AREA-WIDE CONTROL OF INSECT PESTS

Area-Wide Control of Insect Pests

From Research to Field Implementation

Edited by

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in Food and Agriculture,
Vienna, Austria

Springer

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN 978-1-4020-6058-8 (HB)
ISBN 978-1-4020-6059-5 (e-book)

Published by Springer,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

www.springer.com

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Preface

The world population is still growing at an alarming rate, requiring ever increasing productivity and less waste in agriculture to cope with the increasing demands to satisfy food security for all humans. Alleviation of poverty is in many countries hampered by a myriad of insect pests that cause enormous economic losses to agricultural commodities, both at the pre- and postharvest stages. Initially, most of these insect pests were controlled to a varying degree by the use of broad-spectrum insecticides. However, the indiscriminate use of these chemicals as a control tactic is no longer sustainable in view of increased development of resistance, pollution of soils and surface water, residues in food and the environment, representing risks to human health and biodiversity, etc. As a consequence, demands have been voiced at least since "Silent Spring" in 1962 for control tactics and approaches that are not only efficient, but also sustainable and friendlier to the environment.

Integrated pest management (IPM) has been accepted since the 1960's and 70s as a viable pest management strategy that aims at integrating control tactics to maintain damage levels below a certain economic threshold level whilst also protecting the environment by thriving to limit the use of pesticides. Classical IPM is however a localized approach, with the objective of protecting crops or livestock that is largely under the control of each farmer, with little collaboration or any coordinating structure. Control is exercised only in the areas of economic interest, often resulting in the main or residual pest population pockets remaining in the surrounding areas that have no economic value. These constitute permanent sources from where the commercial areas under control are re-invaded.

A quite different, more efficient and sustainable approach is the integration of control tactics against an entire pest population, i.e. area-wide integrated pest management (AW-IPM) or total population management. The AW-IPM is a coordinated, sustainable and preventive approach that targets pest populations in all areas, including non-commercial urban settings, non-cultivated and wild host areas.

The coordination required among farmers and all other stakeholders for an area-wide approach, makes AW-IPM programmes complex, management intensive, requiring long-term commitment and funding. Although they result in more sustainable control of insect pests, there is by no means a guarantee for success. This new textbook on area-wide control of insect pests collates a series of selected papers that attempts to address various fundamental components of AW-IPM, e.g. the importance of relevant problem-solving research, the need for essential baseline data, the significance of adequate tools for appropriate control strategies, and the value of pilot trials, etc. Of special interest are the numerous papers on pilot and operational programmes that pay special attention to practical problems encountered during programme implementation.

The book is a compilation of 66 papers that are authored by experts from more than 30 countries. Each paper was peer-reviewed by at least one, in most case two or more independent, outside experts and edited for the English language by Dr James Dargie, former Director of the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture. We both thank the many reviewers and Jim whose meticulous work and suggestions improved many of the papers. In addition, the editors subjected each paper to an in-depth technical quality control process. As a result, we trust that the technical quality of the papers is optimal, the information provided accurate, up-to-date and of a high international standard. This process of peer-review, editing and formatting has taken considerable time and we appreciate the patience of the authors.

The Editors
June 2007

DISCLAIMER

Introductory Remarks

Since area-wide integrated pest management (AW-IPM) programmes almost always are social enterprises each with a diverse set of stakeholders reliant on advanced technology, they tend to be complex to implement, especially in terms of management. Therefore, the appearance of this book, "Area-wide control of insect pests: from research to field implementation" is most timely, and it will be invaluable for informing concerned scientists, leaders of private firms, commodity organizations and public agencies, bankers, legislators, students and those interested in placing management of major insect pest problems on a sustainable and environmentally acceptable footing.

Although the need to develop and implement more effective strategies of combating pests and pathogens has always been dire, the urgency of this challenge has increased sharply for two reasons. The first reason is the rapid increase in the world population, which more than doubled from roughly 2.5 billion to 6 billion people in the second half of the 20th century; and the second reason is that the rapid globalization of travel and trade in agricultural and other products has dramatically increased the spread of pests, pathogens and other invasive harmful organisms.

Many of the economically most damaging pests are invasive alien species that have escaped the constraints, which keep their populations in check in their regions of origin. In North America roughly one-half of the major pests originated abroad, and this seems also to be true in other continents. Major exotic pests and pathogens – many adapted for wide dispersal and high rates of reproduction – are becoming established with increasing frequencies on all continents and on many ecologically sensitive islands. Therefore, to facilitate the expansion of international agricultural trade while minimizing the further spread of some major pests, commodities of which they are hosts are increasingly produced for export in pest free areas or in areas of low pest prevalence that obtained their favourable phytosanitary status through AW-IPM approaches.

Currently, for the most part, the control of many highly mobile and very destructive insect pests is still carried out by individual producers who rely heavily on the use of broad-spectrum insecticides. Although other control technologies are often incorporated into the producer's IPM system, these technologies, too, are usually applied by producers independently of other producers, and without due consideration of surrounding host and non-host areas. Such an uncoordinated farm-by-farm IPM pattern provides opportunities for the pest population to build up and to establish damaging infestations.

Consequently, on most farms insect pest populations increase to damaging levels each year, and the farmer is forced to apply fast-acting insecticides as a rescue treatment. This defeats the primary goal of the IPM system, which is to take maximum advantage of naturally occurring biological control agents. Similarly in combating pests and pathogens of concern to human and animal well-being, less than thorough treatment of the entire population fails to provide durable relief. Thus the key concept of the AW-IPM strategy is to address the whole pest population including all places of refuge or foci of infestation from which recruits could come to re-establish damaging densities of the pest population in areas of concern.

The area-wide approach is not new, but originated several thousand years ago. In the Roman Empire it was recognized that some services carried out area-wide were more efficient and cheaper than when left to the action of individual citizens. As such, garbage was diligently removed from some cities, clean water was brought from distant sources and public baths were provided. The sudden appearance in 1347 of Black Death, a bacterial disease transmitted by the flea, *Xenopsylla cheopis* (Rothschild), led to the invention of quarantine to contain the epidemic and to stamp it out. Beginning in the late 1920s, when catastrophic locust plagues were widespread in Africa and southwest Asia, continent-wide campaigns have been organized to protect against highly devastating locust species; and these campaigns, now led by FAO's Locust Group, employ sophisticated technologies. During the past one-half century the area-wide application of the sterile insect technique in combination with other technologies against an array of major insect pests has served to focus the attention of scientists and administrators on ways of applying the area-wide approach in the combat against many other pests and diseases.

The principles of AW-IPM are addressed in this book's introductory chapter. The chapter argues that each fundamental component of classical IPM, be it a cultural, biological or chemical control tactic, applied against an entire insect population (total population management) will lead in most cases to more sustainable pest control as compared to a localized farm-by-farm approach. Some fundamental management and strategic challenges of AW-IPM programmes are likewise addressed, including the make or break environmental and economic issues.

Successful AW-IPM programmes require basic research and preparatory activities including methods development, feasibility studies, pilot trials and a regulatory framework. These aspects are dealt with in subsequent sections. Section 2 covers and illuminates several important basic research areas including genetics, transgenesis, genetic sexing, cryobiology, physiology, insect symbionts and mating behaviour strategies.

Ecological heterogeneity at within field, within farm, and broader spatial scales profoundly affects the population dynamics of pests and their natural enemies and other aspects of their ecology. Methods of systems analysis, mathematical modelling and a number of geo-spatial technologies (geographic information systems and global positioning system) have been adapted to cope with the spatio-temporal complexity in AW-IPM programmes and have contributed greatly to increased effectiveness and efficiency of programme activities. These and other methods development tools are described in section 3.

Feasibility studies addressing economic, social and technical considerations are required prior to any major and costly field programme. A science-based analysis of these considerations will enable a judgment to be made as to whether the various control tactics can be applied on an area-wide basis and whether the envisioned control strategy is the most appropriate for the particular pest situation. Section 4 provides examples of how such elucidating studies have been conducted for different pest situations.

AW-IPM programmes are dependent on the synergistic collaboration of many stakeholders. They require the entry onto private properties. They can affect the movement of goods, and they can also impact or inconvenience the non-farming community. Thus AW-IPM requires that a sensitive and effective regulatory framework be developed by the relevant national and international regulatory agencies. Commercialization of part or even entire AW-IPM programmes, a complex and sometimes contentious issue, holds the promise of properly capitalizing such programmes, introducing efficiencies and tackling pest problems that government cannot afford to address. These regulatory and privatization issues are discussed in section 5.

Pilot field programmes are often carried out following a feasibility study with a favourable outcome. Such programmes are needed to evaluate and fine-tune various control tactics and field methodologies to increase their effectiveness and efficiency. Pilot programmes can vary in size and scope as is described in the chapters in section 6.

Section 7 describes operational AW-IPM programmes against key pests such as the boll weevil, several lepidopteran pests, the bont tick, termites, mosquitoes, fruit flies, etc. Several of the chapters emphasize the technical and managerial difficulties encountered during the implementation of eradication, suppression, containment or preventive AW-IPM programmes and attempt to extract important lessons.

As a concluding chapter (section 8) a critical review is provided of AW-IPM programmes in terms of their successes and failures, and key factors are identified which must be addressed in order to improve the chance of success.

The chapters in this text book originate from papers and selected posters presented at the 2nd FAO/IAEA International conference on area-wide control of insect pests. To complete the book, several invited chapters have been included. This book is an invaluable compendium of reports on operational AW-IPM programmes. It will help to further develop the theory, technology and practice of such programmes. Graduate students will learn much about the history, accomplishments, problems and the great potential of the area-wide strategy. Entrepreneurs and policy-makers will gain in-depth perspective on aspects of commercialization.

I am honored greatly to have been asked to write these introductory comments in this text book devoted to the area-wide management of insect pests. The prodigious progress in AW-IPM made in recent decades confirms that the area-wide strategy has a far greater potential than any other approach to achieve sustainable management of many major insect pests. Truly we are now at the beginning of an era of decidedly improved and sustainable insect pest management.

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Section 1

Setting the Scene

Area-Wide Integrated Pest Management (AW-IPM): Principles, Practice and Prospects

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ABSTRACT Integrated pest management (IPM) has remained the dominant paradigm of pest control for the last 50 years. IPM has been endorsed by essentially all the multilateral environmental agreements that have transformed the global policy framework of natural resource management, agriculture, and trade. The integration of a number of different control tactics into IPM systems can be done in ways that greatly facilitate the achievement of the goals either of field-by-field pest management, or of area-wide (AW) pest management, which is the management of the total pest population within a delimited area. For several decades IPM and AW pest control have been seen as competing paradigms with different objectives and approaches. Yet, the two "schools" have gradually converged, and it is now generally acknowledged that the synthesis, AW-IPM, neither targets only eradication, nor relies only on single control tactics, and that many successful AW programmes combine a centrally managed top-down approach with a strong grass-roots bottom-up approach, and that some are managed in a fully bottom-up manner. AW-IPM is increasingly accepted especially for mobile pests where management at a larger scale is more effective and preferable to the uncoordinated field-by-field approach. For some livestock pests, vectors of human diseases, and pests of crops with a high economic value and low pest tolerance, there are compelling economic incentives for participating in AW control. Nevertheless issues of free riders, public participation and financing of public goods, all play a significant role in AW-IPM implementation. These social and managerial issues have, in several cases, severely hampered the positive outcome of AW programmes; and this emphasises the need for attention not only to ecological, environmental, and economic aspects, but also to the social and management dimensions. Because globalization of trade and tourism are accompanied by the increased movement of invasive alien pest species, AW programmes against major agricultural pests are often being conducted in urban and suburban areas. Especially in such circumstances, factors likely to shift attitudes from apathy to outrage, need to be identified in the programme planning stage and mitigated. This paper reviews the evolution and implementation of the AW-IPM concept and documents its process of development from basic research, through methods development, feasibility studies, commercialization and regulation, to pilot studies and operational programmes.

KEY WORDS area-wide IPM, field-by-field IPM, suppression, eradication, feasibility studies, pilot programmes, operational programmes, commercialization, regulation, public good, free rider, public participation

M.J.B. Vreysen, A.S. Robinson and J. Hendrichs (eds.), Area-Wide Control of Insect Pests, 3–33.

1. Introduction

If major advances are to be made in coping with most of the major arthropod pest problems, then the tactics and strategies for managing such insects, ticks and mites must change. They must change from the current, limited scale, reactive, broad-spectrum measures to preventive measures that are target-pest specific and rigidly applied on an area-wide basis (Knipling 1992).

Around 850 million people remain malnourished (FAO 2006) in spite of significant progress over the last four decades towards food security in several regions of the world, and numerous positive developments in the area of food and agriculture. In 1996, the World Food Summit held in Rome, Italy addressed this persistent crisis by launching the very ambitious goal, later incorporated into the Millennium Development Goals, of halving the number of hungry people by 2015 (FAO 1996). However, the Food and Agriculture Organization of the United Nations (FAO) has analysed the world food insecurity situation and indicated that, unfortunately, progress is insufficient to meet the Summit's target (FAO 2006). Furthermore, the world population is expanding by ca 75-80 million people each year, and most likely will rise to about 9000 million by the year 2050, and thus require food production levels at least 50% higher than those in 2000 (Alexandratos 1999). At the same time agricultural research and extension budgets and aid to agriculture are shrinking, natural resources are degrading, and the growth of the world's agricultural production is continuing to slow down (Bautista and Valdés 1993, Braun et al. 1993, Alexandratos 1999).

This continued rapid growth of the world population, which is causing the biggest surge in demand for food in history, including demands for significantly more animal proteins (Delgado et al. 1999) and biofuels, stands in stark contrast to the shrinking *per capita* land area available for agriculture. This discrepancy cannot be addressed by horizontal agricultural expansion, i.e. by an increase in cultivated surface area, but requires development and promotion of more intensive cropping and livestock systems on existing farmland (Borlaug 1997). Access to new technologies and the knowledge to use or adapt them locally will be vital, coupled with less wastage and improved penetration into national and global markets. As expansion of arable land will only play a minor role in some regions and attaining substantial increases in crop yields will become increasingly difficult in others, the focus will have to shift towards a more efficient use of agricultural resources (Trewavas 2001). There could hardly be a less efficient use of resources than to invest land, water, fertilizer, seeds, labour, and energy to produce agricultural commodities, only to have the investment partially or totally destroyed by insects or other pests. Preharvest losses in developing countries are estimated at more than one third of attainable crop production, while postharvest losses add at least another 10-20%. Insects, followed by pathogens and weeds, cause the largest portion of these losses (FAO 1975, Oerke et al. 1995, Yudelman et al. 1998, Thomas 1999).

Insects have proven to be among the most formidable adversaries of mankind. Since they appeared on the scene some 390 million years ago, they have diversified into several million species that have adapted to almost all available ecosystems. This large diversity has allowed them to effectively compete with mankind since the introduction of agriculture over the last ten millennia. The increase in agricultural production of the past decades has not been accompanied by a comparable reduction in overall losses inflicted by insect pests: on the contrary, agricultural intensification has increased both yields and vulnerability to pests (Yudelman et al. 1998). Furthermore our mobile society is redistributing species around the globe at an unprecedented pace with major consequences for agriculture and ecosystems (FAO 2001). Undoubtedly, insects will continue to challenge mankind, and their resourcefulness is forcing a review of established ways of dealing with these pests and stimulating the development of new innovative control tactics (Klassen 2005). Investing in improved pest management should therefore be an integral component of national strategies to raise productivity and to assure future global food security.

The sudden availability of very effective and persistent synthetic organic insecticides immediately after the Second World War marked the onset of chemically-based warfare against most insect pests. Before that, insect pests had to be kept at bay by making use of various natural control factors. The importance of the new synthetic chemicals to control vectors of major diseases and their contributions to the green revolution cannot be questioned (Oerke et al. 1995). Chemical control has offered an effective and economical way to deal with a multitude of arthropod problems, to quell outbreaks, to decimate vectors of parasitic and infectious diseases of humans and livestock, to suppress noxious insect developing in dung on rangelands where domestic animals are produced, to suppress mites in honey bee hives, and to control termites and numerous household pests in urban ecosystems, etc. Pesticides have offered the pesticide user the freedom and flexibility to control pests on his property at any time without regard for the opinions and actions of his neighbours. Without chemical pest control, global agricultural productivity would have been less, food prices much higher and the available food of lower quality (Knipling 1979). The ready accessibility of these "off-the-shelf", relatively cheap and often subsidized chemicals was undoubtedly one of the main reasons the uncoordinated control of key insect pests on a field-by-field basis became so widely and firmly established during the last 60 years.

The drawbacks of the widespread use of these broad-spectrum insecticides were, however, recognized early (Carson 1962). They pollute soils and water, are a hazard to many non-target and beneficial insects, lead to outbreaks of secondary pests, cause acute and chronic poisoning of farmers, accumulate and biomagnify in the food chain and represent serious concerns to human health (Repetto and Baliga 1996). The general public's increased awareness and demand for more environment-friendly pest control tactics, the swift development of pesticide resistance, and the need for ever new, more complex and much costlier products, gave rise to the concept of integrated pest control (IPC) (Stern et al. 1959, FAO 1966), later called integrated pest management (IPM) (Bottrell 1979). In the 1960-70s, stimulated by this need for reduced and more selective use of insecticides, IPM became gradually accepted as a viable and sustainable pest management strategy that incorporates some of the traditional practices of the pre-insecticide era (such as field sanitation, biological control and use of pest and disease resistant livestock breeds and crop varieties) together with more selective synthetic organic pesticides to maintain pest population levels below an economic threshold. IPC-IPM has remained the dominant paradigm of pest control for the last 50 years (Kogan 1998).

2. Integrated Pest Management (IPM): a Reaction Against the Abuse of Insecticides

IPM offers a strategic approach to solving pest problems in an ecosystem context while guarding human health and the environment (Brader 1979). It has been endorsed by essentially all the multilateral environmental agreements that, since the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, have transformed the global policy framework of natural resource management, agriculture, and trade. More than half the world's human population lives in countries that are guided by national IPM policies, and that account for most of the world's staple crop production. IPM is increasingly practiced in agroecosystems featuring perennial tree crops, annual field crops, crops, in protected cultivation, ornamental crops, rangelands, intensive pastures, roadways, recreational parks, forests, dairies, barnyards, and urban ecosystems. Small-scale family farms in tropical and temperate zones as well as multinational corporate food producing and processing firms apply IPM. IPM systems range over a continuum, from those still dependent to a considerable degree on the use of pesticides all the way to those called biointensive that rarely require chemical treatments (Vandeman et al. 1994). Along this continuum, reliance on pesticide treatment-oriented interventions decreases and reliance on biological and cultural practices increases and requires an increasing number of available methods in managing pests (Benbrook et al. 1996).

2.1. FAO's Code of Conduct on the Distribution and Use of Pesticides

The International Code of Conduct on the Distribution and Use of Pesticides (revised from the original 1985 version) was adopted by the 123rd session of the FAO Council in November 2002. The Code embodies a modern approach, leading to sound management of pesticides with a focus on risk reduction, protection of human and environmental health, and support for sustainable agricultural development by selectively using pesticides as a component of various IPM strategies (FAO 2003a). Thus, the Code designed standards of conduct to promote IPM, including the integrated management of public health vectors.

The Code defines IPM as:

> *...the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption in agroecosystems and encourages natural pest control mechanisms (FAO 2003a).*

The Code has been approved and adopted by 185 FAO member governments, endorsed by non-governmental organizations and by the pesticide industry. Therefore the definition of IPM in the Code carries a degree of accessible authority that many other published definitions of IPM do not (Bajwa and Kogan 1996). In its article on pesticide management, the Code calls for support to alternatives to conventional pesticides:

> *Governments, with the support of relevant international and regional organizations, should encourage and promote research on, and the development of, alternatives posing fewer risks: biological control agents and techniques, non-chemical pesticides and pesticides that are, as far as possible or desirable, target-specific, that degrade into innocuous constituent parts or metabolites after use and are of low risk to humans and the environment.*

The Code reflects evolving responses to changing conditions with emphasis on protecting the integrity of agroecosystems, encouraging natural pest control mechanisms, and reducing risks to human health and the environment. In the articles of the Code on pesticide management, the wider range of stakeholders, and the emphasis on promoting increased participation of farmers, women's groups, and others reflect recent experiences with successful IPM (van den Berg 2004).

2.2. Selected Successes of IPM

IPM has had a varied history, and simply mixing different management tactics does not constitute IPM (Ehler and Bottrell 2000). Successful IPM is "knowledge intensive" and has never been successful without basic research on ecosystems, particularly to comprehend the food webs or communities of species through which energy flows in agroecosystems (Barfield and Swisher 1994, Wood 2002). Understanding why a pest becomes a pest (Lewis et al. 1997) comes from a fundamental understanding of the pest's life history and the ecology of crop-pest-natural enemy interactions, and rarely from a revolutionarily new control tactic (Kogan 1998, Thomas 1999).

The rice brown planthopper *Nilaparvata lugens* (Stål) was the key insect pest of the Asian green revolution in rice. While single tactics of insecticides and vertical host-plant resistance largely dominated research and pest control application, a series of studies in the mid 1970s elucidated the mechanism of outbreaks of secondary pests due to the overuse of subsidized insecticides. This was shown through analyses of multi-species rice field agroecosystems that concentrated on the rice crop, the planthoppers, their predators, and parasitoids. The results, made available by FAO, were then successfully applied in the mid 1980s through national IPM policies and programmes in the Philippines, Indonesia, India, Vietnam, China, and other major rice-producing countries (DeBach and Rosen 1991, Kogan 1998, Bartlett 2005). As a result of these policies, over USD 250 million per year in governmental insecticide subsidies were eliminated.

Subsequently Settle et al. (1996) showed how the rice field's aquatic food web, driven by decomposition of rice roots, rice straw, and other organic matter from previous seasons, through dozens of aquatic arthropods, produced sufficient numbers of predators, to protect the rice crop from the seedling stage to maturity. Rice field dwelling arthropod species that do not feed on rice still serve as important food sources in building up populations of natural enemies of rice pests. The species richness of natural freshwater ecosystems (streams, ponds, rivers, and lakes) permits irrigated rice agroecosystems to draw from their larger natural species pools to quickly fill in the essential guild structure of the cultivated aquatic rice agroecosystem, buffering it from immigrant pest populations. In addition, Ives and Settle (1997) challenged the conventional wisdom on synchronous rice planting, showing that in the presence of natural enemies asynchronous rice planting results in the lowest overall pest densities, since early arriving generalist predators decimate incipient infestations of pests and suppress their populations to a greater extent than is accomplished by killing large numbers later.

3. Field-by-Field and Area-Wide Pest Management Approaches

3.1. Field-by-Field Pest Management

Insect pest control measures can be applied either field-by-field (Fig. 1) or on an AW basis (Fig. 2), the latter addressing the total pest population within a delimited area. The simplest and most widely used strategy has been field-by-field management, which addresses only small fractions of a pest population at any given time. It allows individual crop and livestock producers, households, and businesses, to control pests independently, without investing effort in coordination, without having to obtain the consent or collaboration of other stakeholders and most importantly without taking into account the pest individuals that frequently migrate into the treated area from infestations in the untreated surroundings. Insects, themselves, are mobile but, can also be transported passively with wind, on animal hosts, or in infested commodities traded locally or internationally. This mobility severely compromises the effectiveness of uncoordinated farm-by-farm, orchard-by-orchard, or herd-by-herd control efforts, and results in the frequent need for curative or therapeutic back-up measures (Lewis et al. 1997) and the eventual overreliance on them. However, field-by-field pest control does not demand long-term commitment to an organized effort and its funding requirements, but relies on remedial interventions triggered when a pest population reaches a certain threshold. Field-by-field pest control is, therefore, largely a reactive approach to protect humans, animals, crops, forests, houses, wooden structures, etc., rather than a preventive pest population management approach (Pedgley 1993, Abeku 2007).

As a result of the complexity of many agroecosystems, as well as the site-specific nature of a majority of pest problems, predetermined thresholds often become operationally intractable and in some pest situations, the threshold is zero tolerance (Ehler and Bottrell 2000). Thus a field-by-field IPM approach is often insufficient, particularly when pests are quite mobile. Furthermore, the cost of generating the large amount of ecological information needed to develop and implement functional IPM systems for such local situations cannot be afforded by most devel-

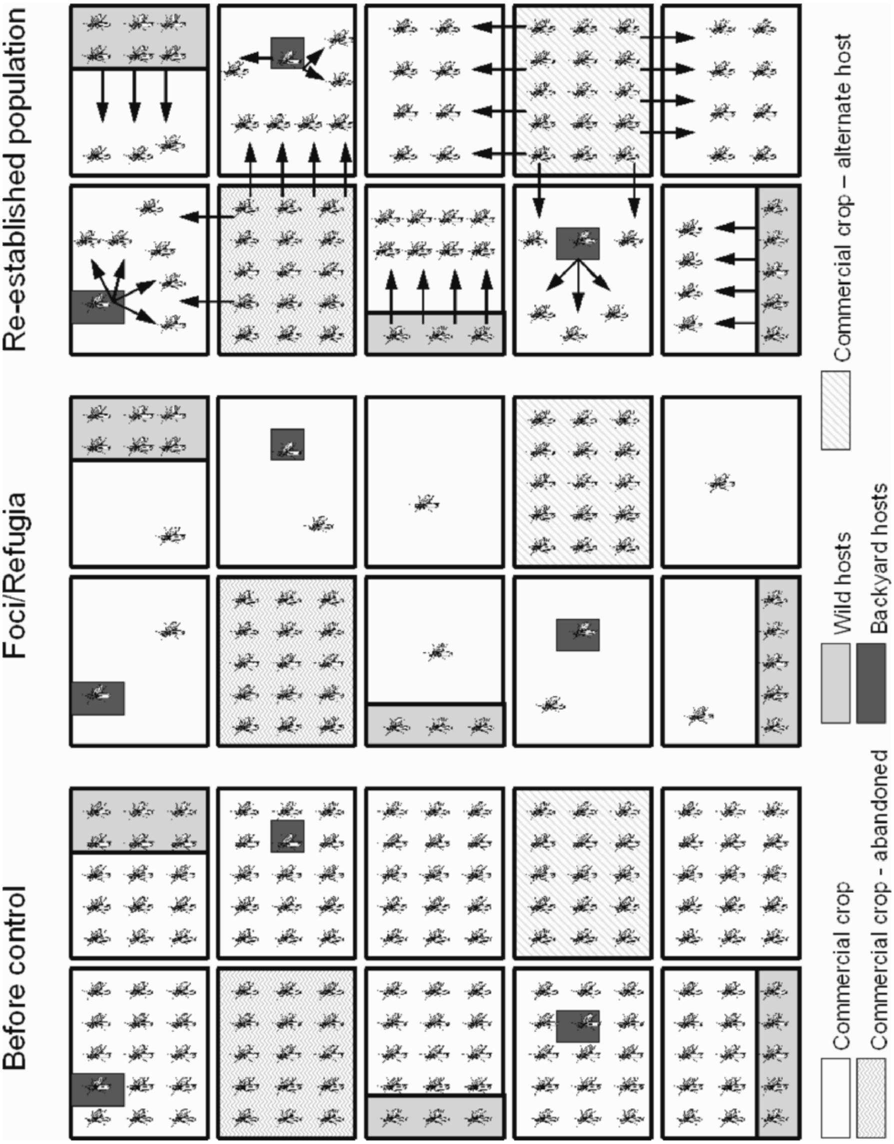

Figure 1. *Graphic display of field-by-field IPM, where the pest is suppressed below an economic threshold level in areas of commercial interest, but often not in abandoned crops, alternate hosts, backyard hosts or on wild hosts. As a result, significant untreated refugia of the pest remain from which recruits re-establish damaging densities of the pest population.*

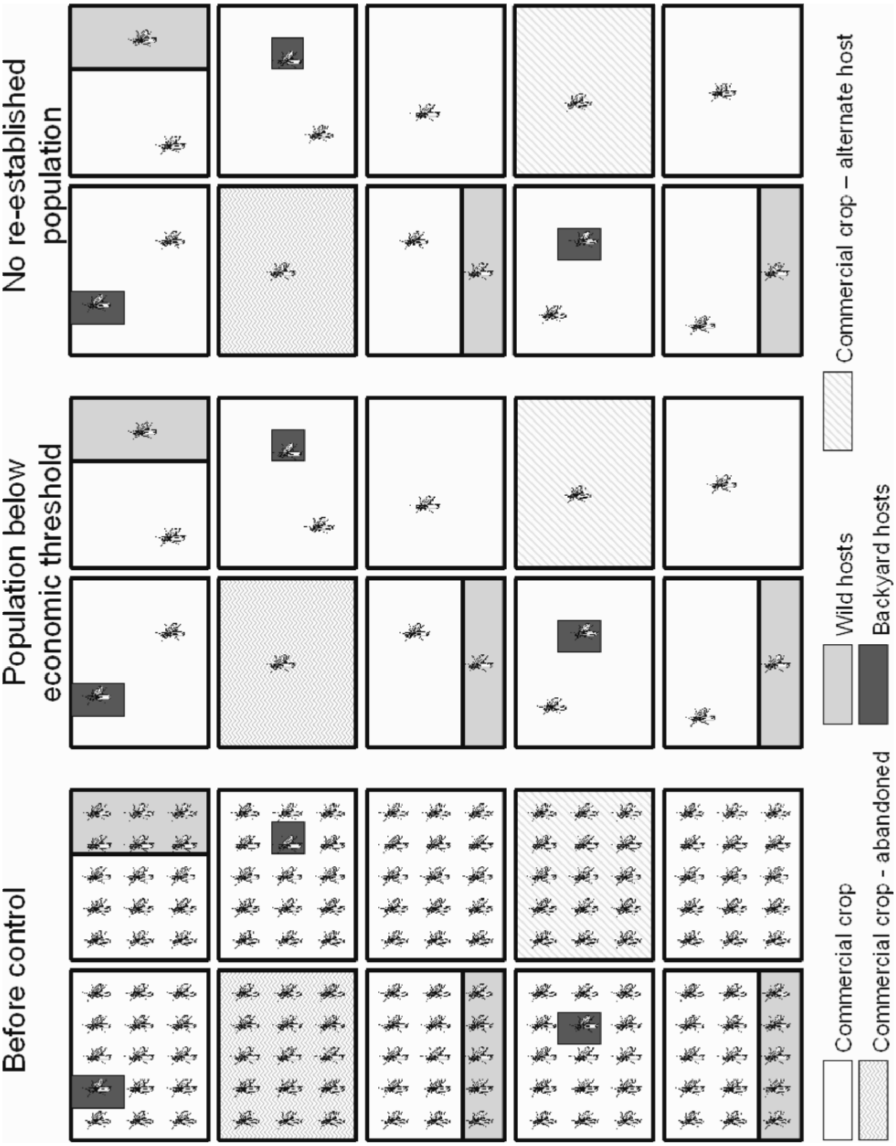

Figure 2. *Graphic display of AW-IPM, where the pest is suppressed below an economic threshold level in all areas, including abandoned crops, alternate hosts, backyard hosts or on wild hosts. As a result, no significant untreated refugia of the pest remain from which recruits can re-establish damaging densities of the pest population.*

oping countries (Morse and Buhler 1997).

3.2. *The Principle of Total Population Management*

Knipling (1960, 1972) used simple population models to show that small fractions of an insect pest population left uncontrolled can rapidly nullify the benefits of strongly suppressing the main pest population in a large area. One of these models compares the dynamics of an hypothetical insect pest population that has a fivefold natural rate of increase per year in an area, and where each year 99 percent of the population is destroyed on 90% of the host resources (but no control is conducted on the remaining 10%) with an area where only 90% of the population is destroyed on 100% of the total host resources (Table 1). The model shows that because no control was exercised on 10% of the host resources, 100 times more pests were produced in the first scenario (where 99% kill was achieved each generation in the large treated fraction) than in the second scenario where no refugia were left but the total population was subjected to only 90% kill in each generation.

From this Knipling (1972, 1979) deduced the basic principle of total population control:

> *Uniform suppressive pressure applied against the total population of the pest over a period of generations will achieve greater suppression than a higher level of control on most, but not all, of the population each generation.*

These refugia are permanent and prolific sources of immigrants and therefore represent a constant economic threat, requiring applications in cultivated areas of significant amounts of insecticides year after year, even in situations where major pests are managed under an IPM approach. This failure to address the total pest population in an area often compromises the basic goal of IPM, i.e. the reduction of insecticide use. In contrast the central paradigm of AW control, variously also called landscape, large-scale, preventive or total population management (Pedgley 1993, Ekbom et al. 2000, Carrière et al. 2001, Smith et al. 2006), recognizes the need to address the existence of all foci/refugia from which recruits can invade suppressed or cleared areas (Byers and Castle 2005, Klassen 2005).

Total population management is also required to reduce the probability of the development of insecticide resistance, or of the emergence of strains of a pest capable of over-

Table 1. *Relative number of insects developing each generation in two hypothetical population management systems. Each of the two populations has an initial population size of one million insects and a fivefold increase in reproducing insects is assumed with each generation (after Knipling 1979).*

Generation	Number of insects in an area with				
	99 percentage control on 90 percentage of the target population			90 percentage control on 100 percentage of the target population	
	treated area (90%)		untreated area (10%)	treated area (100%)	
1	900 000	9000[1]	100 000	1000 000	100 000[1]
2	45 000	450	500 000	500 000	50 000
3	2250	22	2 500 000	250 000	25 000
4	110		12 500 000	125 000	
Total insects in 4th generation:		12 500 110		125 000	

[1]number of insects surviving treatment

coming host resistance. In particular, AW pest management strategies, guided by the effective use of geographic information systems (GIS) technology, can be applied to achieve effective resistance management (Carrière et al. 2001, Sexson and Wyman 2005, Wu, this volume). Nevertheless, there is a potential danger in AW population suppression, since continuous and thorough suppression applied on an AW basis will select genes in the pest's gene pool that enable the pest to overcome the survival threatening control agent. For example, in the absence of refugia, as part of a resistance management programme, repeated AW applications of an insecticide will select for resistance to that insecticide, repeated AW use of baits will select for avoidance behaviour, and repeated AW planting of the same resistant crop variety will select genes for overcoming the crop's host resistance.

3.3. Origins of Area-Wide (AW) Approaches

The AW approach is not new but evolved centuries ago. Reduced cost, increased effectiveness and greater physical protection were generally the underlying reasons for the development of AW services. In earlier times, essential items such as the water supply, fuel, lighting, and sewage disposal were provided on an individual basis and each extended family satisfied these needs independently of its neighbours. This was an uncoordinated approach with the result that these individual services often proved to be not only unreliable, but also inefficient and could only be obtained at great individual expense. The desire for more effective and efficient delivery of these essential services transformed them from "individual" to "area-wide" and led eventually to the creation of public or private companies that supplied clean water and electricity, and that took responsibility for the collection of the garbage and disposal of sewage. Likewise, originally each head of the clan took responsibility for the physical protection of his kin. Soon feudal societies developed in which some individuals and later institutions specialized to provide protection for much larger groups. Eventually, police forces, state and national armies emerged that were able to deal with larger-scale military threats. The AW approach for these services made them more effective and less costly because the providers could use technically more advanced methods that were not available to the individual (Lindquist 2000). Today, AW services (e.g. mail service, retailing, ambulance, fire protection, public health, high-speed transport, telephone, internet services, etc.) are much more widespread than ever before.

3.4. Area-Wide Approaches Applied to Insect Pest Control

Applied to insect pests, AW approaches have their ancient roots in coping with vector-borne diseases and locust plagues (Klassen 2000, 2005). In the 14th century, the systematic use of quarantines in some European city-states contained bubonic plague transmitted by the oriental rat flea *Xenopsylla cheopsis* (Rothschild) and this approach was gradually adopted throughout Europe. The late 19th century included AW approaches such as the development of classical biological control and the use of pest-resistant plants (for example the grafting of all European grapes on phylloxera-resistant American rootstocks in the 1870s).

A campaign to eradicate the invasive gypsy moth *Lymantria dispar* (L.) from 1890 to 1901 in Massachusetts mainly using a modestly efficient phytotoxin, was quite successful initially but had to be abandoned after public opposition to the spraying. Since then, the objective of this AW campaign has reverted to limiting or retarding the spread of this pest (Sharov et al. 2002).

In 1906, a massive effort in the southern USA was initiated to eradicate two *Boophilus* cattle tick species that transmit cattle tick fever (Klassen 1989). A strategy of starving the ticks by making most pastures cattle free, combined with an arsenic-dipping programme and restricting cattle movement to tick-free counties was rigorously implemented for 37 years. In 1943, the ticks had been eliminated from the USA at a total cost that was equivalent to the yearly losses before the programme was initiated. To date, the southern USA has remained free of these ticks, as the result of an effective quarantine programme.

In 1911 the Government of Portugal decided to eradicate the tsetse fly *Glossina palpalis palpalis* Robineau-Desvoidy and trypanosomosis from the Island of Principe off the west coast of equatorial Africa. The suppressive system consisted of sticky black cloths worn by workers, treatment of people with the trypanocidal arsenical, atoxyl, clearing of vegetation, corralling of domestic livestock and eradication of feral pigs. The campaign was concluded in 1914 (McKelvey 1973): it was the first successful tsetse eradication programme.

After the World Health Assembly urged the World Health Organization (WHO) to organize the eradication of malaria in 1955, enormous progress was made in the following 15 years, and malaria was declared eradicated in 37 countries (Spielman et al. 1993). Social pressure to devolve more control to the local level and the banning of DDT resulted in the disintegration of the programme. To date, more than 400 million malaria cases are reported annually worldwide and more than one million people, mainly children in Africa, succumb to the disease every year (Marshall 2000).

In the 1950s and 1960s, a significant AW campaign was implemented against the introduced Khapra beetle *Trogoderma granarium* Everts which had become established in the south-western USA and northern Mexico. A major quarantine and treatment effort, which involved the fumigation of all warehouses, seed storage facilities, ships and other transport facilities, was initiated cooperatively by all states in these regions. Funding for this AW programme was shared between the federal and state governments and the private sector. By 1966 all known populations of the pest had been eradicated. Another introduction of this pest was eliminated between 1980 and 1983 in the north-eastern USA (Klassen 1989).

In 1973, the exotic cassava mealybug *Phenacoccus manihoti* Matile-Ferero was observed attacking cassava around Kinshasa (Democratic Republic of Congo, formerly Zaire) and Brazzaville (Republic of Congo) and in subsequent years it dispersed throughout sub-Saharan Africa, causing starvation of more than 200 million people (Neuenschwander et al. 1988). The International Center for Tropical Agriculture, Cali, Colombia, identified a suitable parasitoid *Epidinocarsis lopezi* DeSantis in Paraguay, which was brought to Africa by the International Institute for Tropical Agriculture in Ibadan, Nigeria. The parasitoid was successfully mass-reared and released in 38 African countries. This is an outstanding accomplishment in classical biological control, and it continues to keep the mealybug at bay.

Cereal aphids have become a major threat to production of sorghum, wheat and barley in central-western North America following the emergence of virulent biotypes of the green bug *Schizaphis graminum* (Rondani) during the 1960s, the establishment of the Russian wheat aphid *Diuraphis noxia* (Kurdjumov) in 1986, and the subsequent emergence of new biotypes of the latter species. These pests have been causing annual losses in grain production in excess of USD 250 million, and have caused large and unsustainable increases in the use of insecticides on these low profit margin crops. Therefore, a very large classical biological control programme involving the introduction of parasitoids from Eurasia was inititated (Brewer and Elliott 2004). However, an analysis of the wheat agroecosystem has revealed the presence and economic impact of many species of indigenous natural enemies, and it has been difficult to demonstrate any contribution from imported exotic species. As in the above mentioned problem of the brown planthopper on rice, understanding the community structure of the agroecosystem, initially intended as a side product of the classical biological control campaign, turned out to be the crucial foundation of the AW-IPM programme. Many other examples of successful or unsuccessful AW programmes to suppress or eradicate insect pest populations are listed in Klassen (1989, 2005).

3.5. Public Participation, Public Good, and Free Riders

As discussed above and by Vreysen et al. (this volume), AW programmes are not always successful. Social concern over methods, too many free riders, or insufficient compliance by all stakeholders have in several cases severely hampered success (Klassen 2000), emphasizing the need for attention not only to ecological, environmental, and economic, but also to social and managerial dimensions.

3.5.1. Public Participation

Public participation or "ownership" by the general public of AW programmes is crucial for their success. Yet often such support is weak, and special public information efforts are needed to convince the stakeholders of the wider benefits. Mumford (2000) summarizes this aspect well:

> *The main area in which problems lie with area-wide pest control appears to be in the mechanisms for public participation. Reports over many years cite technical, economic and environmental success with the concept, but there is still indifference, reluctance and antagonism.*
>
> *... these attitudes may be the result of a lack of opportunity for involvement and ownerships of programmes, which may be seen as being imposed from above/outside, managed by technocrats or otherwise not arising from or meeting the needs of the people directly concerned. None of these issues should be insurmountable, but it is worth noting that area-wide pest management is an activity in which social participation and attention to the "reasonable person" is as important as technical proficiency.*

Outrage factors pose a great threat to AW programmes. Once a large segment of the public has become outraged, it is almost impossible to lead them back to an attitude of trust and support (Sandman 1987). People in significant numbers have expressed outrage against AW programmes conducted for the benefit of agriculture or public health in urban settings, and such instances are likely to increase because of the recent surge in frequency of establishment of invasive alien pests near international airports, seaports and elsewhere in metropolitan areas. Protesters in urban communities fearful of mandatory pesticide applications attempted to halt the campaigns to eradicate the Mediterranean fruit fly *Ceratitis capitata* (Wiedemann) in the Los Angeles Basin by the State of California and the United States Department of Agriculture (USDA) during the 1980s (Lorraine and Chambers 1989). During the recent campaign to eradicate citrus canker from Florida (1995-2006), protesters in urban communities in south-eastern Florida, outraged by the entry of inspectors and workers into backyards of homes without search warrants and the destruction of apparently healthy citrus trees, delayed programme implementation from 2001 to 2004 by challenging its legality in court. In 2004 three hurricanes spread the canker bacterium from infected trees left untouched during the three-year litigation so widely that the programme was judged to be not feasible, and it was terminated in 2006 after the expenditure of ca USD 875 million (Bouffard 2006). In India a WHO programme to eradicate *Aedes aegypti* (L.), the vector of yellow fever and dengue, was terminated during the 1970s because journalists incited irrational fear of the sterilized male mosquitoes (Nature 1975). Clearly potential outrage factors need to be identified during the planning stages of AW programmes, and a well funded public information programme must be launched at the outset of each programme. Public information specialists must be trained to be up front, open and honest about all issues which may be perceived negatively especially by urban stakeholders.

3.5.2. Public Good

Public health, a clean environment, ecosystem services, roads, public education, a wholesome food supply, etc., have all been labelled as public goods (Johnson 2005). The application of IPM in agriculture and human health gives rise to positive externalities for the common or public good, resulting in benefits such as reduced risks to humans and the environment. In contrast a negative externality arises when a farmer, through injudicious pesticide use, pollutes the environment and harms his neighbours. In the case of mobile pests, damage is a function of the total pest population in the entire area. Pest control by any farmer results, therefore, in pest suppression and less damage for the neighbours as well, although only the one farmer incurs the cost of the control. This spill-over benefit for the other farmers in the vicinity is a positive externality, which unfortunately encourages free riders and is often not conducive for a collaborative programme against the pest within a community or at larger scales (Yu and Leung 2006).

3.5.3. Free Riders

Free riders are individuals choosing to benefit from a public good or a positive externality without contributing to the costs of producing the benefits (Johnson 2005), and they represent a problem for IPM implementation against mobile pests. Farmer associations or "community IPM", effectively promoted by FAO through IPM farmer field schools in developing countries (van den Berg 2004), can help address this problem. Actually community IPM is more than pest management and offers an entry point to improve the farming system as a whole, developing the enhanced management skills necessary for sustainable environment-friendly agricultural and rural development (Dilts 2001). Nevertheless, the cultural and socio-economic background of stakeholders significantly affects the collaboration rate in community-based projects (Smith et al. 2006, Stonehouse et al. 2007).

Non-collaborators represent a major weakness when operating programmes at a larger scale (for example regional public health vaccination campaigns, or global rinderpest or polio eradication). A few free riders or "refuseniks" can negate many positive impacts of AW programmes. Since externalities may affect a large number of stakeholders, obtaining full participation and dealing with sceptical, negligent, or even antagonistic third parties is an unavoidable and difficult challenge. In addition, merely because a good is said to be public, such as an unpolluted or disease-free environment, does not automatically imply that all people value it equally. Nevertheless, often a public good cannot be provided, or provided to an adequate extent, without strong support for a mechanism of collective action.

3.5.4. Subsidies, Government Provision, and Legal Authority

State subsidies, or complete government provision, and/or regulation or even legal authority for enforcement by authorities can at least partially overcome this type of market failure. All of these solutions represent an "involuntary" provision through taxation to partially or fully fund the public good. With benefits at least as large for society as for growers and other IPM practitioners who carry the financial burden of implementation, a strong case has been made for financial incentives as a stimulus to entice more participation and expansion of IPM adoption (Brewer et al. 2004). Since benefits to society of AW interventions tend to be unusually large, the allocation of public funds to many of such programmes in public health and agriculture appears to be strongly justified, and indeed, many AW pest control programmes are partially funded by the state (Bassi et al., this volume). The establishment and enforcement of legal rules by authority (Klassen 2000), for example, the removal of mosquito breeding sites, the implementation of quarantines, or the removal of wild hosts in the surroundings of crops (Kovaleski and Mumford, this volume) is greatly facilitated by establishing such "official" AW pest management activities.

3.6. Linking Area-Wide Approaches with IPM (AW-IPM)

The concept of AW pest control, developed by USDA under the direction of E. F. Knipling, has been closely identified with the programme to eradicate the New World screwworm *Cochliomyia hominivorax* (Coquerel), which started in Florida in 1957 and reached Panama in 2001 (Klassen and Curtis 2005). During these same decades many academic institutions developed and promoted the IPM paradigm. For several decades IPM and AW pest control were seen as competing paradigms with different objectives and approaches (Perkins 1982), and each competing against the other with its own core organizational base, i.e., state universities (IPM) versus federal research and regulatory agencies (AW).

3.6.1. Suppression versus Eradication

While under IPM suppression, pests can be tolerated at certain levels as part of healthy agroecosystems in which all components have a functioning role, IPM practitioners perceived AW pest control as targeting only eradication, an end point to which some had strong philosophical objections. Practitioners of AW control were accused of only wanting to eradicate pest populations based entirely on the initial promise of synthetic insecticides and that they were unwilling to manage and otherwise learn to live with pests. However in reality, Knipling (1966, 1969, 1972) had early on included suppression in AW control of key pests, although the possibility of eradication of selected populations of major pest species, if practical and economically and environmentally advantageous, was preferable (Kogan 1998). For example, since about 1960 Knipling worked toward the eradication of boll weevil *Anthonomus grandis* Boheman in the USA, but in this he was effectively opposed for decades by IPM practitioners. Eradication of this key invasive pest on cotton, which was finally initiated in the 1980s and is now nearing completion (El-Lissy and Grefenstette, this volume), was foreseen to significantly and permanently reduce insecticide use and provide major environmental and economic benefits. It was also foreseen that removal of the pest would cause much cotton production to shift from the central part of the cotton belt to the south-eastern USA, where in the absence of this pest cotton production is the most profitable. Currently none of the several ongoing AW control programmes are intended to eradicate the target plant pest or pest complex; instead they are designed to manage selected pests across an expansive geographic landscape (Pedgley 1993, Coop et al. 2000, Hendrichs et al. 2005, Sexson and Wyman 2005, Carrière et al. 2006, Abeku 2007).

In recent years organizations concerned with the preservation of biodiversity and conservation of natural ecosystems have become alarmed that their investments in conservation are at serious risk of being undone by invasive alien species (Sklad et al. 2003). Moreover, conservation scientists have found eradication to be essential for the restoration of certain natural ecosystems badly damaged by invasive species, and attitudes toward eradication are being revisited (Myers et al. 2000, Clout and Veitch 2002, Simberloff 2002, Pérez Sandi Cuen and Zimmermann 2005).

3.6.2. Area-Wide Integration

While the integration of compatible control tactics was seen as the cornerstone of the IPM concept, adherents of the IPM school did not perceive such integration to be integral to AW pest control systems, even though most AW suppression or eradication campaigns employed simultaneously several control tactics to achieve their goal. However, the integration of all available weapons is a fundamental requirement for the success of both field-by-field and AW-IPM. For example the New World screwworm eradication programme relied not only on the release of sterile insects, but integrated their use into a system including quarantines to prevent spread and reinvasion, closely scheduled examination of all livestock, collection and identification of specimens from wounds, diligent treatment of all wounds, navels and other sites of oviposition of the parasite, scheduling of cultural practices related to livestock management such as branding, castration and dehorning only when the parasite was least prevalent, and extensive public information activities to obtain transparency and secure the collaboration of all stakeholders. Clearly, the New World screwworm eradication programme targeted both the adult and immature stages of the parasite. Indeed Knipling (1979) proposed integrating control tactics that address immature stages (for example natural enemies) with those that target the adult stage (sterile insects, mating disruption), or those that are very effective against high population densities (use of bio-pesticides and baits) with those that are effective against low population densities (mating disruption systems, sterile insects, parasitoids, etc.).

3.6.3. Top-Down Approach

While for IPM a bottom-up approach at the farmer and community level was the operational mode, AW control was seen as needing a top-down approach, centrally managed by an organization, and with a mandatory component to insure full participation of stakeholders within a region. Even though AW programmes are usually, but not always, centrally managed, they cannot afford to ignore the concerns of farmers and communities. Indeed AW programmes cannot succeed unless they secure the active enthusiastic participation of all stakeholders, especially that of farmers and rural communities to achieve their goals. And where such a programme involves urban communities, it is even more important to assure that the urban people understand the importance of the programme and are willing to tolerate and contribute to its costs.

While not all AW-IPM programmes include mandatory components to insure stakeholder participation, a regulatory framework undoubtedly facilitates programme effectiveness. Some regulations established by regulatory authorities with stakeholder input are critical to success of certain AW programmes. These may include mandatory crop destruction by a certain date to prevent overwintering of the pest, mandatory seeding or planting dates to provide for suicidal emergence of the pest, access to private property by inspectors, etc. Since such regulations may be difficult to enforce, it is important that at the outset a referendum is held to determine if at least two-thirds of the stakeholders would willingly comply. On the other hand special regulations are not needed to assure the success of many AW programmes, and in such instances it would be most unwise to impose them.

3.6.4. What is Area-Wide?

The term area-wide, coined for total population management is widely entrenched, even though it can be misleading (and has been at least partially responsible for misunderstanding the concept), since the concept deals primarily with a total population in a delimited area, the influence of migration/dispersal on its dynamics, and its ecological relationships within its ecosystem. Including the distribution of the pest population in space and availability in time appears to be the logical next step in the ongoing evolution of IPM from originally managing a single pest in a field, to multiple pests in a field, to a larger scale that includes multiple fields and multiple crops. Actually large geographic areas are not a prerequisite for the AW approach, because addressing pest populations within a closed greenhouse, for example, also involves managing them at the population level, where their temporal dynamics and spatial distribution are known (Casey et al. 2007).

3.6.5. Merging of IPM and AW Control

Over time, as described above, the two schools have gradually converged and the differences between them have turned out to be less critical than originally perceived (Coppedge 1994, Kogan 1994, 1995, Parry 1995, Kogan 1998, Coop et al. 2000, Tan 2000, Faust 2001, Yu and Leung 2006). AW-IPM is a very broad and flexible concept and is increasingly accepted for those situations of mobile pests where management at a larger scale is advantageous to maximize the AW, not necessarily local, efficacy of management tactics (Cronin et al. 1999). At the same time grower education, for example through the FAO-organized IPM farmer field schools, is also leading to some concerted action to scale up the IPM movement at the community level (Dilts 2001, Pontius et al. 2002). Rice farmers are gradually moving from field-by-field to

AW-IPM implementation by coordinating at the village, subdistrict, and in some cases even district levels (Matteson 2000).

The interaction of AW application of tactics and coordination of activities among stakeholders is also not straightforward. While synchronous AW application of control measures is generally more efficient to preclude pest population refugia (Byers and Castle 2005), in other situations AW spatial asynchrony is deliberately adopted over broad geographic regions. For example, spatial asynchrony of control measures has a greater effective suppressive effect on the total pest population in the rice agroecosystem, because it favours earlier migration of natural enemies into the rice fields (Ives and Settle 1997).

3.6.6. Situations Advantageous for Area-Wide Control

Economics undoubtedly plays a major role in the initial grower decision to participate in AW-IPM (Sexson and Wyman 2005), and deteriorating market conditions may cause the grower to neglect or even abandon a crop in a field or an orchard. Farmers who cultivate crops with a high economic value and low pest tolerance risk suffer greater losses than farmers who cultivate crops with a low economic value and high pest tolerance (Yu and Leung 2006). In the latter situation there are fewer incentives for farmers to cooperate through an AW approach, whereas in the first case the economic advantages of participation are much greater (Stonehouse et al. 2007). This is particularly so for crops such as vegetables and fruit, or for some livestock or human diseases, where the acceptable thresholds are so low that the presence of even a few pest or vector individuals often triggers the need for remedial applications.

Using a mathematical model, Yu and Leung (2006) derived several favourable and unfavourable conditions for implementing AW-IPM. In their view, AW-IPM is more likely to succeed where the number of farmers is small, and the cultivated crops are similar (low farm heterogeneity). The stability of the cooperation among the farmers is enhanced by short detection times and high discount rates. The model likewise demonstrates that a one-off suppression of the pest under the leadership of a third party facilitates the cooperation of heterogeneous groups of farmers in AW-IPM.

4. Area-Wide Control of Insect Pests: from Research to Field Implementation

Operational AW-IPM programmes are complex, long-term and proceed from basic research, through methods development, feasibility studies, commercialization and regulation, to field pilot studies, which could eventually culminate into an operational programme. The various components of this development process are briefly documented and discussed.

4.1. Basic Research

AW-IPM is a science-based activity and, hence, relies on knowledge generated in basic science to provide new tools and technologies. The link between basic science and AW-IPM programmes is often seen as tenuous, as much time and applied research is required to turn a basic invention into a product for use in a field programme. One example of this process has been the basic genetic research conducted over ten years that culminated in the development of genetic sexing strains for the Mediterranean fruit fly. Genetic sexing has revolutionized the use of the sterile insect technique against this pest. Unfortunately this technology cannot be transferred directly to other species, although it could be created in many pest species with somewhat less effort than was required in the Mediterranean fruit fly. Moreover, genetic transformation of insect pests may lead to the development of generic sexing systems. Many of the proposed uses of genetic transformation aim to replace or complement existing technologies, and, therefore, do not represent completely new concepts. As such, genetic sexing, insect marking, and sterilization are all proposed as targets for genetic transformation. In a few pest species all these goals have been achieved at the laboratory scale, but the larger challenge of scaling up and validating these systems at meaningful levels for AW-IPM programmes remains to be done.

Genetic transformation was first developed to study gene function in *Drosophila melanogaster* Meigen and then roughly ten years of effort were required to simulate this accomplishment in the first major pest species, the Mediterranean fruit fly. Now, it is possible, through the development of better vector systems and transformation markers, to genetically engineer most pest species, including several dipteran and lepidopteran pests (Atkinson, this volume). Lepidoptera have a different sex determination system than Diptera and this difference could be exploited to produce a genetic sexing strain with non-transgenic males for release (Marec et al., this volume). The identification of specific chromosome markers (Makee and Tafesh, this volume) will aid this approach.

Each AW-IPM programme requires a regulatory framework tailored to its specific needs. However none of the currently existing regulatory frameworks provides for the deployment of any genetically transformed product. This issue was discussed in Rome at a meeting on risk assessment, which provided some guidance on deploying transgenic arthropods (IAEA 2006). Currently, the North American Plant Protection Organization (NAPPO) is developing a regional standard (RSPM) to facilitate the importation and confined release of transgenic arthropods (NAPPO 2007). Strategies to facilitate the acceptance of deploying transgenic insects in AW-IPM programmes are being developed (Handler et al., this volume).

Characterization of pest populations to be targeted by an AW-IPM programme is an essential first step in mounting an AW-IPM programme. To this end advances in DNA analysis are providing increasingly sophisticated tools to assess the genetic variability of different field populations of a pest species including the degree of isolation between them (Torres et al., this volume). However, these studies do not provide information on the presence or absence of behavioural mating barriers between various field populations or between released sterile insects and target populations. The existence of behavioural barriers to mating must be determined through the conduct of mating compatibility studies; and these should be conducted under semi-natural conditions (Cayol et al. 2002, Vera et al. 2006).

The quality of performance in the field of insects released in AW-IPM programmes is of paramount importance. Therefore, great diligence is exercised in the mass-rearing and handling of predators and parasitoids in augmentative biocontrol programmes and of sterile males released in SIT programmes. Thus it is important to note that dietary, hormonal, and semiochemical treatment of sterile males prior to release (Teal et al., this volume) can greatly increase their effectiveness. Similar conclusions were reached with respect to predators reared for release in augmentative biocontrol programmes (Thompson 1999).

Likewise, new techniques that allow the storage of insects for varying lengths of time and at various stages could be very beneficial to AW-IPM programmes. Maintenance of certain strains of the pest insect that have particular characteristics is labour intensive, expensive and tends to expand as new strains are developed. Strains also need to be maintained over long periods of time even though they may only be used for limited periods. In addition, storage of insects can alleviate potential hazards of the rearing process such as strain deterioration, disease outbreaks, labour unrest, or mechanical failure. Cryopreservation is considered to be a possible solution, and recent advances have made this technology available for some pest insects such as transgenic New World screwworm (Leopold, this volume).

Population suppression in AW-IPM programmes can be achieved by reducing the reproductive potential of the target population using either natural or artificially induced sterility. Four decades ago, cytoplasmic