on needs in biological control regulation, involving attending over 300 meetings and presenting over 200 invited talks on biological control regulations over a four-year period, was the NBCI-facilitated "Strawman," which discussed the ten area of most concern to APHIS' biological control customers (Delfosse 1996).

The "Strawman" is apparently the first scientific document placed on the Internet for peer review. Comments virtually unanimously supported the new procedures in the "Strawman" (a few reviewers liked the processes suggested, but thought they could be more strict in some areas). A coalition of eight Western States considered the "Strawman" at a biological control of weeds regulatory summit in April 1996, and concluded (Mullin and Fugere 1996) "We support [the "Strawman"] with minor modifications, as a guiding document for biological control of weeds regulation in the United States." The Working Group on Biological Control of Weeds of the Nearctic Regional Section of the International Organization for Biological Control (IOBC) also supported the "Strawman" at a meeting in Billings, Montana, on 26 July 1996.

Customers emphasize that biological control is regulated in the United States under a series of laws created for other purposes and that these laws don't meet the needs of the public or regulatory agencies. A new law, similar to the *Australian Biological Control Act 1984*, has been suggested, that would enable and protect biological control.

Miller and Aplet (1993) correctly point out that there is currently no federal statute that requires that biological control agents be reviewed before release, and that "existing federal regulations of biological controls is obscure and fragmented." They state that the review process considers economically valuable species but ignores "harm to non-economic species and to ecosystem integrity;" focuses on organisms rather than ecosystems, which allows repeated application in new habitats; largely ignores movement of indigenous natural enemies; and lacks requirements for post-release evaluation.

Also, after reviewing the three types of statutes now in place (quarantine acts to exclude unwanted organisms, registration acts for approving desirable organisms, and protective acts for preserving endangered species), the authors conclude that there is an inadequate regulatory framework for biological control in the United States. They then reviewed the Australian *Biological Control Act*, which they feel offers a "partial model" for the USA. They state positive aspects of the Australian *Act* as providing a procedural framework for discussion; limiting liability after agent approval; and approval for release in Australia only occurring after a decision that the agent "would not cause any significant harm to any person or to the environment."

Miller and Aplet (1993) propose a new federal statute, the *Biological Control Act*, which would implement a public review process for all biological control applications, emphasizing an ecosystem orientation, and acknowledging that biological control agents do not recognize borders between States and countries. The new law would also create a *Division of Biological Control* within USDA or EPA to oversee the process, provide coordination, maintain a biological control database and library, and generally serve as a "clearinghouse" for biological control information (this point is relevant to review criterion [1]). States should also consider similar legislation, although it is unclear how this would operate.

At a recent TAG meeting, it was discussed that a new biological control law would be beneficial as it could provide balance or possibly even precedence over T&E species issues if benefit:risk analyses suggest that a challenged project should proceed. Currently, USDA programs can be totally blocked by implementation of the *Threatened and Endangered Species Act*, regardless of potential positive benefits.

APHIS published a *Proposed Rule* entitled *Introduction of Nonindigenous Organisms* on 26 January 1995 (*CFR* 5288-5307, Docket No. 93-026-1). On 16 June 1995 APHIS withdrew the *Proposed Rule* (*CFR* 31647, Docket No. 93-026-4) following receipt of 252 public comments, all of which were opposed to the *Proposed Rule* as written. OTA was critical of the lack of any provisions for post-release monitoring in the proposed rule, stating that this "suggests a possible reluctance by APHIS to confront the impacts of its permitting activities," and was "clear evidence that APHIS has not yet succeeded in assigning priorities and addressing ... risks."

APHIS published an *Advance Notice of Proposed Rulemaking* (*ANPR*; *CFR* 61:189, 50767-70), which was distributed to attendees prior to the USDA Workshop. The *ANPR* addresses inadequacies in plant pest regulations with regard to providing a means of screening organisms prior to introduction to determine the potential plant pest risks they may present, and covers many aspects of regulation suggested in the "Strawman" and by OTA (1995). Comments to the *ANPR* were mixed, and APHIS is currently analyzing them.

ACCOUNTABILITY OF USDA BIOLOGICAL CONTROL

There have been many suggestions by authors cited above of increased accountability by USDA agencies in biological control regulation and implementation. Mullin and Fugere (1996) also suggested that the membership of TAG should be expanded, and TAG should review all proposed projects. In the *APHIS Biological Control Philosophy*, Administrator Melland stated, "APHIS believes that public input on procedures to approve the release of biological control agents is a desirable and necessary step, and will strive to gather input from scientists, industry, and the public." Mullin and Fugere (1996) suggested creating a clearinghouse for new projects so they can be announced before explorations and to cover unprecedented releases. This approach would enable interested parties to comment and could also alert possible funding cooperators. It was suggested that ARS *Documentation Center* compile information and pass to NBCI for dissemination. These authors also suggested that appropriate States should be notified by APHIS of releases of precedented species and proposed releases be publicized for comment, that a programmatic Environmental Impact Statement should be prepared by all USDA agencies, to which *EAs* could be tiered, and that *EAs* should include benefits and risks.

NRC (1996) recommended that coordinated multidisciplinary and interdisciplinary research was needed to develop and implement *EBPM*, with public oversight to help evaluate risks associated with biological control organisms.

OTA (1995) suggested that increased financial accountability was needed, and proposed the following options (note that the references to ARS in the following options refer equally well to all federally funded research programs across Agencies):

***Option.** Congress could increase the accountability of ARS to the operations and land management agencies by designating funds within these agencies for pass-through to ARS for meeting their operational needs. Because new funding is unlikely in the current fiscal climate, these funds would have to be derived from the current budgets of these agencies.*

***Option.** Congress could direct the ARS to allocate a proportion of its BBT funds to a targeted competitive grants program within the agency. These funds would be available for collaborative research projects that provide the follow through into field applications. Evaluation of the needs of farmers or other users at the inception of the research and of ways n which the BBT would meet this need would be essential to ensure real-world applicability. The size of this effort would need to be balanced against its potential effects on the agency's capability to conduct longer-term studies.*

OTA emphasized that proper "recordkeeping and monitoring systems" are needed to advance knowledge, improve development of new BBTs and allow development of a "tighter match between risks and regulatory testing requirements." OTA specifically highlighted the relative lack of biological weed control and post-release monitoring, and suggested two options:

Option. *Congress could direct the ARS and CSREES to allocate a greater proportion of their research funding toward control of weeds.*

Option. *Congress could direct all federal agencies that conduct or fund biological control programs to initiate or fund monitoring projects, especially for higher risk categories (see chapter 4 for discussion of risk categories). One way this might be accomplished is to give higher priority to research projects that include a monitoring component.*

Lack of incorporation of BBTs into IPM programs and disappearing systematic expertise were highlighted by OTA (1995) as obstacles to implementation of biological control. They suggested three options in this area:

Option. *Congress could support education in IMP through the Land Grant University system. Various approaches might be possible, for example, funding graduate fellowships in IPM.*

Option. *Congress could direct the ARS to increase resources and staff slots allocated to the Biosystematics Laboratory for work related to biological control.*

Option. *Postdoctoral fellowships from APHIS's NBCI have been used successfully to support U.S. taxonomic work. Congress could direct APHIS to allocate a larger share of its biological control funding for this purpose.*

Cook and Granados (1991) suggested that accountability could be increased through long-term, interdisciplinary research on basic and applied problems; transfer of technology from the laboratory to the field must involve greater enhanced educational system and stronger support of extension system; and overcoming the economics of producing a product for control of a single disease or pest which discourages companies from investing the capital necessary to produce, formulate, register, and market such a product.

The areas of accountability and feedback to USDA agencies have not been adequately explored in previous reports and thus warrant significant attention by Workshop attendees. Whereas the other areas of consideration need selection of appropriate options for implementation and fine tuning, new options need to be brainstormed by the group to best determine how to assess USDA effectiveness on delivering biological control technologies to States, producers and other customers. Agency Administrators and their staffs then need to work together and with the Secretary's Office to determine how best to allocate resources with each of the Agencies to accomplish the overall biological control goals of the Department and to more effectively link biological control activities with existing IPM operations.

A CONSISTENT USDA POLICY ON BIOLOGICAL CONTROL

OTA (1995) identified at least 11 Federal agencies involved in biological control, with an annual expenditure of over $210 million, and highlighted their overlapping activities in regulations, research, funding, implementation, education and technology transfer. In addition, the States spend abut $90 million each year on BBTs. An estimate of public sector funding for biological control in the United States is given in Table 2; 1988-96 average annual Federal expenditure was $146.1 million; State expenditure in 1994 was $9.2 million.

Five priority funding areas have been identified: research; implementation; evaluation; meetings; and particularly, systematics. Granados *et al.* (1991) suggested that biological control should be funded as an activity for the "public good" by a tax on pesticides. Inadequate core funding, staff positions, and funding for mass-rearing, distribution and evaluation also limit biological control.

OTA (1995) concluded that strategies not considered biological control by traditionally trained biological control workers (such as the sterile insect technique, plant breeding, use of transgenic natural enemies, cultural control, etc.) are increasingly lumped with biological control and called "biologically-based pest management" or "ecologically-based pest management," which may divert funds that formerly were applied to traditionally defined biological control. Approximately 50% of the resources reported by ARS currently fund traditional biological control research, and the other 50% fund other BBTs.

Thus, public sector funding for biological control is significant, but "appears to be largely uncoordinated and to lack adequate prioritization" (OTA 1995). Private sector investment in augmentative biological control has decreased, due in part to "the regulatory climate" (Tolin 1991). It is clear that additional focus of available funding for biological control is needed, and that partnerships (Federal, State, local, private sector and international) need to be formed to make the best use of resources.

NBCI is addressing the need for providing increased and focused funds for biological control in several ways. Following consultation with customers to determine their needs, a peer-reviewed, small grants program was established in 1990, in collaboration with other Federal and State agencies. The program was coordinated in particular with other funding bodies, to ensure that it was synergistic with their programs, and would leverage resources and begin to fill some of the gaps identified by customers. A summary of the NBCI small grants program is presented in Table 3.

Several gaps in implementing biological control were identified by customers, including economic constraints, particularly very limited core funding, staff positions, and funding for mass-rearing, distribution and evaluation. Concern was expressed over the lack of understanding of basic mechanisms of biological control, and of the lack of quality control guidelines for the commercial sector. Many of the NBCI grants (Table 2) were designed to begin to meet some the these needs, raise the visibility of biological control, and to leverage resources in other groups. The *NBCI Postdoctoral Fellowships in Systematics* is particularly important in biological control, understanding biological diversity, ecology, and training students, etc.

OTA found that NSF and NIH also provide a small amount of resources for BBTs, and the CSREES-ARS IR-4 funds a small amount of research on biorationals. EPA contributes about $2 million annually to CSREES for training of pesticide applicators.

Table 2. Funding (in millions of US dollars) for biological control in the United States (updated from OTA 1995, Table 5-1 and Figure 5-2).

Group	1988	1989	1990	1991	1992	1993	1994	1995	1996	TOTAL	Avg.
FEDERAL[1]											
USDA											
ARS	82	80	82	87	101	98	104	104	104	842	93.56
CSREES	30	37	40	36	37	39	41	43	44	347	38.55
APHIS	3	4	6	7	8	10	12	10	10	70	7.78
FS	3	5	4	5	5	5	5	5	-	37	4.63
EPA	-	-	-	-	-	1	1	1	0	3	0.75
ACoE	0.9	0.8	1.3	1.2	1.4	1.5	1.4	1.4	0	9.9	1.10
DoI	-	-	-	1	1	1	1	1	1	6	1.00
Subtotal	**119**	**126.8**	**133**	**137**	**153**	**156**	**165.4**	**165.4**	**159**	**1,314.90**	**146.10**
STATES[2]	-	-	-	-	-	-	9.2	9.2	9.2	27.60	9.20
TOTAL	**119**	**126.8**	**133**	**137**	**153**	**156**	**174.6**	**174.6**	**168.2**	**1,342.43**	**156.54**

Adjusted[3]	**110**	**112**	**112**	**113**	**124**	**125**	**137.04**	**136.17**	**131.18**	**1,047.10**	**122.10**

[1]USDA= U.S. Department of Agriculture; ARS= Agricultural Research Service; APHIS= Animal and Plant Health Inspection Service; CSREES= Cooperatives States Research, Education and Extension Service; FS= Forest Service; EPA= Environmental Protection Agency; ACoE= U.S. Army Corps of Engineers; DoI= Department of Interior.

[2]28 States have biological control programs :AZ, CA, CO, CT, FL, HI, ID, IN, KS, MD, MI, MN, MO, MT, NC, ND, NE, NJ, NV, NY, OR, RI, SD, TX, UT, VA, WA, and WI. OTA state figures were for 1994 only; we assumed for this analysis that state funding of biological control was stable for 1994-96.

[3]Adjusted by OTA on the producer price index (PPI). In base year 1992 the PPI was 1.00; in 1995-96, it was estimated to be 0.78.

Table 3. Summary of the NBCI small grants program, 1991-6 (amounts in USD).

Type of Grant	Number	Amount	Avg.
Development of databases	8	$ 184,352	$ 23,044
Education and information	10	193,894	19,389
Implementation projects	47	679,829	14,464
Focus groups and workshops	4	25,700	6,425
Mentoring and staff development	7	86,770	12,396
Meetings	26	135,419	5,208
NBCI Postdoctoral Fellowships in Systematics (2-year grants)	5	373,952	74,790
Publications	22	165,229	7,510
TOTAL	129	$ 1,845,145	$ 14,403

OTA suggested the following options for Congress:

Option. *Proposed research funding for fiscal year 1996 provided through CSREES under the USDA IPM Initiative has taken this approach to ensure "buy in" by researchers, farmers, and others involved in all phases of the development and implementation of IPM programs (see box 5-1). Congress could fund this research initiative. Its potential influence on BBT research is unclear, however, because the role of BBTs in the IPM Initiative has not been explicitly stated. Hence, funding of the research component of the IPM Initiative would affect BBTs only if Congress instructed USDA to identify the role of BBTs or to allocate a proportion of the program for IPM research that incorporates biologically based approaches (i.e., bio-intensive IPM).*

Option. *Alternatively, Congress could allocate to the operations and land management agencies "redeemable credits" toward research that targets their needs by the USDA research agencies. These credits would obligate the research agencies to conduct a specified amount of research to meet the needs of the operations and land management agencies, but no exchange of funds would occur (i.e., funds would remain in the research agencies.) The research agencies would have to be informed, during their appropriations processes, of their obligations, and some tracking mechanism might be necessary to assure accountability for conducting the work and producing results according to the agreed priorities.*

Option. *Congress could improve the match between ongoing research and the needs of farmers by requiring research agencies to seek input from farmers and other users into funding decisions. For example, representatives of user groups, commodity groups, etc., could sit on funding panels or make recommendations to the Deputy Administrator of the National Program Staff of the ARS.*

Option. *Congress could create a competitive grants program specifically targeted toward BBTs that are well researched but not yet in practical use. The goal would be to invest in bringing research discoveries that currently lie unused into the field, particularly those of high technical merit but likely to yield profits too low to be of commercial interest. Such funds might be administered through CSREES, perhaps as part of its extension functions. Although new money would be required to set up the program, it would be very cost-effective, because only technologies on the verge of application would be funded. The same type of targeted funding mechanism currently underlies the Cooperative Research and Development Agreements under which private-sector companies invest in government research (see also chapter 6 for further options related to CRADAs). However, those agreements primarily address research that is amenable to commercial development.*

Despite the long list of major articles published over the past decade (including the OTA and NRC reports; see references), there is a strong perception of an "overall lack of advocacy to get biological control on the national agenda" (Granados *et al.* 1991) and of a major need to ensure that biological control becomes the strategy of first consideration in IPM. Obviously, pesticides can be valuable IPM tools when used properly. Too often, however, biological control is only considered after a pest becomes very widespread and other management strategies have failed or produced an inadequate level of control. NRC (1996) suggests biological control as the primary strategy to be used to manage pests with more intensive and environmentally costly alternatives applied only when BBTs do not adequately solve the problem. Other have made recommendations to establish national centers to supply information about biological control and demonstrate the efficacy of BBTs (e.g., Granados *et al.* 1991) and to establish a national program to promote and fund biological control as a "public good."

One of the most serious concerns raised was that biological control has no national advocate and is sometimes portrayed as out-of-date, while other strategies (particularly chemical control) have extremely vocal advocates and lobbyists, and is presented as "cutting-edge."

The "lack of leadership" of biological control and the lack of visibility of biological control are also cited as problems (Chabot 1991, Granados *et al.* 1991). Leadership is needed, for example, to provide philosophical support for developing appropriate biological control regulations. Customers, stakeholders and beneficiaries of biological control products are often not identified, and strategic plans and coordination among agencies can be improved.

However, by the early 1990s several groups had made significant policy changes supporting biological control and IPM suggesting that the interest and potential to develop and implement a coordinated biological control program still exists. A few of these policy changes are:

In a 1993 press release, the Clinton Administration announced a goal of "reducing the risks to people and the environment that are associated with pesticides while ensuring the availability of cost-effective pest management tools for agriculture and other pesticides users. We will intensify our effort to reduce the use of higher-risk pesticides and to promote integrated pest management, including biological and cultural control systems and other sustainable agricultural practices, under the leadership of the USDA" (USDA 1993). This statement led to the USDA IPM Initiative, leading to a goal of "... development of IPM programs and implementation strategies for 75% of acreage within 7 years ...". A comprehensive set of regulatory and programmatic initiatives accompanied this change in philosophy which are being developed.

The Department of Defense (DoD) produced "pest management measures of merit" (DoD 1994) that require "100 percent of all DoD installations [to] have pest management plans" in place by the end of fiscal year (FY) 1997; a reduction of "50% from the FY 93 baseline" of pesticide used by the end of FY 2000, and to ensure proper certification of "100 percent of all DoD installation pesticide applicators" by FY 1998.

In a 1995 memorandum to the Deputy Secretary of Agriculture, the ARS Administrator announced intentions to redirect approximately $15 million of existing weed science resources into research in support of integrated management of exotic, invasive weeds and stated, "ARS believes, in concert with technical experts in land management agencies, that biological control is the best long-term economically feasible and environmentally safe approach to controlling invasive exotic weeds." Specifically, enhancement of ARS activities for foreign exploration for biological control agents, evaluation of these agents for introduction, cooperative program development, and a commitment to work with APHIS on improved regulatory procedures were mentioned.

FS and DoI announced major policy changes to "ecosystem management" in 1992-93.

FS established a *National Center for Forest Health Management* in 1993, then in 1995 combined the *Center* with two other laboratories in an "Enterprise Team" to address forest health issues. Like NBCI, the FS Enterprise Team has an external board of customers that advises on policy and programmatic issues.

CSREES announced a biological control section of the NRI in 1994, with $2.5 million (S. Rockey, personal communication, 1996). Congress eliminated the CSREES line item for biological control in 1995. NRI will continue to fund the program in 1996. Changes are anticipated for fiscal year 1997.

Bruce Babbitt (Secretary of DoI) announced science-based changes in forestry management (Babbitt 1995), emphasizing "Science is not the problem. Science is what has made this country work. Indeed, only science-applied, interdisciplinary science-will let us realize our vision."

APHIS approved a *Biological Control Philosophy* (USDA, APHIS, 1992): "APHIS believes that modern biological control, appropriately applied and monitored, is an environmentally safe and desirable form of long-term management of pest species. It is neither a panacea nor a solution for all pest problems. APHIS believes that biological control is preferable when applicable; however, we also recognize that biological control has limited application to emergency eradication programs. Whenever possible, biological control should replace chemical control as the base strategy for integrated pest management. In support of this philosophy, APHIS will develop regulations that facilitate the release of safe biological control agents, while maintaining adequate protection for American agriculture and the environment. The regulations will give clear and appropriate guidance to permit applicants, including specific types of data needed for review and environmental analysis and specific time limits for Agency review. They will be updated as the science progresses. APHIS believes that public input on procedures to approve the release of biological control agents is a desirable and necessary step, and will strive to gather input from scientists, industry, and the public."

The *APHIS Biological Control Philosophy* was distributed globally, and discussed at dozens of national and international meetings. In 1994 the North American Plant Projection Organization (consisting of representatives from Canada, Mexico and the United States) formally adopted a nearly-identical version as their policy (NAPPO 1994).

ARS reinstated a *National Program Leader* (*NPL*) to oversee the Agency's programs on biological control in 1995, a position that had not been filled for several years. In addition, the *NPL* filling this position has been given the responsibility to enhance inter-agency cooperation, develop biological control action teams in the field, and to conduct targeted workshops to improve technology transfer between ARS research programs and implementation programs of ARS customers and cooperators. Several such inter-agency workshops were conducted over the past year on weed biological control, augmentation biological control, and biological control activities associated with specific commodity programs.

The International Organization for Biological Control (IOBC), the only global scientific society dedicated to biological control and integrated pest management, adopted a similar statement at their September 1996 General Assembly meeting in Montpellier, France.

Several reports were also published in the mid-1990s which support biological control. A National Academy of Sciences (NAS), National Research Council (NRC) five-year landmark study (NRC 1993) entitled *Pesticides in the Diets of Infants and Children* highlighted the danger to children from pesticides. NRC concluded that the pesticides tolerance and regulatory system were lacking and inadequate to protect young children, and residues were permitted that allowed "100-500 times" what is safe for children. Obviously, increased use of biological control can help reduce pesticide application on crops, thus lowering the risk to children of pesticide exposure.

The OTA report, *Harmful Non-Indigenous Species [NIS] in the United States* (OTA 1993a), concluded that there were >4,500 NIS in the United States, of which 15% (>675) cause severe economic or environmental harm. There have been >200 NIS introduced since 1980, and new introductions were increasing. From 1906-91, 79 NIS caused $97 billion direct damage, and OTA concluded that 1991-2000, introduction of just 15 NIS could add $134 billion direct damage. OTA made the critical distinction between accidentally introduced pest NIS, which are the type that cause the enormous damage quoted, and the beneficial NIS, including biological control agents, that should be used more because they help manage the harmful NIS.

The U.S. Congress was so concerned about the situation with pesticides that they charged the

OTA to (OTA 1993*b*): 1) evaluate to what extent biological pest control can help fill the expected pesticide gap; 2) examine the relative safety of biological pest control and how some of the problems experienced with large-scale use of chemical pesticides, such as pest resistance, can be anticipated and avoided; 3) determine whether the current system of Federal funding, research, incentives and regulations helps or hinders the development and use of biologically-based approaches; 4) address the potential for transfer of biological pest control technologies from agriculture to other pest problems; for example, to weeds on Federal lands, lawn care, household pests, and vector-borne human diseases; and 5) develop policy options for Congress.

The final report (OTA 1995) entitled *Biologically Based Technologies for Pest Control*, was remarkably comprehensive, as discussed above.

Thus, establishment of a national advocacy and philosophical support of biological control has been recommended independently by several groups over an extended period of time. Such a program could help develop educational and informational materials, establish demonstration projects on farms, help coordinate activities and programs, and maintain a "coalition of stakeholders" (Granados *et al.* 1991, Chabot 1991). It could also help to capitalize on the IPM policy initiatives developed independently by a wide variety of groups.

OTA (1995) stated that Congress has responded to the "significance of pesticide losses, pest resistance and emerging pest threats" in several ways in the 1990 *Farm Bill* and subsequent legislation, and notably, by the June 1993 press release by the Clinton Administration, leading to the IPM Initiative.

Charudattan and Browning (1992) stated that State extension agents are key targets for education, who perhaps unknowingly, represent chemical interests through familiarity and training. Growers, who suspect slow-acting technologies, need to understand basic principals of biological control strategies. Regulators, in some cases, are challenged to differentiate a biological control organism from a chemical or similar material. Legislators, who do not know the impact that can be made or even what could be made are "waiting" for a need to act.

Concern was expressed over commercial (generally, augmentative) biological control agents not being predictably reliable, and that the incentives to develop products are insufficient (Glenister 1991, Ridgway *et al.* 1981, Tauber and Helgesen 1981). The private sector often stated that the regulatory system impedes, rather than facilitates, commercial development of biological control agents. There is a lack of ecological information about the fate of commercial biological control agents. Finally, agricultural cosmetic quality standards are thought of as being too high, and unachievable for some products using biological control.

Financial incentives are needed for the commercial sector to increase the supply of biological control agents. It was suggested that incentives for "private good" biological control should include "an 'Orphan Drug Act' for small market biopesticides, research and development tax credits, ... and lowering capital gains taxes to help research and development investments" (Granados *et al.* 1991).

EPA is primarily responsible for regulation of commercial biological control agents (Mendelsohn *et al.* 1993). As a response to customer suggestions, EPA has recently updated their regulatory procedures for approving commercial biological control agents.

Increasing commercialization of biological control remains a global challenge. The private sector can contribute significantly more to this effort if incentives (funding, regulatory and partnerships) are increased.

Concern was expressed over agents not being predictably reliable, and that the incentives to develop products are insufficient. The private sector often stated that the regulatory system impedes, rather than facilitates, commercial development of biological control agents. There is a lack of ecological information about the fate of commercial biological control agents. Finally, the product cosmetic quality standards are thought of as being too high, and unachievable for some products using biological control. NBCI has worked with the private sector, particularly the Association of Natural Bio-Control Producers, on these issues, but much more progress can be made.

CSREES, APHIS, State departments, companies and private consultants educate farmers and other citizens about use of BBTs, according to OTA (1995). However, OTA (1995) stressed that information of use of BBTs is "usually unavailable" to growers, and stressed the need for more activity in this area. OTA identified this as a "significant weak link" in implementation of BBTs, and suggested two options for Congress:

Option. *The Federal Insecticide, Fungicide and Rodenticide Act prohibits the federal government from requiring training in IPM for certification of pesticide applicators. Congress could amend the act to rectify this situation and require that pesticide applicators be knowledgeable in the full range of pest control options, including BBTs.*

Option. *Several different types of consultants affect pesticide use decisions. Several professional associations influence the types of information these consultants provide through training programs and certification standards. Extension has worked with at least one society, the Agronomy Society, to help integrate IPM into their certification program. Congress could encourage similar efforts through the Cooperative Extension System, perhaps by providing targeted competitive funds for projects that involve collaboration between extension personnel and professional societies to integrate BBTs and IPM into training programs or certification standards.*

THE 1996 USDA BIOLOGICAL CONTROL WORKSHOP

In July 1996, the Deputy Secretary of Agriculture Mr. Richard Rominger charged USDA with examining how appropriate regulation and increased coordination of biological control could increase research and implementation of biological control as part of integrated pest management (IPM). A Steering Committee was formed with members from all USDA agencies and NBCI, to convene a biological control workshop and provide recommendations to the Deputy Secretary.

Prior to the workshop, the Steering Committee reviewed and evaluated representative literature covering regulation, coordination and accountability of biological control (Carruthers and Petroff 1997). During the workshop consensus was reached on all items: the NBCI-facilitated "Strawman" document (see below) should be the basis from which future regulatory activities in biological control; a Biological Control "Center" should be established at the Secretary of Agriculture level, based on NBCI, to coordinate USDA biological control activities; and USDA biological control should be made more accountable by setting priorities and desired outcomes with customers, and reporting each year on the progress toward meeting the outcomes.

GLOBAL IMPLICATIONS OF DEVELOPING AND SUPPORTING BIOLOGICAL CONTROL PROGRAMS

It is interesting to note that increasing public advocacy and philosophical support for biological control was considered a necessity by so many groups. Part of the reason appears to be the conundrum of increasing public support for biological control, yet decreasing funding (in real terms), coordination and numbers of programs using biological control, and increasing regulatory challenges. Despite over 100 years of outstanding contributions to managing introduced pests globally with classical biological control, it is still often not considered as the first option for pest management; other types of biological control are similarly often considered only after other options have failed. It was felt that increasing advocacy and philosophical support for biological control could help clarify these issues. However, developing a "biological control first" policy (in which biological control may, of course, be dismissed first, if other IPM strategies are more appropriate for a given pest situation) challenges decades of contrary thinking and established actions. One way to increase biological control research and implementation may be to accept a "biological control first" policy, developed and advocated by biological control programs.

Development of strategic regulations that enable and facilitate biological control can be very challenging. The process can be helped by a national program which gathers and analyzes views from all parties and proposes solutions that meet the needs of researchers and the private sector, and the legal requirements of regulators. The input of individuals to this process is crucial. However, experience has shown that a coordinated proposal is much more likely to achieve results than individual comments. An open, empowering legal environment, where the public participates in changes to laws, regulations and procedures is essential to keep the legal system focused; science will always proceed much faster than the law. This is particularly important with augmentative biological control, where there can be significantly more private sector input.

Can a national biological control program play a role in successful research and technology transfer of biological control, or are scarce resources better used elsewhere? Success in biological control requires a unique combination of science, sociology and law. Programs must be based on science and carefully evaluated and monitored to begin to understand the mechanisms underpinning interactions between natural enemies, their pest hosts, and potential non-target species. Without this scientific basis, serendipitous "successes" (in the narrow sense of management of the target pest without understanding the mechanisms and interactions) will still occur, but no one will know why. Long-term evaluation on appropriate non-target species is essential to evaluate the safety and stability of biological control agents, even though many of the evaluations will likely show no deleterious effect at the population level, and to demonstrate the ethical, environmental stewardship role of most biological control practitioners. Coordination of programs requires considerable social skills and teamwork to avoid duplication and to leverage increasingly scarce resources.

A national biological control program can help provide the essential leadership to facilitate all of the above. It can provide a single reference point to focus biological control advocacy, and can increase the visibility of biological control in the political sphere, which must happen be to ensure long-term support. Properly placed and empowered, a national biological control program can influence policy to ensure that biological control is increasingly considered as the "first option" and the base strategy for IPM. A national program can help facilitate mutually agreed changes in regulations by gathering input from a wide range of public and private sector customer groups and synthesizing suggested changes for consideration by the regulatory bodies. Focused funding (and increases in funding) and establishing priorities can be organized by a national program, and the coordination that results can greatly leverage implementation and technology transfer. A national program can also work with private sector and international interests to encourage an environment where investment in biological control is increased.

All of these efforts call for a strong commitment to biological control. More agencies, scientific societies, Plant Protection Organizations and other groups should adopt formal policies in support of biological control. We agree with sentiments expressed by Rita Colwell, President of *Sigma Xi* (1991):

> In the 1990's, the scientific and technical community possesses a body of knowledge sufficient to influence human destiny. This knowledge makes it incumbent upon us, as scientists and engineers, to take a leading role in formulating solutions to problems that will affect the quality of life on this planet in the next century and beyond.

In summary, without broader global philosophical commitment to biological control, it is unlikely that change will occur, and the problems of "lack of leadership" and "lack of visibility of biological control" will remain. Increased use of nuclear techniques for the production and augmentative release of biological control agents for insect pests will thus be slower without

this commitment. National biological control programs can help provide this commitment, and can improve technology transfer of needed biological control to developing countries.

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THE POTENTIAL ROLE OF NUCLEAR TECHNIQUES IN SUPPORT OF THE PRODUCTION OF BIOLOGICAL CONTROL AGENTS OF INSECT PESTS

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While nuclear techniques *could* play a vital role in enabling cost-effective mass production of beneficial insects for use in augmentative biological control, surprisingly little use has been made of these techniques or ionizing radiation produced by other means (e.g., x-rays or electron beams from linear accelerators) for mass rearing beneficial insects. This technology has been available for quite some time, having been used to reproductively sterilize screwworm flies as early as 1951 (Bushland and Hopkins). Similarly, gamma radiation has been accepted internationally for human food preservation and disinfestation for many years (Anon., 1995). Quite a number of gamma radiation sources exist at or near USDA ARS and APHIS facilities throughout the U.S., as well as in many universities. Still, relatively little use has been made of this approach to assist in mass rearing of beneficial insects for use in augmentative biological control. As pointed out by Benbrook (1996), pest management is at a crossroads, and there still is a great need for new, biointensive pest management strategies. Nuclear techniques should play an increasing role in the future, as the overall thrust of biological control moves more and more toward augmentative releases (Knipling, 1992). It is the intent of this presentation to review some of the existing and potential uses that can be made of nuclear techniques and other sources of ionizing radiation in support of the biological control of insect pests.

SOME POTENTIAL APPLICATIONS OF IONIZING RADIATION

Ionizing radiation offers a reliable means to achieve: (1) developmental arrest of hosts/prey for use in *in vivo* rearing; (2) reproductive sterilization of hosts/prey to prevent release of viable pests along with beneficial insects; and (3) microbial pasteurization or sterilization of artificial media and possibly even natural hosts/prey (e.g., to kill *Nosema*).

Gamma radiation has been used to inhibit development of Caribbean fruit flies, *Anastrepha suspensa* (Loew), that escape parasitization by *Diachasmimorpha longicaudata* (Ashmead) (Sivinski and Smittle, 1990). This was done to preclude the inadvertent release of fertile adult fruit flies along with parasitoids in inoculative and inundative release programs in Florida. In this case, the fruit fly larvae were irradiated using ca. 4 kR (40 Gy) during the third instar, prior to exposure to parasitoids. This was a more useful application of gamma radiation than that of Ramadan and Wong (1989), who exposed pupae of the oriental fruit fly, *Dacus dorsalis* Hendel to gamma radiation *after* having already exposed the larvae to parasitization by *Diachasmimorpha (Biosteres) longicaudata*, resulting in sterility of the adult parasitoids. In the studies of Sivinski and Smittle, the dose of gamma radiation (from a

^{137}Cesium source) prevented adult eclosion of non-parasitized caribflies, but it did not prevent these larvae from serving as viable hosts for *D. longicaudata*. This allowed the investigators to safely set out puparia from larvae exposed to parasitoids without fear of releasing fertile flies into the area. Their work paralleled the earlier studies of Morgan et al. (1986), who used gamma radiation (50 kR, or 500 Gy) to inhibit development of pupae of *Musca domestica* L. that were then used as hosts for the parasitoid *Spalangia endius* Walker. Similar benefits were obtained by Roth et al. (1991), who used irradiated horn fly pupae as hosts for hymenopterous parasitoids. Morgan et al. also found that irradiated housefly pupae could be held successfully for an extended period (ca. 10 weeks) prior to parasitization by storing them at low temperature (4.4° C), as long as adequate humidity was maintained.

Gamma radiation also has been used to cause inherited sterility among progeny of radiation-exposed insects (i.e., F_1 sterility), so that these reproductively incompetent insects can be safely field-released for use as hosts/prey for indigenous natural enemies. This subject will be covered in detail by J. Carpenter elsewhere in this report, and therefore will not described further here.

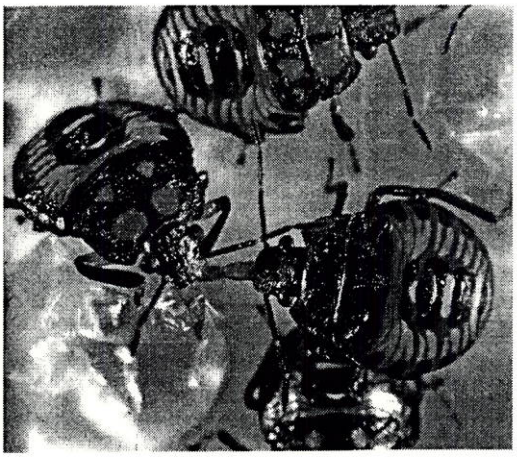
Another application for ionizing radiation that has promise is to inhibit the cellular and/or humoural defense reactions of host insects that might otherwise serve as optimal factitious hosts for beneficial insects. This approach was tested as a means of inhibiting encapsulation of the parasitoid *Microplitis croceipes* (Cresson) in a candidate factitious host, *Galleria melonella* L.(S. Ferkovich, personal communication). This parasitoid usually attacks larvae of *Heliothis* and *Helicoverpa* spp., but it will oviposit into *Galleria* larvae, and ca. 20% routinely escape encapsulation and complete development in this laboratory host, although the *Microplitis* adults derived from *Galleria* larvae were considerably smaller than those reared in *Heliothis/Helicoverpa* larvae (Gupta et al. 1996). It was felt that by using gamma radiation, it might be possible to substitute *Galleria* larvae for *Heliothis/Helicoverpa* larvae and thereby economize considerably in the rearing of *Microplitis*. Unfortunately, at no radiation dose (up to 100 Gy) was it possible to achieve an increase in success in use of *Galleria* (S. Ferkovich, personal communication); Although this approach was not successful in this instance, the principle should be kept in mind for other host-parasitoid systems, to enable more economical *in vivo* rearing.

An untested, but promising, application for gamma radiation is to inhibit the *behavioral resistance* of hosts/prey, so that they can be made more suitable for attack by parasitoids and/or predators that may otherwise be injured by their hosts. Simliarly, it may be possible to prevent other behaviors that diminish the suitability of candidate hosts/prey, such as bothersome web spinning by *Galleria melonella* larvae.

A superb application for ionizing radiation is for use in microbial pasteurization and sterilization of artificial media and even natural hosts/prey for rearing parasitoids and predators. Gamma radiation, as well as X-rays, provide a non-destructive means of killing bacteria, fungi, viruses, and protozoa that may impair growth and development of insect parasitoids and predators, and it can be used to dramatically increase the shelf life of artificial media. This approach is ideally suited to use in insect rearing for several reasons. First, it is easy to achieve repeatable doses. Second, there is no thermal degradation of the diet components, in contrast to use of steam or dry heat sterilization, which change the physical properties of media due to denaturation of proteins, for example. In addition, thermolabile enveloping membranes and diet packaging films such as Parafilm® generally are unaffected by gamma radiation and x-rays at the rates used for these purposes. Ionizing radiation also can be easily employed to sterilize materials that cannot be filter sterilized, such as thick, viscous media with numerous particles present. One of the greatest virtues of this approach is that it can be used to sterilize media *after* packaging (described as "terminal sterilization" in the pharmaceutical industry). This helps ensure long shelf life during storage, and helps prevent rapid microbial contamination of media when presented to beneficial insects.

As recently as 1984, little success had been made in development of artificial media for entomophagous insects (King and Leppla, 1984). However, in the past ten years or so, great advances have been made in developing artificial media that are suitable for a myriad of insect natural enemies (see Anderson and Leppla, 1992; Grenier et al. 1994 and references therein). In many of these instances, I believe it would be extremely helpful to use ionizing radiation to improve upon the rearing success on artificial media. This approach has been of great value in our own studies on a variety of predators and ectoparasitoids that we are rearing on an artificial medium free of any insect components (Greany & Carpenter, 1996; Carpenter & Greany, submitted, 1997). Our approach is to prepare the medium under clean (but not sterile) conditions, and then to encapsulate it before subjecting the final product to gamma radiation, using a dose of ca. 1 kGy. This achieves a high degree of microbial control, which along with storage at 4° C, allows the product to be kept for at least several weeks. Use of this system is illustrated in Fig. 1, showing feeding of *Podisus maculiventris* nymphs upon our medium encapsulated in Parafilm.

Fig. 1. Fourth instar nymphs of *Podisus maculiventris* feeding on "DI-diet" encapsulated in Parafilm, & irradiated after encapsulation using gamma radiation



We are currently working jointly with a chemical engineering firm to develop a sophisticated encapsulation process for our medium which will also include sterilization by gamma radiation. This combination of high volume diet packaging and sterilization should significantly reduce the cost of rearing a variety of beneficial insects and simultaneously improve upon success in use of the artificial medium. I believe the approach may be very useful to complement the excellent artificial diet and rearing system developed by Rojas et al. (1996) for the boll weevil parasitoid, *Catolaccus grandis.*

Finally, it may also be possible to use ionizing radiation to kill disease organisms such as the microsporidian *Nosema* that are often present in host organisms intended for parasitoid/predator rearing, and which can be transmitted from infected hosts to their natural enemies. For example, Undeen et al. (1984) showed that spores of *Nosema algerae* could be killed by gamma radiation in excess of 3 kR (30 Gy).

WHY ISN'T THIS APPROACH BEING USED TO GREATER ADVANTAGE?

Considering that many USDA-ARS and APHIS laboratories have a gamma radiation source readily available, relatively little use has been made of these facilities for purposes relating to rearing beneficial insects (Table 1). Commercial firms have had even less opportunity to avail themselves of this promising technology because of difficulty in obtaining access to irradiators (cf. the report by S. Penn).

Table 1. Gamma radiation source availability near ARS & APHIS biocontrol rearing facilities

Location:	Used for augmentative biocontrol?
Gainesville, FL	Yes
Tifton, GA	Yes
Beltsville, MD	Yes
Honolulu, HI	Yes
Yakima, WA	May be in near future
Starkeville, MS	Will be in near future
Weslaco, TX	May be in near future
Otis AFB, MA	May be in near future
Phoenix, AZ	May be in near future
Miami, FL	No

Some persons mistakenly fear that the use of a radioactive source, or even a linear accelerator or x-ray machine, will cause the exposed materials to become radioactive. Another common misconception is that this process will destroy the nutritional value of the irradiated materials, or will cause the formation of an abundance of free radicals of oxygen or other radiolytic products that will render the foodstuff toxic. The comfort level of potential users might be increased through an educational program to enlighten them about the safety of this technology.

One of the genuine "hassles" that inhibits potential users from taking better advantage of this technology is the abundance of regulatory agency requirements that must be met for acquisition and maintenance of a radioactive source, such as a cesium or cobalt source. Along with this, there is a high initial cost for purchase of even a small (ca. 0.5 liter volume) gammacell (on the order of $100,000). The need to ultimately dispose of the radioactive waste also constitutes at least a minor problem.

Fortunately, x-ray machines and linear accelerators for use in food irradiation are being developed. These devices are subject to fewer regulatory constraints than ^{137}Cesium or ^{60}Cobalt sources, and they may prove much more user-friendly for the insect rearing community. Relatively low-cost cabinet x-ray machines are being developed that will suffice for many small-scale users. It is possible that through the USDA Small Business Innovative Research program (SBIR), funding could be made available to accelerate the development of affordable x-ray devices (on the order of $30,000 per unit or less).

SUMMARY

Overall, there is great promise for the use of ionizing radiation in support of the development of improved mass rearing methods to be used for augmentative biological control. The advent of more and more artificial media that are proving suitable for numerous beneficial insects is providing an impetus for development of appropriate sterilization regimes. Similarly, ionizing radiation also may be used to great advantage to improve upon conventional *in vivo* rearing strategies for many parasitoids and predators. Finally, the regulatory climate is becoming much more stringent, and radiation techniques may help facilitate international, interstate, and even intrastate shipments of insect natural enemies, by preventing the accidental release of reproductively viable pest organisms along with their natural enemies (cf. reports of Delfosse and Hill).

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The potential for the integration of nuclear techniques in arthropod biological control

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Summary

Biological control is today being practised more widely than ever before and its popularity looks set to increase further in the future. While the discipline has historically been dominated by "classical" biological control (the one-off introduction of natural enemies to control pests in their adventive range) augmentative biological control (the repeated introduction of biocontrol agents to a particular crop or forest) has increased substantially over the past 20 years and is likely to increase in importance further in the future. This view is supported by an assessment of some of the key issues facing the discipline of biological control today.

There is no clear role for nuclear techniques in the future of classical biological control. However the use of irradiation as a means of creating increased rates of mutation in natural enemy populations being selected for enhanced beneficial traits (such as insecticide resistance), might be useful and could be investigated further. There is scope for the use of irradiation in killing or sterilising insect diets and hosts, a technique which has been used for over 25 years without gaining wide acceptance. Augmentative biological control as an adjunct to SIT may have a role in future pest control campaigns, although it is likely to prove difficult to provide a clear economic justification given the technical difficulties of measuring separately the effects of the two techniques.

It is suggested that the technical advances in project development and implementation (e.g. insect rearing techniques and field application) which have been made by SIT practitioners have a potentially useful role in assisting the development of improved production and delivery of biological control agents for augmentative release.

1. Introduction

This paper reviews briefly the history of biological control and the main issues facing it today. It goes on to consider the potential use of nuclear techniques in biological control, and briefly, the use of SIT by-products such as mass produced eggs or larvae of pests for biological control agent production.

Biological control, the applied science of using living organisms as pest control agents, is a little over 100 years old. The discipline is usually divided into three parts:

- *Classical biological control*: The one-off introduction of a natural enemy from the area of origin of the pest.

- *Augmentative biological control:* The deliberate and repeated introduction of natural enemies into an area either *inoculatively* (small numbers of natural enemies released, typically at the start of a crop growing season) or *inundatively* (large numbers of natural enemies released, usually several times throughout the crop growing season).

- *Conservation of indigenous natural enemies:* The preservation and enhancement of natural enemies *in situ* through habitat modification (e.g. provision of nectar sources) and by not using harmful chemicals.

Classical biological control remains the dominant form of biological control, based upon the continuing accidental introduction of new pest and weed species (Figure 1) . However augmentative biological control has increased in importance over the last 20 years.

Classical biological control

Classical biological control is by far the most important and widely-adopted type of biological control with about 4,800 recorded introductions of biological control agents against insect pests in 196 countries or islands. These have resulted in complete control of the pest in between 10-16% of cases (depending upon interpretation of published reports) (Greathead and Greathead 1990; Greathead 1995; Hall *et al.* 1980), and partial control in up to 46% of introductions (Hall *et al.* 1980). The most suitable targets for classical biological control, by far, have been the Homoptera, followed by Lepidoptera and Coleoptera (Greathead 1995). Other orders of insects have only rarely been the subject of successful control programmes.

Classical biological control is based largely upon the ecological principle of the restoration of a stable endemic pest population level through the action of co-evolved natural enemies from its area of origin. Most successful biological control agents are specifically adapted to the target pest or closely related taxa. Classical biological control is permanent and sustainable and has proven time and again that it can be the "magic bullet" for the control of some pests. However, history shows that it fails in this endeavour more often than it succeeds, and most of the time it provides only a partial solution to pest problems.

Augmentative biological control

Augmentative biological control is used to enhance the effectiveness of natural enemies which, if left to their own devices, provide an inadequate degree of control. They have been used in a wide range of cropping situations but the largest use of augmentation has been targeted against the eggs of lepidopterous pests using the chalcidoid parasitoids in the genus *Trichogramma,* and for the control of covered crops (van Lenteren 1995a).

2. Current issues in biological control

From IIBC's viewpoint, the main issues facing arthropod biological control today are the effects of biological control agents on non-target organisms, the place of indigenous natural enemies in pest control, the increasing use and future place of augmentative biological control, and the changing face of biological control implementation procedures and stewardship of biological control organisms under the Convention on Biological Diversity. All of these issues will have an effect upon biological control practice in the future and they point towards a probable shift of emphasis towards augmentative biological control using indigenous natural enemies and away from classical biological control (though this will remain the first line of attack against new adventive pests). These issues are discussed briefly in turn.

2.1 The effects of biological control agents on non-target organisms

Most successful biological control agents have narrow host ranges, and many feed exclusively on the target pest organisms (Greathead 1995). However, many potentially useful biological control agents are oligophagous, feeding on the target pest and closely related species. While the history of modern biological control shows that it has been outstandingly safe, there are some reports of introduced biological control agents having unanticipated effects upon non-target arthropods (Howarth 1991). There is also a growing awareness that biological control agents should be screened for host specificity against the non-target indigenous arthropod fauna. Several countries now require that this testing be carried out in advance of the introduction of new biological control agents. This procedure, which has always been a feature of weed biological control programmes, will make it more difficult in the future to introduce oligophagous arthropod biological control agents. It will in turn, place more emphasis on the use of indigenous natural enemies through conservation or augmentation.

2.2 The conservation and enhancement of indigenous natural enemies

With the development of integrated pest management systems, and the use of selective pest control techniques (e.g. Bt, semiochemicals, augmentative biocontrol etc.) has come a new awareness of the presence and the importance of indigenous natural enemies in many cropping systems. Those natural enemies which, for decades, had been suppressed by the use of broad spectrum pesticides are now re-emerging as potentially powerful natural control agents. Perhaps the best known example of this is the control of rice planthoppers by an assemblage of over 400 species of predators in paddy fields in South-East Asia, and the implementation of IPM through discovery learning programmes (farmers' field schools) which has led to dramatic reductions in pesticide use in rice cultivation (FAO Inter-country rice programme; FAO 1996; Ooi and Kenmore 1995).

A less well known but equally instructive example is the study of natural predation of *Helicoverpa armigera* in East Africa (van den Berg 1993). This study was carried out by IIBC in the late 1980's, and showed that the pest has over 80 species of recorded parasitoids and scores of predators. Key mortality factors in the larval stages were predation by several species of anthocorid bugs and ants, the former being mostly undescribed species. This study, the first of its kind against what is arguably the most important Old World insect pest, highlights the general lack of information on the agro-ecology of insect pests globally.

Both of these studies demonstrate that there are a wealth of natural enemies in agro-ecosystems which do not suffer from chemical disruption, many of which could be amenable to augmentation in future control programmes if needed.

2.3 The rise of augmentation

Augmentative use of *Trichogramma* began in the 1920's following the development of mass rearing systems (Flanders 1929). Over the last 20 years, the use of *Trichogramma* has grown substantially. It is now used in about 30 countries around the world, principally on maize, cotton, sugarcane and rice for the control of lepidopterous borers (Kloptseva 1991; Li 1994). However it is being used increasingly on vegetable and horticultural crops, especially covered crops (van Lenteren 1995a).

The main countries using *Trichogramma* (about 20 species) augmentation are those of the former USSR, China, and Mexico. The estimated total area of *Trichogramma* use was 32 million hectares of agriculture and forestry in 1992 (Li 1994; Kholptseva 1991), of which up to 27.6 million hectares was in the former USSR, with China and Mexico each treating about 2 million hectares. A feature of the use of *Trichogramma* on a broad scale has been the lack of effective evaluation studies in many situations. While good evidence exists to show that inundative releases of *Trichogramma* can be effective (e.g European corn borer in Switzerland (Bigler 1986; Li 1994)), there is contrary evidence to show that extensive *Trichogramma* release campaigns have had no immediate impact upon pest populations and damage (e.g their use for control of *Diatraea spp.* in the Caribbean (Metcalfe and Breniere 1969)). In addition to this, field studies of *Trichogramma* efficacy have rarely attempted to separate the effects of augmentative releases of parasitoids on pest populations from the effects of enhanced levels of other natural enemies which have increased following the cessation of insecticide usage in the area. However, one such study in China has shown that populations of naturally occurring indigenous natural enemies increase by 2-5 fold following the cessation of spraying (Zhou 1988).

The use of augmentative biological control in covered crops, using a variety of parasitoids and predators to control a range of pests (mainly spider mites, thrips and whitefly) has increased significantly in recent years (van Lenteren 1995a; Figure 2).

Augmentative biological control is being pursued on a wide range of crops in many countries (Li 1994), both at research and implementation levels and in the public and private sectors. At least some of this activity in developing countries and those of the former USSR (which have a substantial record of use of biological control augmentation) lacks commitment to the necessary investment in the development of commercial production and delivery systems appropriate to their economies. For example, the widespread use of augmentative biological control demonstrations currently being carried out by the extension services in India needs further evaluation and potentially transforming into a viable commercial activity. Elsewhere, the massive use of *Trichogramma* on cotton in former USSR countries, developed under a centrally planned economy, is now clearly in need of evaluation and upgrading. These could be done by linking together local researchers and producers with augmentation specialists and economists to develop commercially viable systems for field and vegetable crops.

2.4 A code for the implementation of biological control programmes, and issues arising from national stewardship of biodiversity resources

The UNCED "Convention on Biological Diversity" agreed that parties to it should endeavour to create conditions to facilitate access to genetic resources for environmentally sound uses by other contracting parties. However, the convention also requires signatories to develop legislation defining their rights of ownership and regulating access to and the use of their biodiversity. So far, only Australia has done this, though many other signatory countries are expected to follow suite over the next 5-10 years. Clearly this could have a considerable effect upon the free exchange of biological control agents in the future, and it will be important to develop mechanisms to ensure the continuing exchange of biocontrol agents within the context of this new legislative environment, and to provide for fair and equitable sharing of income from commercial exploitation.

The FAO has recently developed and ratified a code of conduct for the import and release of exotic biological control agents. These provide for the safe introduction and use of biological control agents, either as classical or augmentative introductions. IIBC, which contributed to the development of these guidelines, has adopted them as a standard for all of its projects, ensuring that minimum standards are adhered to. A central feature of the guidelines is the preparation of a dossier summarising information on the pest and natural enemies, host range, geographical range, recommendations for host specificity testing and background to their previous use as biological control agents.

These moves to regulate and codify the discipline of biological control by applying minimum standards are timely and welcomed. They will contribute significantly to the safe practice of biological control throughout the world and ensure that the increasing demands for stricter host range testing and natural enemy purity can be met. However in practical terms, they are likely to lead to increased delays in the implementation of biological control programmes and to increase their administrative cost. It may also lead to increased emphasis on the augmentative use of indigenous natural enemies at the expense of the importation of exotic natural enemies.

3. Potential uses for nuclear techniques in biological control

Some potential uses of irradiation in biological control are as follows:

3.1 Sterilisation of insect diets and hosts

This is a relatively straightforward use of irradiation, as a sterilant for insect diets or hosts, and was first used over 25 years ago (Barton and Stehr 1970). It potentially has wide application.

3.2 Production of new strains of biological control agents

The enhancement of biological control agents through selection for strains with better characteristics is still in its infancy. However, the technique has been used to produce parasitoids and predators which are resistant to certain classes of pesticides (Markwick 1986: Grafton-Cardwell and Hoy 1986; Hoy and Cave 1988), which have altered diapause characteristics (Gilkeson and Hill 1986) and improved searching ability (Gaugler et al. 1989).

To date all of these techniques have used straightforward selection processes on wild or laboratory-adapted populations of the natural enemy. The use of methods such as radiation to increase the number and frequency of mutations in a population of natural enemies under selection has not, to our knowledge, been attempted with arthropod natural enemies. However, major behavioural and physiological traits linked to the performance of natural enemies will probably be controlled by several genes (Beckendorf and Hoy 1985). Thus the use of irradiation to increase rates of mutation, and with it the likelihood of discovering improved natural enemy genotypes, is likely to be a difficult process with a very high level of redundancy (van Lenteren 1995b).

The use of mutagens for altering biological control agents has been applied experimentally in the biological control of plant pathogens. Chemical mutagens have been used for the production of non-pathogenic strains of fungal and bacterial pathogens such as species of *Xanthomonas* (Daniels *et al.* 1984) and *Bacillus thuringiensis* (Arunson *et al.* 1995). However in a recent research project carried out at the International Mycological Institute, the use of chemical mutagens for the development of non-pathogenic strains of *Pseudomonas solanacearum* was ruled out because it was estimated that the rate of production of a useful non-pathogenic mutant by this technique was about 800,000:1 By contrast, non-pathogenic strains were produced easily and in a much more controlled fashion by gene addition and deletion procedures (Julian Smith IMI pers. comm.). Thus, current research in plant pathogen biological control is moving away from the use of mugatens towards the more controlled technologies of genetic manipulation.

The use of nuclear techniques in arthropod biological control to create random mutations - where the researcher is seeking to select for increased natural enemy effectiveness rather than non-pathogenicity, would appear to be an unlikely area for future developments with current technology (including genetic manipulation). However, if sufficient resources were brought to bear on the problem it might be instructive to investigate empirically the use of irradiation in assisting the selection of improved arthropod natural enemies for traits which are known or are likely to be under single gene control (e.g. pesticide resistance).

A suitable model system could be phytoseiid mites. These are easy to rear and have been successfully manipulated in the past by workers selecting for insecticide resistance (e.g. Croft 1976; Markwick 1986)

3.3 The use of SIT project expertise in augmentative biological control

The practice of sterile insect technique around the world has provided many instructive examples of the requirements for large-scale, highly organised, capital intensive and area-wide pest control campaigns (e.g. examples in IAEA 1993). Much of this information could usefully be brought to bear on augmentative biological control. In particular, expertise in insect mass rearing, storage and application technologies, and project organisation and economic evaluation.

As indicated above, there are currently several augmentative biological control programmes around the world which would benefit from a more critical appraisal of their current status and future needs, and would benefit from experienced technical inputs. It would be useful to explore the role which SIT specialists could play in the development of augmentation biological control, by transferring expertise in these disciplines.

3.4 The combined use of SIT and biological control

While nuclear techniques appear to have no immediately identifiable place in "classical" biological control, their potential use in combination with augmentative biological control could be much greater. This is particularly true where numbers of parasitoids or predators can be reared as a by-product of the SIT insect mass production process at relatively low marginal economic cost, as is the case with Mediterranean fruitfly control with SIT and parasitoid mass releases in central America (Jeronimo this meeting) and Hawaii (Wong *et al.* 1992).

The principle of SIT is based upon the maintenance of a high ratio of sterile to wild type insects. The target populations should therefore already be at a low density. In addition, they should be relatively confined within a geographical area, not highly dispersive or invasive.

Classical biological control works by driving down the average population density of the pest and the effects of the natural enemy are usually density dependent - the degree of population suppression is greater at high pest densities. The use of augmentation in biological control is thus normally used in situations in which the degree of population regulation is insufficient to reduce pest incidence below an acceptable threshold. This makes it complementary to SIT and suggests that it could best be used to drive down pest populations prior to, or in concert with, the use of SIT.

The single published example of the combined use of these techniques against Mediterranean fruit fly in Hawaii (Wong et al. 1992) suggests that the two techniques act synergistically. However the paper presents insufficient data to allow any firm conclusions to be drawn and it is possible that the augmentative biological control, in this case, was of no practical benefit over and above the SIT - which is clearly having the dominant depressing effect upon the population of Mediterranean fruit fly.

This example raises a crucial point that it is very difficult and costly to quantify adequately the effects of SIT and augmentative biological control together such that the economics of augmentation as an additional intervention complementary to SIT, can be satisfactorily determined. However it is very important that this be done to establish its usefulness in future insect control operations.

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United States Departament of Agriculture
Animal and Plant Health Inspection Service
Plant Protection and Quarantine
Guatemala Medfly Station
U.S. Embassy/APHIS
Unit 3319
APO AA 34024

BIOLOGICAL CONTROL OF THE MEDITERRANEAN FRUIT FLY IN GUATEMALA BY MEANS OF AUGMENTATIVE RELEASES OF FRUIT FLY PARASITOIDS

NAME OF PROJECT: Biological control of the Mediterranean fruit fly in Guatemala by means of augmentative releases of fruit fly parasitoids.

Objective

Develop an ecologically sound approach for population suppression of the Mediterranean fruit fly for its integration into action programs.

Participants

Moscamed, Guatemala
Moscamed, México
ARS-Gainesville, FL.
USDA-APHIS-PPQ, Gainesville, FL.
USDA-APHIS-IS, Guatemala
USDA-APHIS-PPQ, Guatemala

Summary

This project initiated four years ago (in 1993) due to interest manifested by local program managers for developing new strategies in the control of the Mediterranean fruit fly *Ceratitis capitata* (Wied) "medfly". Two species of fruit fly parasitoids were studied, *Diachasmimorpha longicaudata* (Ashmed) and *Dichasmimorpha tryoni* (Decameron). Work plans for this project concentrated on: 1) rearing of parasitoids, 2) shipping of parasitized pupae, 3) packing and handling of parasitized pupae, 4) handling and feeding of adult parasitoids, 5) releasing of adult parasitoids, 6) monitoring of medfly population (trapping and fruit sampling) 7) training of personnel at all levels.

All field work in this project was conducted in the coffee area of Guatemala, near the Mexican border. The first part of the project allowed to determine that *Diachasmimorpha tryoni* (Decameron), was the more suitable candidate for fruit fly control under the local conditions. Second part of the project confirmed the efficacy of *Dichasmimorpha tryoni* (Decameron) as a control agent against the medfly in the coffee area in this part of the country.

Current activities in this project include: 1) colony maintenance for *Diachasmimorpha longicaudata* and *Diachasmimorpha tryoni*, 2) colony introduction/establisment of three new species of parasitoids, for each of the three vulnerable stages (ie. egg, larvae and pupae). Small scale rearing for these parasitoids has been carried out under quarantine conditions.

Procedure

The first two years of this project included: a) phase I, laboratory work (implementation, introduction of two species of parasitoids, basic research on rearing as well as mass-production of introduced parasitoids) and b) phase II, field evaluation (site selection, packing and shipping eclosion of adult parasitoids, parasitoid handling at the eclosion facility, ground releases, quantification of field performance).

Field evaluation during this period included the following treatments: 1) releases of large *Diachasmimorpha longicaudata* (Ashmed) reared on *Anastrepha ludens* (Loew) in combination with releases of sterile insects, 2) releases of small *Diachasmimorpha longicaudata* (Ashmed) reared on *Ceratitis capitata* Wied. in combination with releases of sterile insects, 3) releases of *Diachasmimorpha tryoni* (Decameron) reared on *C. capitata* Wied. in combination with releases of sterile insects, 4) releases of sterile insects only, 5) control.

Fruit fly parasitoids were reared at two different rearing facilities in Mexico and Guatemala.

Plot sizes in this test were one square kilometer per treatment. All plots were located at the same elevation (1,100 to 1,200 meters above sea level). Insect release densities per hectare were 2,000 adult parasitoids and 3,000 sterile flies. Releases for both were conducted by ground. Fruit fly population in each plot was determined based on weekly trapping and fruit sampling.

The last two years of project have included large scale activity for both mass-rearing and releases of *Diachasmimorpha tryoni*. Weekly productions of 2 to 5 million parasitoids were achieved along with weekly aerial releases of parasitoids and sterile insects over an area of 25 square kilometers. Treatments in this test were 1) aerial releases of *Diachasmimorpha tryoni* (Decameron) reared on "medfly" in combination with sterile insects, 2) aerial releases of sterile insects only, 3) control. In each plot, a core and a buffer area were defined. Aerial releases of insects were conducted using the paper bag system currently being employed for releases in Guatemala and Mexico. Insect densities in this test were 2,500 and 3,000 adult insects per hectare for parasitoids and sterile flies respectively. Insect rearing was conducted at the mass-rearing facility in Guatemala. Weekly activities on fruit fly trapping and fruit sampling were necessary for data collection.

RESULTS

Results on this project are shown in attached figures, a final publication of results is still pending.

Based on available information from this test, it is evident that the utilization of

biological control agents in large action programs is recommended specially where a wide range of fruit host do occur and where each one of the other control methods play their own role but when used alone do not eliminate the problem. In the past (12-15 years ago), some ground releases of parasitoid *Diachasmimorpha longicaudata*, were made in the coffee area of Antigua Guatemala, at present a high percent parasitism still exists, as yearly collections of coffee berries had reported (unpublished data), which means that the parasitoids established themselves in the area.
With the introduction of the new species of parasitoids, an integrated program of releases can be implemented in the near future, this new approach could optimize present program efforts.

PROJECT NEEDS

Large scale evaluation of *Diachasmimorpha tryoni* in the coffee area of Guatemala (rearing and releasing of 20 million adult parasitoid per week, during a period of 5 months).

Field evaluation of the new species of parasitoids after quarantine process is completed (this should comply with scientific research protocol), this can be done at the beginning in a small area and later on, into a larger location.

Integration of all available fruit fly parasitoids into a control project in an specific area (this would require participation of scientist from some other countries with broad experience on this topic).

Investigate more about the chilled adult release technique applied to the aerial releases of fruit fly parasitoids this is proposed, due to promising results obtained in preliminary tests in the coffee area of Guatemala.

SUMMARY OF WORK PROGRESS ON FRUIT FLY PARASITOIDS PROJECT IN GUATEMALA.

Year 1993

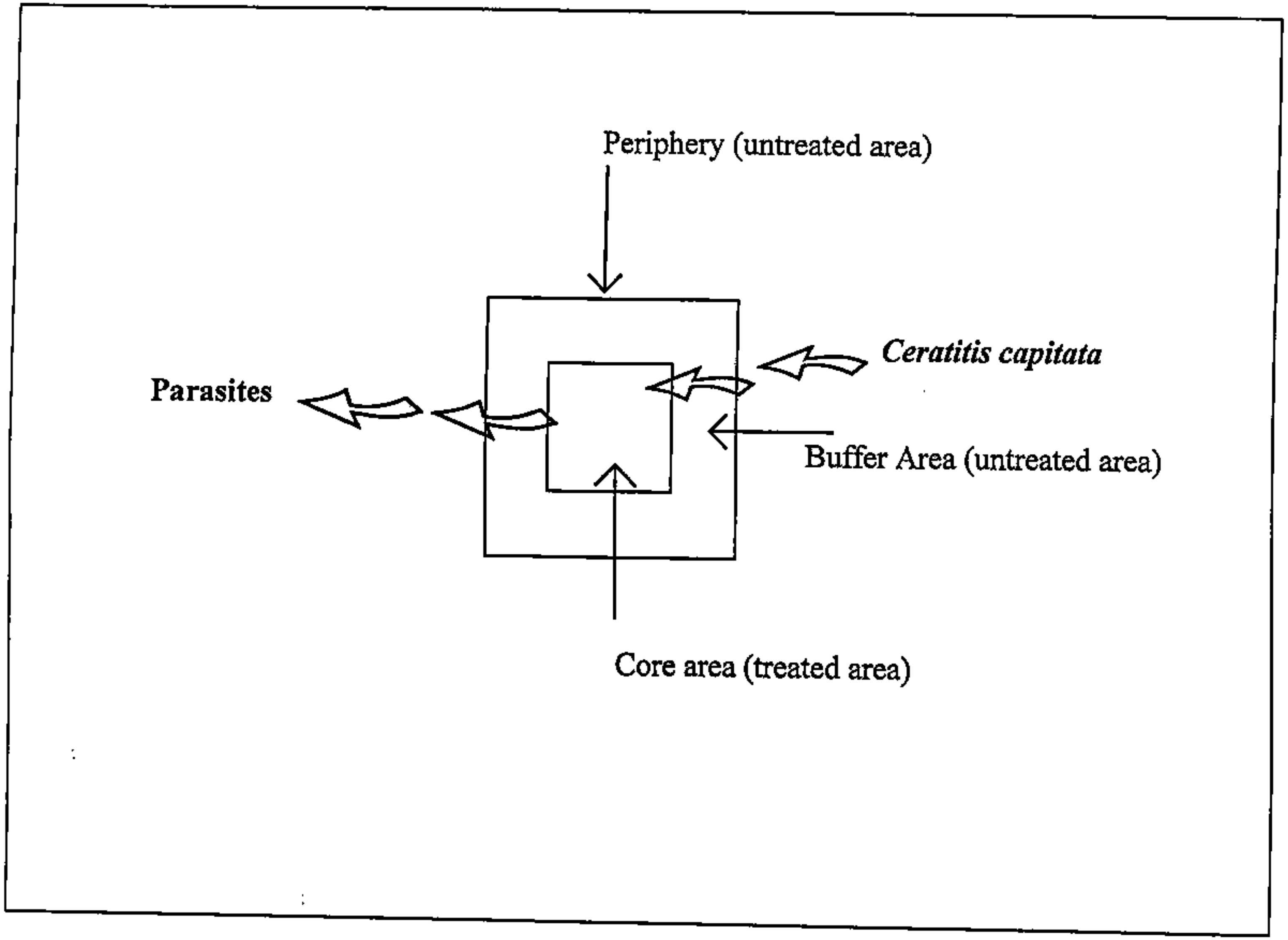
Project framework definition.
Project funding.
Research protocol definition.
Mass-rearing facility implementation.
Trainning for laboratory personnel.
Introduction of fruit fly parasitoids.
Small scale rearing of fruit fly parasitoids.

Year 1994

Mass-rearing of *Diachasmimorpha longicaudata* (Ashmed).
Field evaluation of *Diachasmimorpha tryoni* and *Diachasmimorpha longicaudata* reared at different facilities.

cont....

Year 1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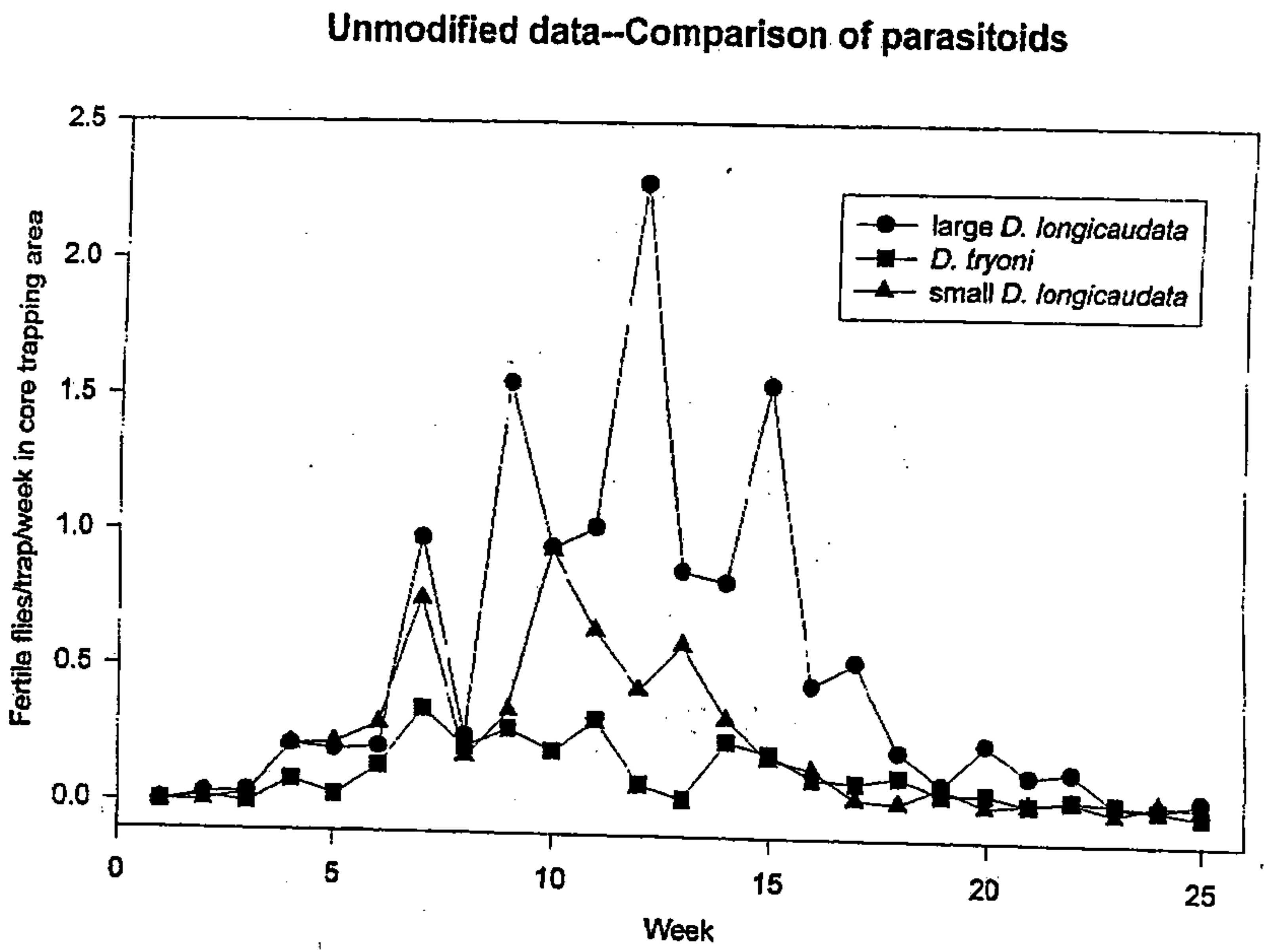
Ceratitis capitata
Parasites
Buffer Area (untreated area)
Core area (treated area)


Unmodified data--Comparison of parasitoids
large D. longicaudata
D. tryoni
small D. longicaudata
Fertile flies/trap/week in core trapping area
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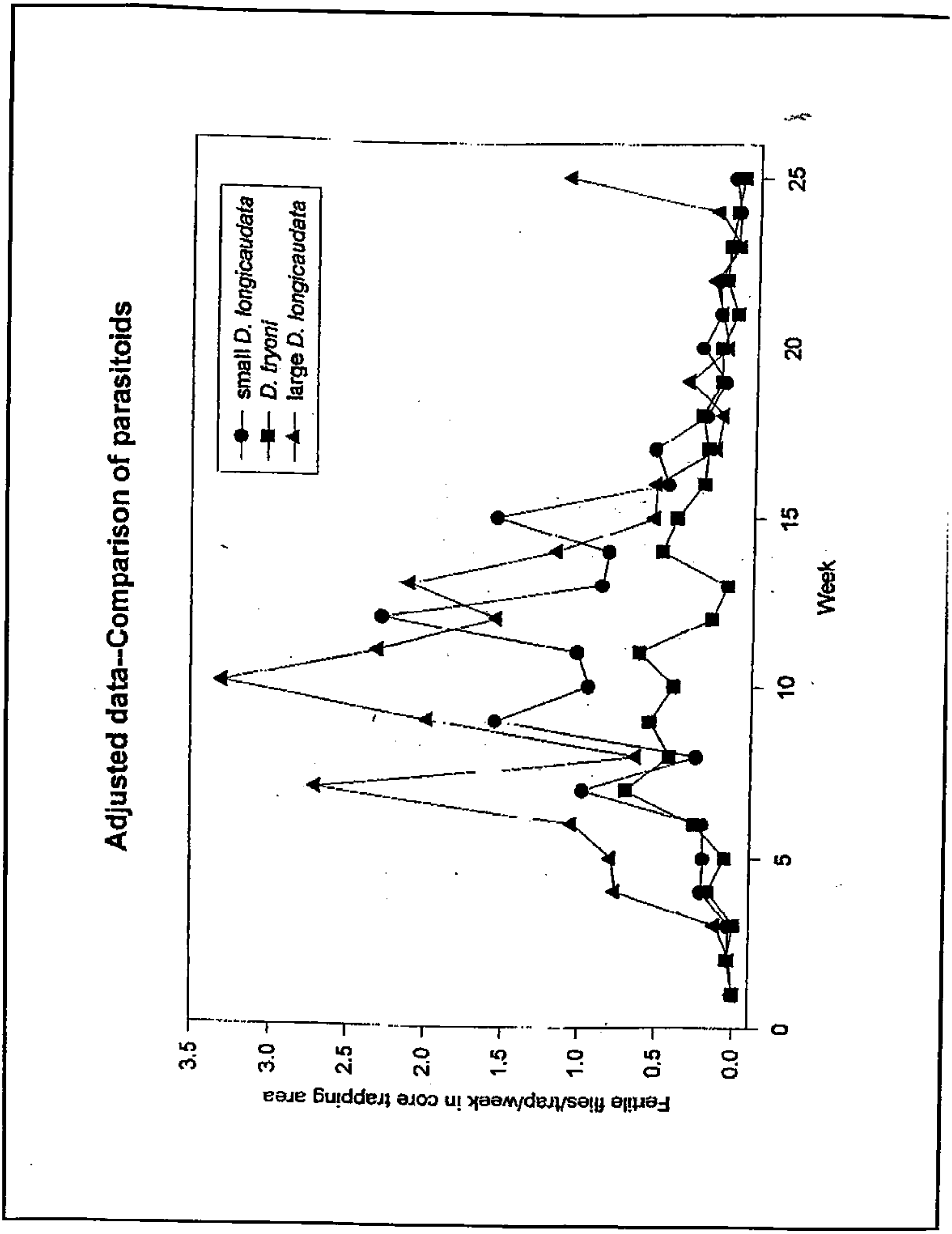
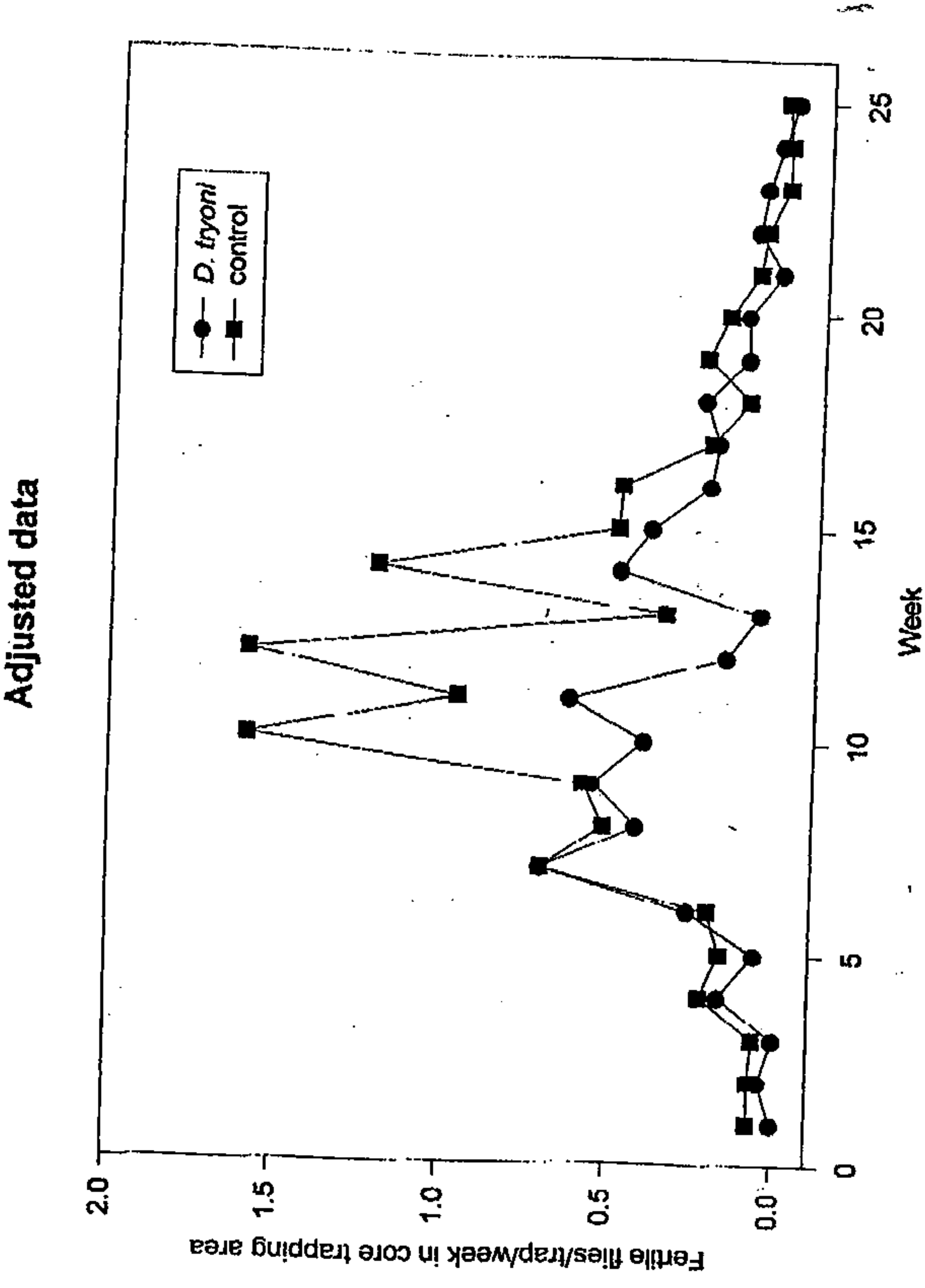
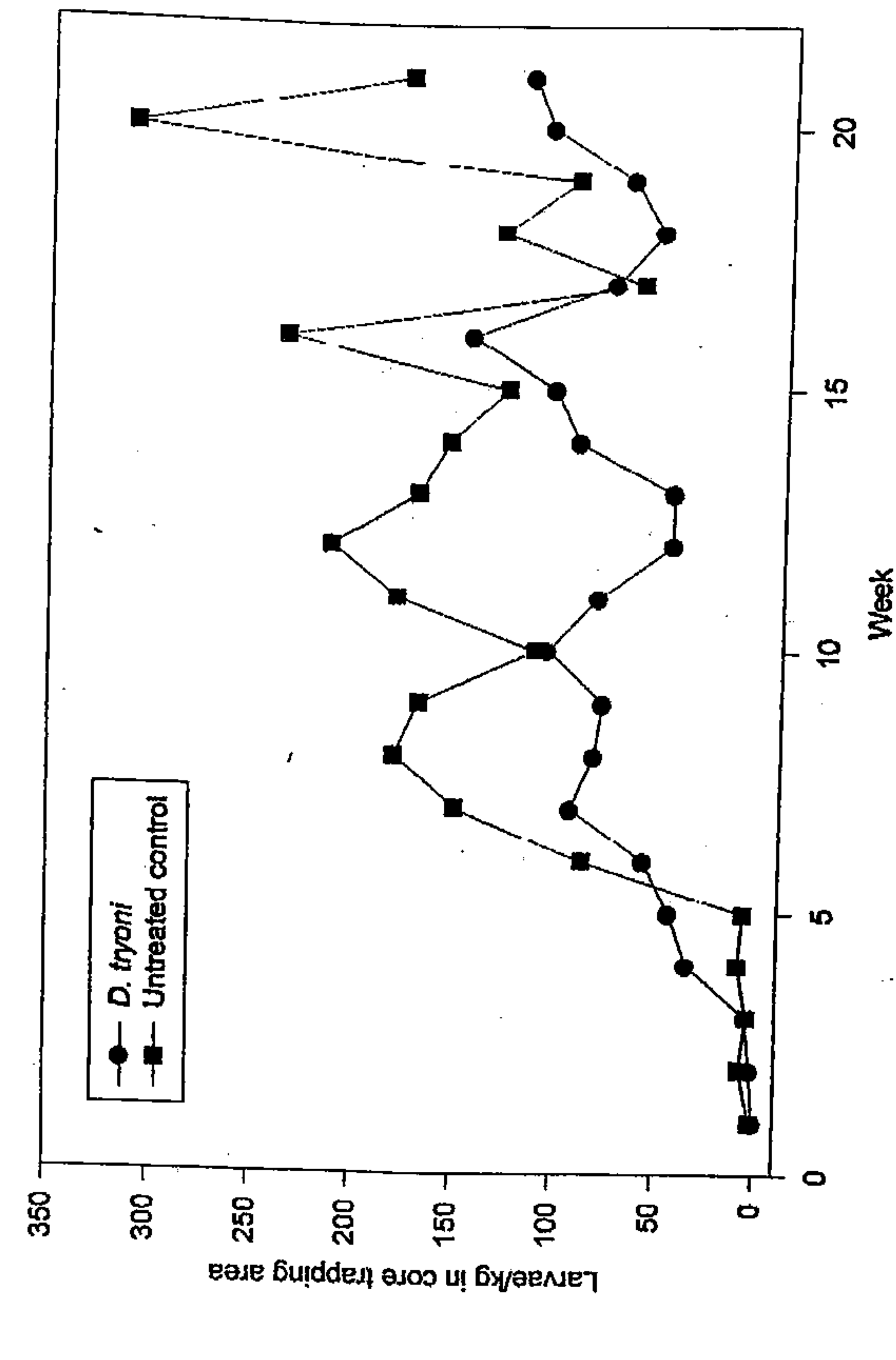
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Week



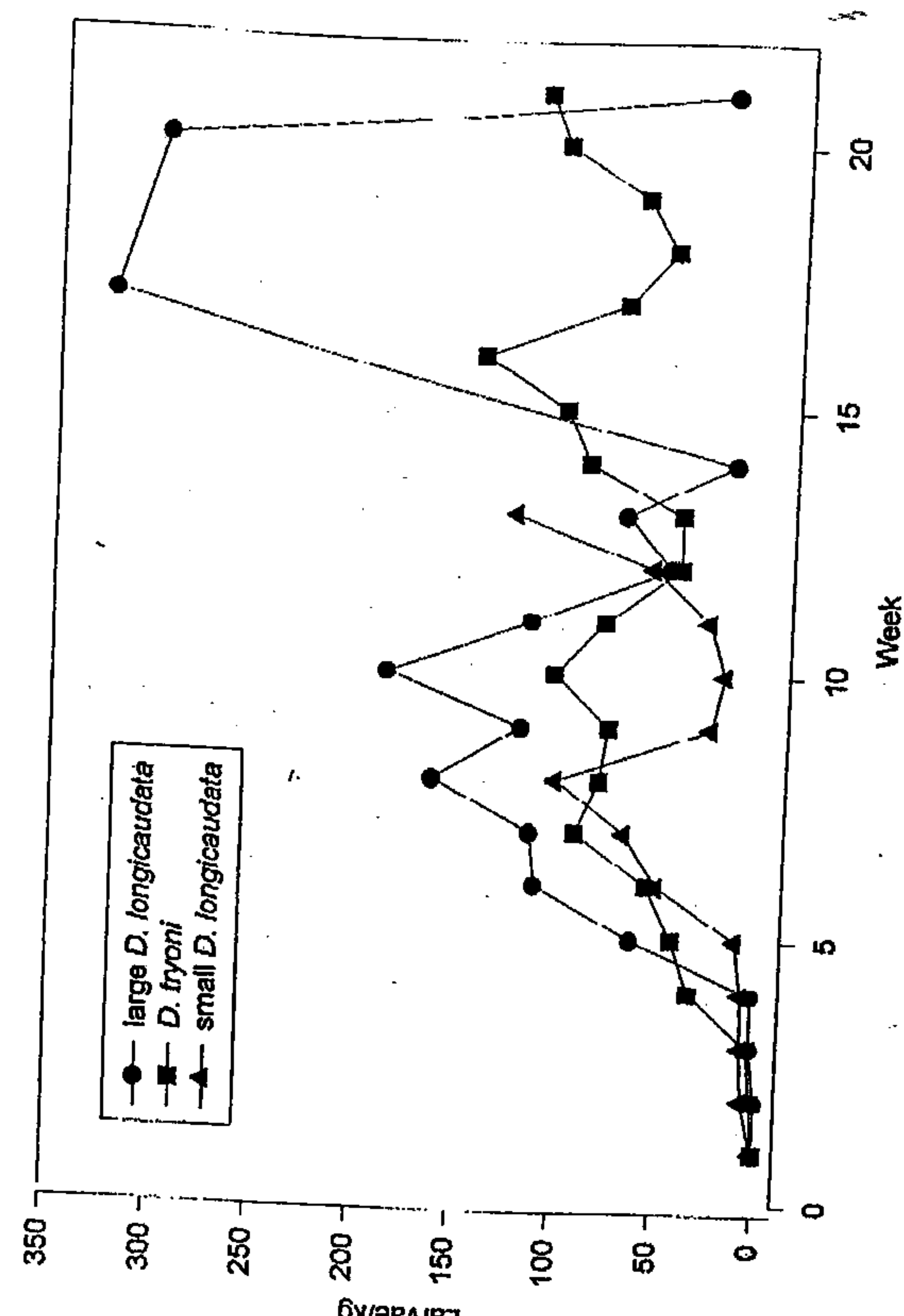
Adjusted data--Comparison of parasitoids
small D. longicaudata
D. tryoni
large D. longicaudata
Fertile flies/trap/week in core trapping area
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Week
0
5
10
15
20
25



Adjusted data
D. tryoni
control
Fertile flies/trap/week in core trapping area
Week
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25



D. tryoni
Untreated control
Larvae/kg in core trapping area
Week
0
50
100
150
200
250
300
350
0
5
10
15
20



large D. longicaudata
D. fryoni
small D. longicaudata
Larvae/kg
0
50
100
150
200
250
300
350
Week
0
5
10
15
20

SUMMARY OF WORK PROGRESS ON FRUIT FLY PARASITOIDS PROJECT IN GUATEMALA.

Year 1995

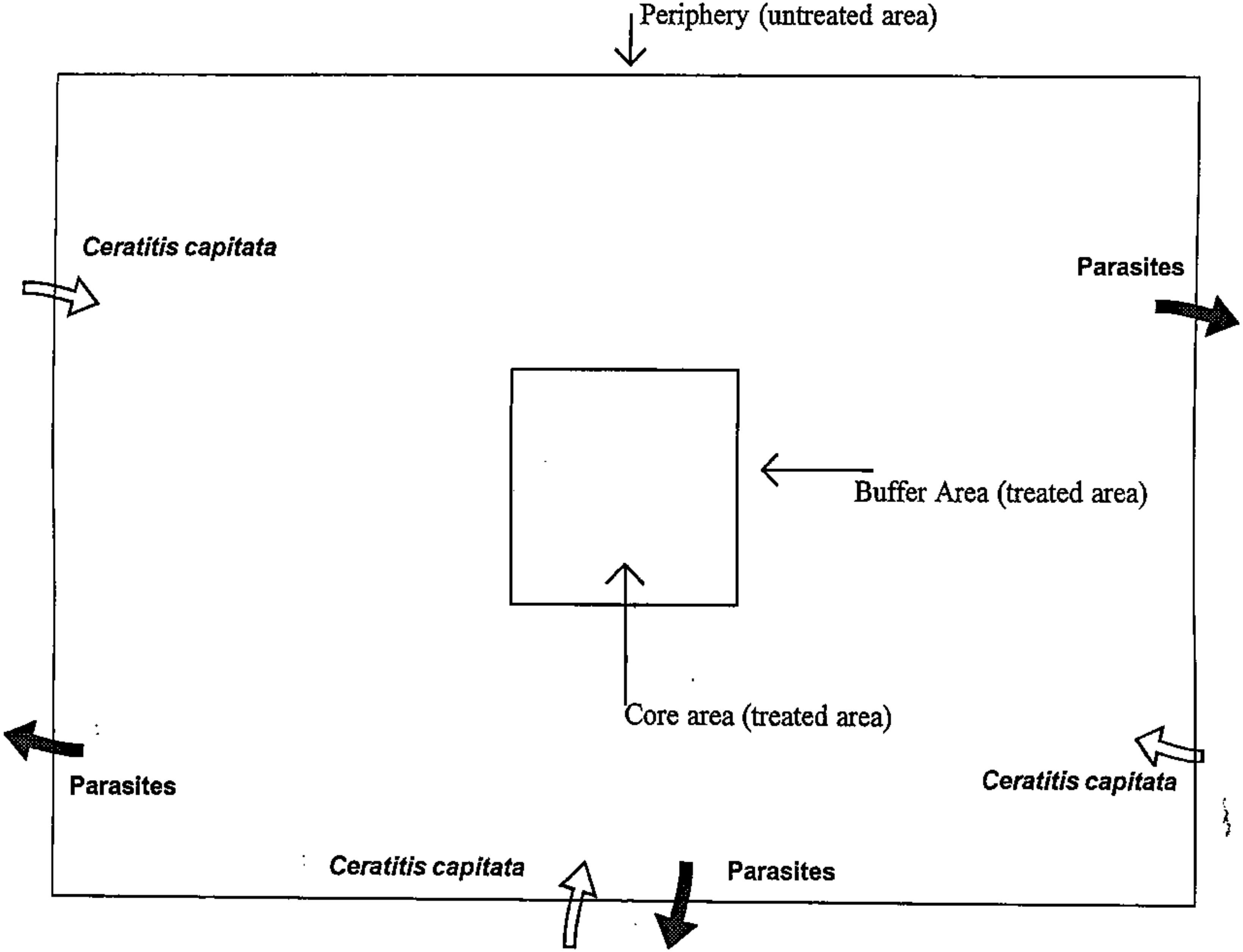
Research protocol preparation for large scale field evaluation of *Diachasmimorpha tryoni* (Ashmed).
Paper work for purchase 5 million parasitoids per week.
Contingency work plan for rearing 2 million parasitoids per week.

Year 1996

Mass-rearing of 2 million fruit fly parasitoids.
Weekly aerial releases of fruit fly parasitoid and sterile insects.
Weekly data collection from field activities.
Data analysis.

cont....

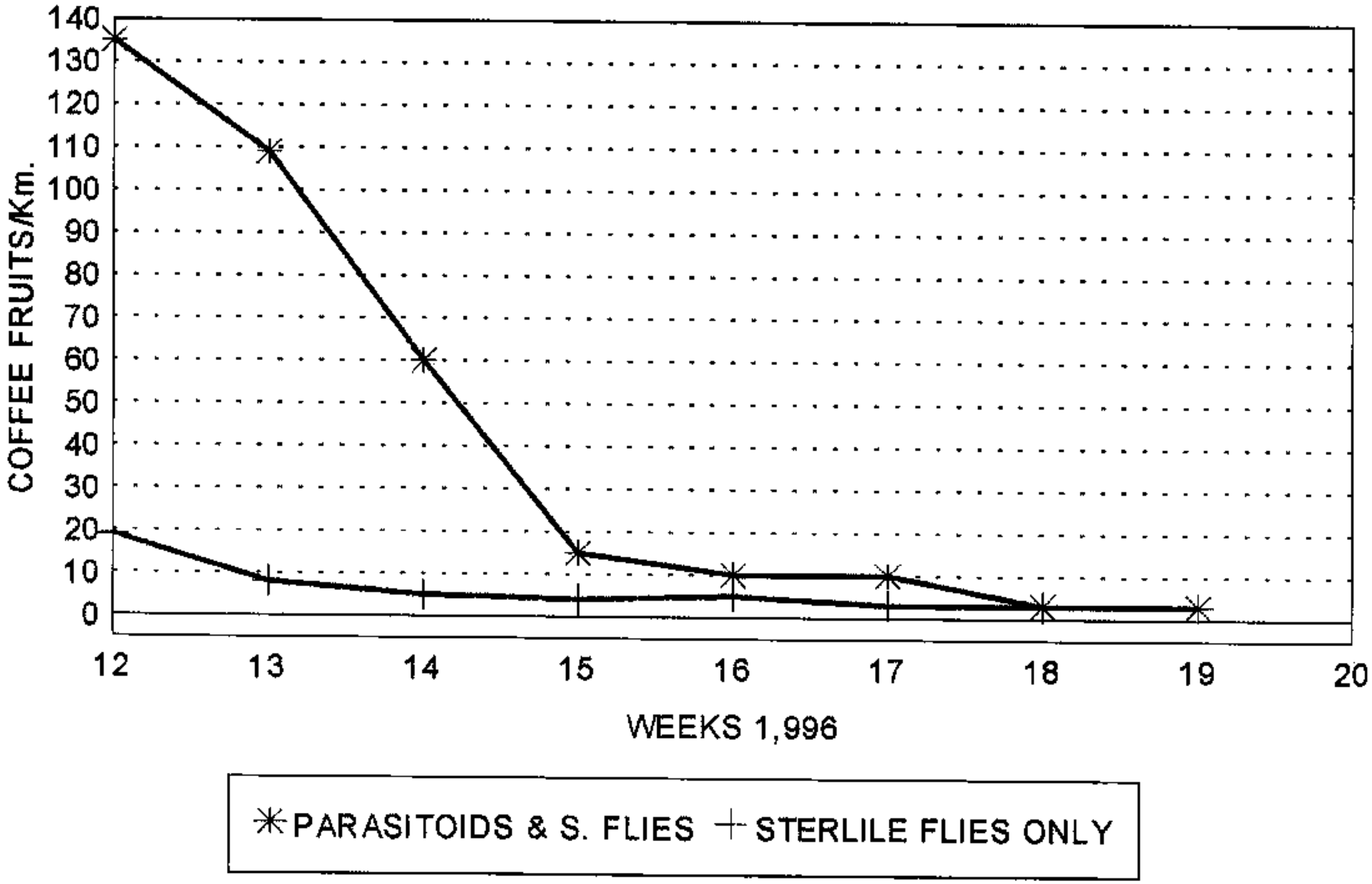
Year 2


Periphery (untreated area)
Ceratitis capitata
Parasites
Buffer Area (treated area)
Core area (treated area)
Parasites
Ceratitis capitata
Ceratitis capitata
Parasites

FRUIT FLY PARASITOIDS

Diachasmimorpha tryoni

FIELD EVALUATION

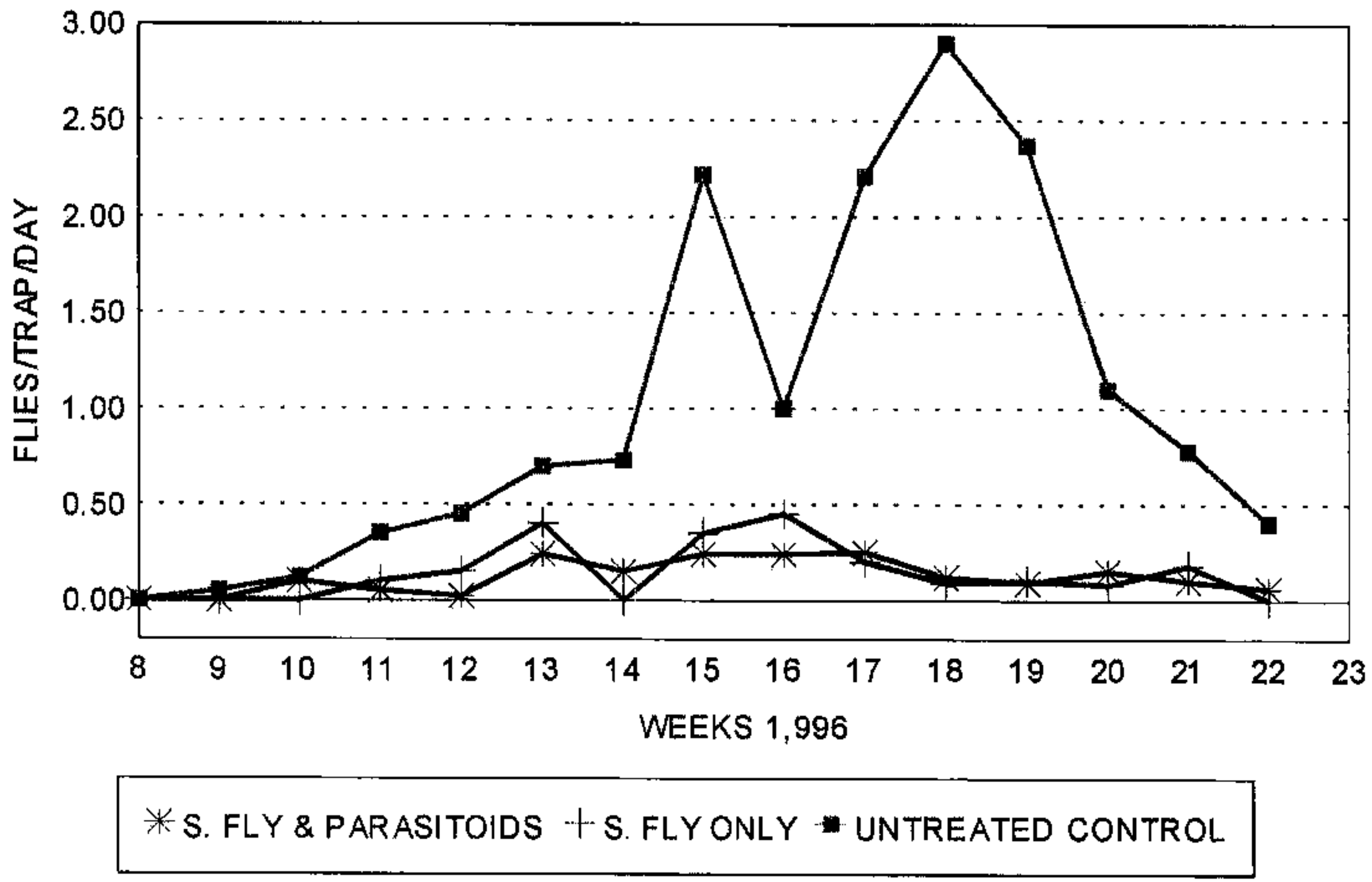


METHODS DEVELOPMENT
Guatemala 1,996.

FRUIT FLY PARASITOIDS

Diachasmimorpha tryoni

FIELD EVALUATION

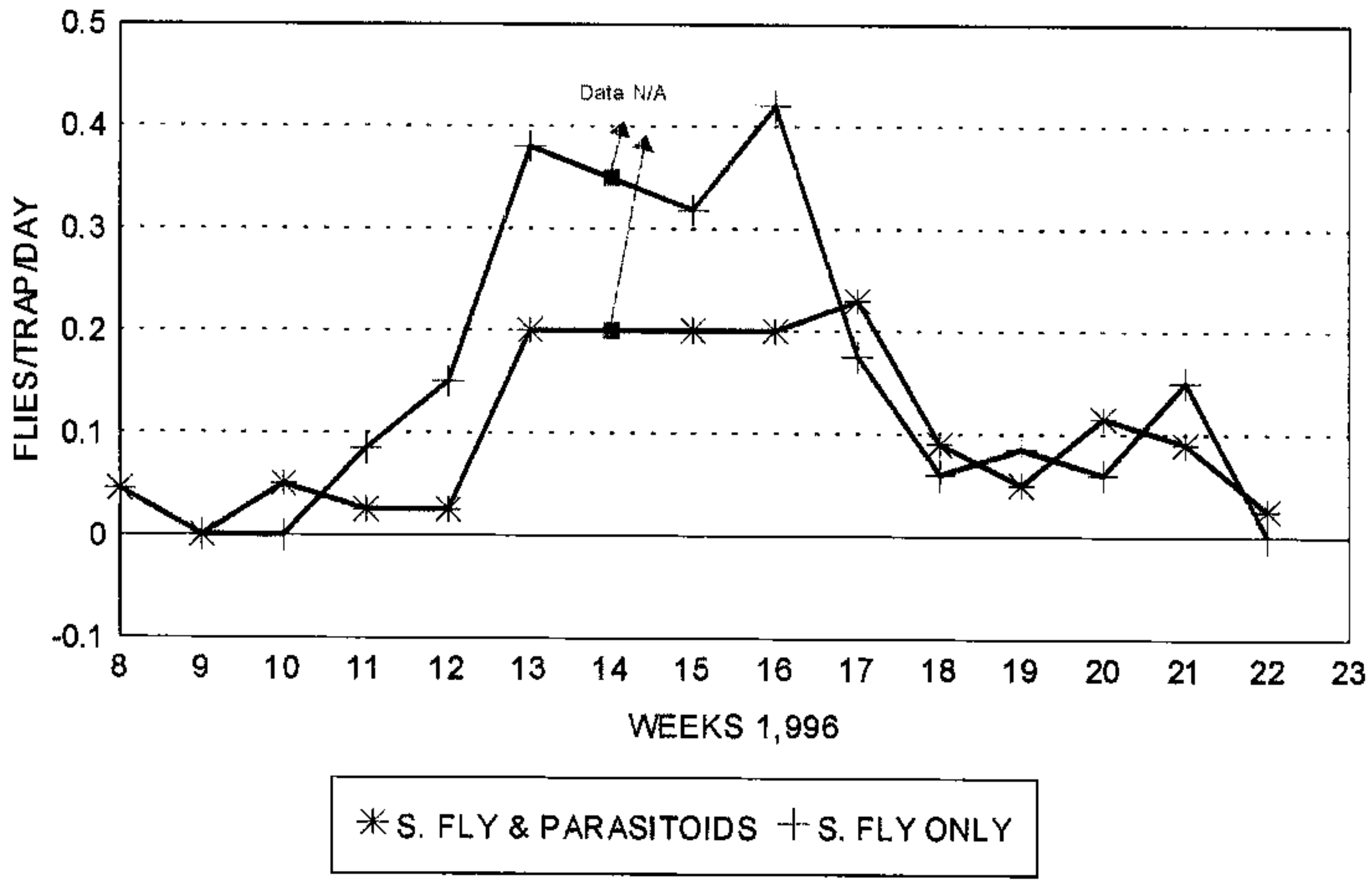


METHODS DEVELOPMENT
Guatemala 1,996.

FRUIT FLY PARASITOIDS

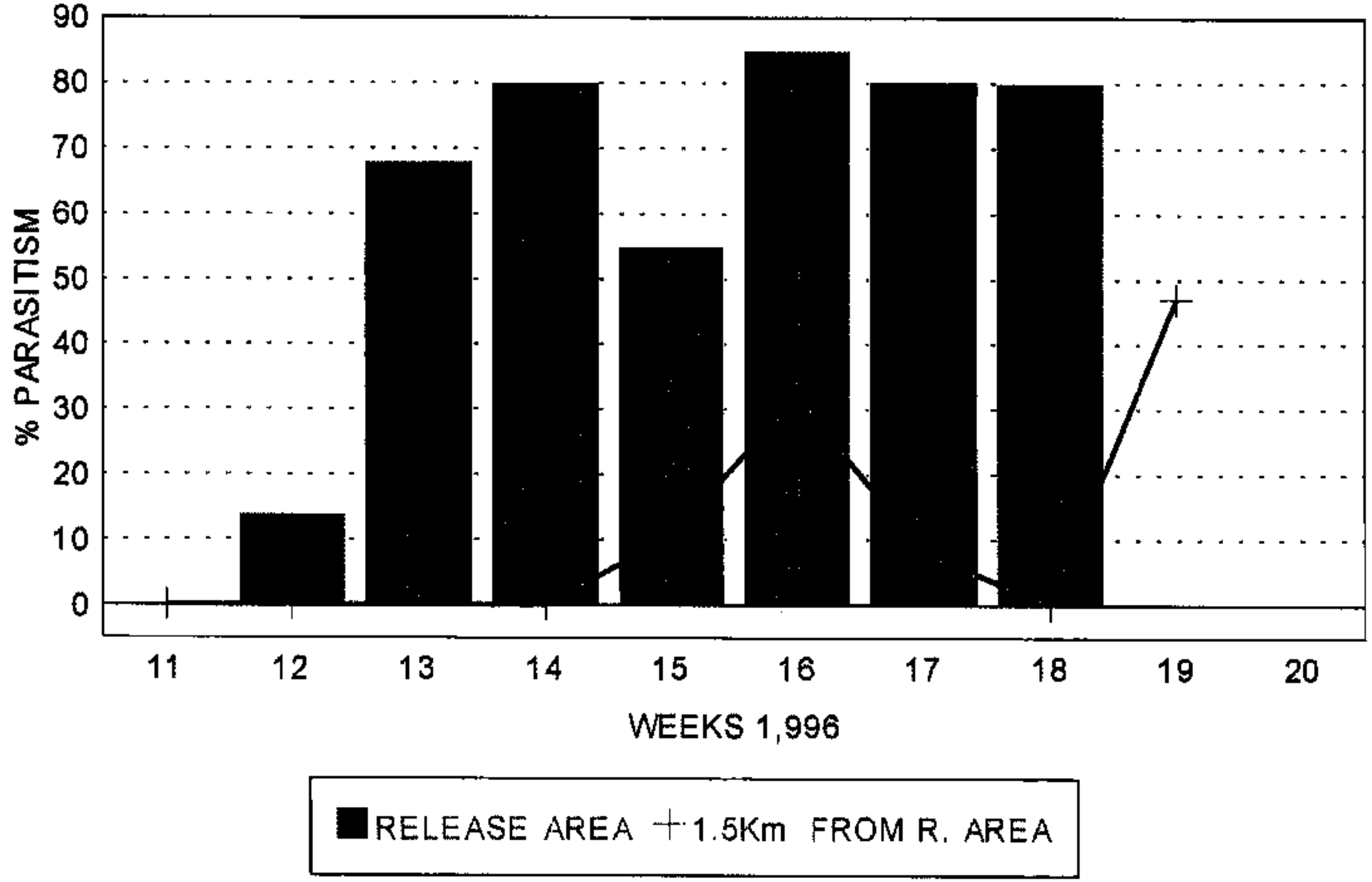
Diachasmimorpha tryoni

FIELD EVALUATION



METHODS DEVELOPMENT
Guatemala 1,996.

FRUIT FLY PARASITOIDS
Diachasmimorpha tryoni
FIELD EVALUATION



METHODS DEVELOPMENT
Guatemala 1,996.

SUMMARY OF WORK PROGRESS ON FRUIT FLY PARASITOIDS PROJECT IN GUATEMALA.

Year 1997

Colony maintenance for *D. longicaudata* and *D. tryoni*.
Introduction of new fruit fly parasitoids:
A) For larvae.
B) For pupae.
C) For egg.
Small scale rearing of new fruit fly parasitoids.
Field evaluation of new fruit fly parasitoids.
Mass-rearing of new fruit fly parasitoids (After selection)

PROCEDURE FOR SELECTION OF NEW SPECIES OF FRUIT FLY PARASITOIDS.

ESTABLISHMENT OF COLONY IN QUARANTINE

DETERMINE IN LABORATORY:
1.- Development in irradiated host
2.- Development in Anastrepha suspensa
3.- Hyperparasitism of Diachasmimorpha longicaudata

DETERMINE PARASITOID LIFE SPAN

INVESTIGATE IN FIELD CAGES, AT VARIOUS ALTITUDES AND WITH VARIOUS HOST FRUITS (e.g., coffee, caimito, sour orange)
1.- Parasitism relative to D. longicaudata
2.- Adult survival relative to D. longicaudata

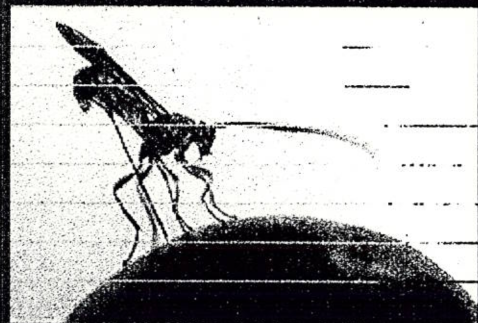
DISCARD COLONY ON THE BASIS OF HOST RANGE

DISCUSS ESTABLISHMENT WITH USDA AND MOSCAMED PERSONNEL

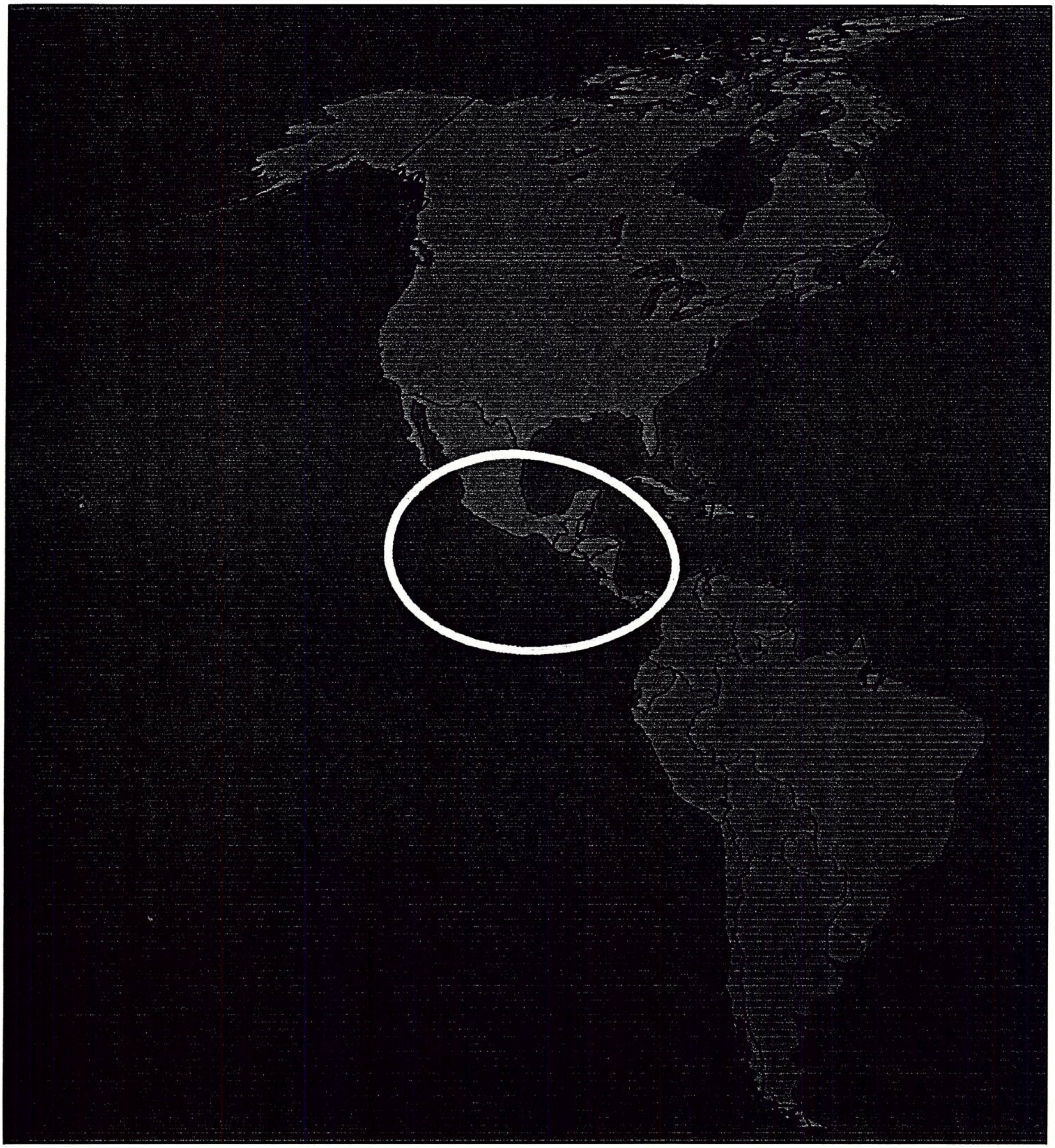
DISCARD COLONY DUE TO THE LACK OF ADAPTATION TO ENVIRONMENT OR POOR COMPETITIVENESS RELATIVE TO D. longicaudata

ATTEMPT ESTABLISHMENT (PERHAPS IN ANTIGUA AND WITH AID LOCAL FARMERS

DISCARD OR WAIT FOR FURTHER INFORMATION



REGIONAL PROJECTS



REGIONAL PROJECTS

Costa Rica:

Dr. Hernan Camacho
Diachasmimorpha longicaudata(Ashmed).
Pachycrepoideus vindemiae Rondani.
IPM Programs with mangoe and citrus growers.

El Salvador:

Ing. Gilberto Granados Zuniga.
Diachasmimorpha longicaudata (Ashmed).
Pachycrepoideus vindemiae Rondani.
IPM Programs with citrus growers.

Mexico:

Dr. Martin Aluja.
Fruit Fly Parasitoids Identification.
Fruit Fly Parasitoids Ecology.
Fruit Fly parasitoids Ethology.
Fruit Fly parasitoids Rearing.
INSTITUTO DE ECOLOGIA, Xalapa Veracruz Mex.
Biol. Jorge Cancinos
Diachasmimorpha longicaudata (Ashmed).
Diachasmimorpha tryoni (Cameron).
National IPM Program with mangoe growers in the North part of Mexico.

Guatemala:

PROGRAMA MOSCAMED.
Diachasmimorpha longicaudata (Ashmed).
Diachasmimorpha tryoni (Cameron).
Diachasmimorpha Krausii.
Coptera spp.
Tri-lateral Mediterranean Fruit Fly Action Program.

Working Paper For: FAO/IAEA Consultants Group Meeting on *Use of Nuclear Techniques for the Production and Augmentative Releases of Biological Control Agents of Insect Pests*, 14-18 April, 1997, Vienna, Austria.

THE POTENTIAL ROLE OF NUCLEAR TECHNIQUES TO FACILITATE THE USE OF BIOLOGICAL CONTROL AGENTS, AN INDUSTRIAL PERSPECTIVE

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Biological control is a critical component of Integrated Pest Management (IPM). One strategy of biological control includes augmentation with mass-reared predator and parasitic arthropods (natural enemies). These living organisms must be produced, delivered, and applied in such a manner as to achieve the desired outcome. Increased production and use of natural enemies can be achieved by addressing current constraints, including: high cost of production, very limited storage time, shipping difficulties, inefficient application technology, lack of understanding of the role of these organisms in insect pest management, and lack of enabling regulations. The appropriate use of nuclear techniques could benefit the industry and facilitate the use of these natural enemies if cost-effective, safe, readily accessible facilities are made available.

Nature of the Industry and Its Products

Important distinctions must be made between the commercial and non-commercial insectary. (The term 'insectary' is used by commercial producers of natural enemies as an inclusive term covering production of arthropods in general). The commercial insectary **must** satisfy the customer as the customer is the means of funding and does have a choice. The unsatisfied customer may turn to a competitor in the same industry, or attempt to solve pest problems with chemicals. To further complicate the issue for the commercial producer, satisfaction is **not** guaranteed by delivering a high quality organism which performs as intended. The role of these organisms is complex and not well understood by most customers, thus education also becomes an industry responsibility. For example, pteromalids (pupal parasites of the housefly) are commercially available for control of muscoid flies. The use of these parasites should be viewed only as a component of the pest management program because good sanitation is also a crucial element to the successful suppression of flies. Even when good parasites are delivered the customer may or may not be satisfied for various reasons. These include unrealistic expectations that the commercial product eliminates the need for other crucial program components, possible improper handling of the live organisms, and the misconception that the parasite will attack adult flies migrating into the area. Further, when customer expectation is high, but uneducated, the "results" are viewed differently than when customer expectation is knowledgeable. In the case of fly populations, the tolerance level of one customer can be very different than that of another customer, resulting in a different level of satisfaction.

The commercial insectary industry grew out of the need for a continuous source of predators and parasites. For example, in 1959 and 1960, USDA and University of California scientists introduced *Aphytis melinus* to combat California red scale, *Aonidiella aurantii*, in citrus. The insect did not successfully overwinter and become established in all areas, so production for augmentation was necessary. Today, seven commercial insectaries produce approximately 1.5 billion *A. melinus* to release each year. The widespread use of this parasite has lead to the development of guidelines to test for detrimental pesticide residues and release rates by the University of California (UC IPM Pest Management Guidelines). In Europe, a similar need led to commercial production and sales of *Encarsia formosa*, a whitely parasite, and *Phytoseiulus*, a predator mite. In spite of the success (and need) for biological control agents, authorities in London did not agree that researchers at the Glasshouse Crops Research Institute (GCRI) should mass-rear the organisms so effort was made to interest individuals. Successful use of the biological control agents resulted in a growing commercial industry in Europe (Hussey & Scopes, 1985). In the late 1980's, *Phytoseiulus persimilis* became an important component of the California strawberry pest management program; pesticide resistance and loss of registration of miticides led to more commercial production in the USA.. Approximately 75% of the California strawberry growers use *P. persimilis* in the program (Scriven 1997, Pers. Com.).

More than 100 producers and suppliers are listed for North America alone, (Hunter, 1997), yet on a world wide basis, the industry represents less than 1% of the arthropod pest control market (Ridgway, 1997). Companies include small family businesses with gross incomes less than US $50,000 per year, cooperative insectaries (owned by a group of farmers who only sell when they have excess production), and companies who gross more than one million dollars per year.

Production

Commercial insectaries may establish production according to previously published information, but often make improvements and require a certain amount of confidentiality. Of relevance to this discussion is the possibility of improving production and/or reducing production costs through the use of nuclear techniques. Research has already demonstrated the value of nuclear techniques for some natural enemy production systems (cf. Greany Working Paper) and commercial insectaries can benefit. Beneficial Insectary has experimented with UV light and gamma radiation of hosts, but the lack of cost-effective, readily accessible facilities has resulted in the continued use of a less desirable method. For example, *Trichogramma* require host eggs collected from mass-reared moths, which require massive quantities of wheat or other grain products. Commercial production is dictated by a market that expects product "on demand." The organisms, however, must be produced according to the life cycle of the host and of the natural enemy. Any advantage gained by reducing the complexity of either life cycle can save production costs. Much has been accomplished in the area of artificial diet, but not enough to provide a consistent supply of healthy organisms; moth eggs (hosts) are still required. Host irradiation has great potential for reducing production cost and preventing other possible contamination. Cost reduction occurs as the useful life of the host increases (through appropriate irradiation). We continue to use UV light because it is safe, readily available and inexpensive. Gamma radiation would be quicker, more consistent and allow for longer storage, but is not readily available for our purpose.

Storage and Shipping

Very limited storage time continues to be a major constraint in the commercial production and use of arthropod biological control agents. Storage is a factor in production as well as shipping and use of the organism. The product is highly perishable and cannot be produced in sufficient numbers on a daily basis; some storage (a few days) is usually necessary. The organism is packed and shipped according to best available methods. For example, pteromalids are shipped inside the host pupae and do not require additional food, overnight delivery, or ice packs. *Trichogramma* and *Chrysoperla* eggs require second day delivery and ice packs, but no additional food. Predatory mites, such as *P. persimilis*, however, require overnight shipping, ice packs and prey food. Prey food is also frequently included in shipments of some immature parasites. Nuclear techniques may prove efficient for irradiating the prey food without compromising its intended use. Such irradiation would be extremely useful in mitigating any potential concern of introducing a pest (including a chemically resistant strain) along with the natural enemy.

Application

Timing the release of natural enemies is crucial. Predators must have prey; parasites must have hosts. Nuclear techniques could prove useful in implementation strategy. Irradiated host/prey introduced with the natural enemy would allow more flexibility in the timing of releases and potentially lower costs. For example, *Chrysoperla* are effective predators which cost ten times more when purchased as larvae compared to the cost of eggs. New technology allows for the calibrated delivery, distribution and adherence of *Chrysoperla* eggs to the target plant (Penn, 1995). The potential to add food during the delivery of eggs may allay reported variations in effectiveness (Daane, 1993). Irradiated prey/food would be less expensive than the current use of frozen *Ephestia* or *Sitotroga* eggs. This approach would allow *Chrysoperla* larvae to have access to a first feeding before the pest population is high, allowing earlier releases and promoting growth of newly-emerged predators. More *Chrysoperla* could then successfully feed on more pests than would be possible without the initial feeding.

Field insectaries could be created if irradiated prey/host food is acceptable to the released natural enemy. For example, *P. persimilis* are currently reared on (and shipped with) live prey mites. The potential exists to introduce cost-effective numbers of the predator and build up the population in the field prior to pest arrival. *Trichogramma* may also be a candidate for such a field insectary approach. Strategically placed irradiated moth eggs may provide another means of increasing populations of this natural enemy prior to pest arrival.

Summary

Nuclear techniques could facilitate the use of natural enemies by reducing production costs, increasing storage time, allaying shipping difficulties, aiding the implementation strategy, and mitigating regulatory concerns. Cooperative research and development is needed, but the availability of cost-effective facilities and equipment is equally important for commercial feasibility.

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Appendix 3: Proposed Coordinated Research Programme

1. Title

Use of Nuclear Techniques in Biological Control to Improve Production, Facilitate Trade and Increase Environmental Protection

2. Background Situation Analysis

Biological control is often constrained by costly production systems for natural enemies and by the presence of accompanying pest organisms during shipment. Both of these problems may be ameliorated by use of nuclear techniques to reduce production costs and to eliminate the risk associated with the presence of hitchhiking pests.

3. Overall Objective

To increase the cost-effectiveness and safety of augmentative biological control.

4. Specific Research Objective (Purpose)

To improve production and use of biological control agents by using nuclear techniques to: (a) inhibit reproduction of pests (hosts), (b) abrogate defensive reactions of hosts/prey, and (c) reduce microbial load of media.

5. Expected Research Outputs (Results)

Determine benefit of irradiating hosts/prey on successful parasitization/predation

Increase shelf life of hosts by irradiation

Increase availability of sterilized media (including media sterilized after packaging) for mass-rearing of natural enemies

Reduce the likelihood of spreading hitchhiking pests by irradiating organisms to be used as food for natural enemies

Create alternate uses for by-products of mass-rearing facilities (spent diet, excess production, etc.)

Better pre-release evaluation of natural enemies of weeds by releasing sterile adults and substerile F-1 immatures to evaluate their potential impact on non-target species

Increased pest suppression by combining natural enemies and sterile insects in IPM and AWPM programmes

Publication of results, including a TECDOC, scientific journal articles, etc.

6. Action Plan (Activities)

Activity 1. Formation of a Network of Researchers to Evaluate the Use of Nuclear Techniques for Improved Biological Control

The CRP will involve researchers from some of the following developing and developed countries: Argentina, Australia, Brazil, China, Costa Rica, Czech Republic, Indonesia, Israel, Mexico, Pakistan, Philippines, Poland, Syria, Thailand, Turkey and the USA, and possibly private sector firms. Selection will be based on the relevance of this problem to Member States, based on the scientific qualifications of counterparts, availability of appropriate equipment and research settings, and the quality of proposals obtained.

Activity 2. Award of A Technical Contract

Detail purpose and name of institute after CRP announced, revised, etc.

Activity 3. Organize 1st Research Coordination Meeting to Agree on Protocol and Cooperation for Work to Deliver Specific Outcomes

Details to be provided after contracts approved.

Activity 4. Organize 2nd Research Coordination Meeting to Analyze the Progress Toward Delivering Specific Outcomes Identified at the first Meeting

Details to be provided after contracts approved.

Activity 5. Publish a TECDOC on the Results of the CRP
Details to be provided after contracts approved.

Coordinated Research Project on Use of Nuclear Techniques in Biological Control

Action Plan (cont.) - Research and Reporting Activities by topic:

P1: Determine the possibility of using ionizing radiation (gamma x-ray, or electron beam) to improve the suitability of natural or factitious hosts/prey for use in parasitoid/predatory mass-rearing

Anticipated Activities for Project P1		**YEAR**				
		1	**2**	**3**	**4**	**5**
Phase I: Start up						
A01	Confirm inputs	X				
A02	Confirm source of irradiation is available	X				
A03	Rationalize organism (BCA) for natural host	X				
A04	Rationalize organism (BCA) for factitious host	X				
A05	Identify contingency organism(s)	X				
A06	Train personnel	X				
A07	Prepare programme logic model plan	X				
A08	Attend IAEA technical co-ordination meetings	X				
A09	Prepare experimental design/research protocol	X				
Phase II: Preliminary Experimentation						
A10	Conduct preliminary experiments	X				
A11	Prepare yearly Annual Report	X	X	X	X	X
A12	Refine experimental plan		X			
A13	Oversight and review by colleagues		X		X	
Phase III: Scale up						
A14	Perform cost:benefit analyses				X	
A15	Scale up for large-scale uses				X	
Phase IV: Technology Transfer						
A16	Initiate technology transfer					X
A17	Publication and final report to IAEA					X

P2: Determine the efficacy of ionizing radiation for use in sterilizing artificial media for parasitoid/predator mass-rearing. Dose effect studies should be performed to determine irradiation effects on microbial load and to evaluate any adverse effects on the nutritional quality of the diet.

Anticipated Activities for Project P2		**YEAR**				
		1	**2**	**3**	**4**	**5**
Phase I: Start up						
A01	Confirm inputs	X				
A02	Confirm source of irradiation is available	X				
A03	Rationalize organism (BCA)	X				
A04	Select diet and presentation system	X				
A05	Identify contingency organism(s)	X				
A06	Train personnel	X				
A07	Prepare programme logic model plan	X				
A08	Attend IAEA technical co-ordination meetings	X				
A09	Prepare experimental design/research protocol	X				
Phase II: Preliminary Experimentation						
A10	Conduct preliminary experiments	X				
A11	Prepare yearly Annual Report	X	X	X	X	X
A12	Refine experimental plan (include shelf life studies)		X			
A13	Oversight and review by colleagues		X		X	
Phase III: Scale up						
A14	Perform cost:benefit analyses				X	
A15	Scale up for large-scale uses				X	
Phase IV: Technology Transfer						
A16	Initiate technology transfer					X
A17	Publication and final report to IAEA					X

T1: Determine the feasibility of ionizing radiation needed to reproductively sterilize hosts or prey used as food to be shipped with biological control agents.

Anticipated Activities for Project T1		**YEAR**				
		1	**2**	**3**	**4**	**5**
Phase I: Start up						
A01	Confirm inputs	X				
A02	Confirm source of irradiation is available	X				
A03	Rationalize organism (BCA) for natural host/prey	X				
A04	Identify contingency organism(s)	X				
A05	Train personnel	X				
A06	Prepare programme logic model plan	X				
A07	Attend IAEA technical co-ordination meetings	X				
A08	Prepare experimental design/research protocol	X				
Phase II: Preliminary Experimentation						
A09	Conduct preliminary experiments	X				
A10	Prepare yearly Annual Report	X	X	X	X	X
A11	Refine experimental plan (include shelf life studies)		X			
A12	Oversight and review by colleagues		X		X	
Phase III: Scale up						
A13	Perform cost:benefit analyses				X	
A14	Scale up for large-scale uses				X	
Phase IV: Technology Transfer						
A15	Initiate technology transfer					X
A16	Publication and final report to IAEA					X

T2: Determine the benefit of using irradiated hosts/prey as supplemental hosts/food for field populations of natural enemies. Laboratory tests on effects of radiation on parasitization or feeding should be performed, and field tests on application rates for irradiated hosts/prey should be conducted.

Anticipated Activities for Project T2		**YEAR**				
		1	**2**	**3**	**4**	**5**
Phase I: Start up						
A01	Confirm inputs	X				
A02	Confirm source of irradiation is available	X				
A03	Rationalize organism (BCA) for natural host/prey	X				
A04	Identify contingency organism(s)	X				
A05	Train personnel	X				
A06	Prepare programme logic model plan	X				
A07	Attend IAEA technical co-ordination meetings	X				
A08	Prepare experimental design/research protocol	X				
Phase II: Preliminary Experimentation						
A09	Conduct preliminary experiments	X				
A10	Prepare yearly Annual Report	X	X	X	X	X
A11	Refine experimental plan (include shelf life studies)		X			
A12	Oversight and review by colleagues		X		X	
Phase III: Scale up						
A13	Perform cost:benefit analyses				X	
A14	Scale up for large-scale uses				X	
Phase IV: Technology Transfer						
A15	Initiate technology transfer					X
A16	Publication and final report to IAEA					X

7. Inputs

--Availability of irradiation source (gamma-ray, x-ray or e-beam).
--Facilities and equipment
--Personnel
--Communications capabilities
--Cultures of biological control organisms
--Adequate funding
--Training and trainers
--Time
--Philosophical backing to conduct work

8. Assumptions

Enabling regulatory structure that facilitates use of biological control agents.

9. Brief Summary for the IAEA Bulletin

High-priority opportunities are proposed for use of nuclear techniques to effect improved production and shipping of augmentative biological control agents. Proposed subprojects include use of ionizing radiation to improve the production of insect natural enemies on natural hosts/prey or on artificial diets. Other subprojects pertain to improving the ability to move beneficial organisms in international trade, and in using them in the field. Additional high priority activities were identified proposing use of nuclear techniques to produce sterile and/or substerile F-1 weed biological control agents to help evaluate potential impact on non-target species in the pre-release phase, integration of augmentative releases and F-1 sterility in IPM and area-wide pest management programmes, and utilzation of by-products from SIT mass-rearing facilities in augmentative biological control programmes.