BIOLOGICAL CONTROL AND ECOSYSTEM SERVICES

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Keywords: Biological control, single-species pest, limitations, ecosystem, ecosystem service, ecosystem adaptive management, sustainability, biodiversity, perturbance, stability, hierarchical organization.

Contents

Summary

Biological control can be categorized into classical biological control, natural enemy augmentation and conservation. A review of selected examples and additional literature information revealed some limitations when exclusively used as a single species control

option and showed some opportunities for developing it into an ecosystem management tool.

Biological control evolved from a single-pest control option into a key component of integrated pest management (IPM) in complex agricultural systems structured according to organizational, spatial and species assemblage levels. Agricultural and applied ecological sciences appear to converge at ecosystem management. Sustainability must be the primary objective, and ecosystem management should adjust levels of ecosystem service provision to achieve it. In other words, biological control is incorporated into conditions and processes occurring at the level of ecosystem services that should be harmonized as to yield sustainability on the ecosystem level. Thereby, emphasis is given to the enhancement of environmental sustainability on the basis of measurements and their interpretation within an ecological dynamic framework rather than to the adhesion to the objective of meeting a vaguely defined final state of sustainability. The adjustment of ecosystem service provision for achieving environmental sustainability is a very complicated task and expected to be the subject of intensive future research.

The incorporation of biological control into ecosystem management activity requires a technology that is different from traditional methodology based on scientific experiments because of being reductionistic. Adaptive management instead, is the process of treating management as an experiment and considered as a systematic, cyclical process for continually improving management policies, strategies and tactics based on lessons learnt from operational programs. The assessment of ecosystem performance and qualities after the interventions, may lead to further management operations including additional biological control activities and place the ecosystem on a trajectory leading to enhanced environmental sustainability.

1. Introduction

In response to ever varying needs of human societies, agriculture continuously changed over a number of many centuries. On the road to intensification, agriculture had to overcome many problems including constraints imposed by organisms competing with humans for resources. Moreover, the changing life style of humans modified their exposure to various pathogens often transmitted by vectors. Biotic constraints to human livelihood have been part of human socio-economic development since ancient times and will continue to receive increasing attention by all sectors of the human societies.

Any of the various species that we, as humans, considerer as undesirable or any organisms, such as fungi, insects, rodents, and plants, that harm crops or livestock or otherwise interfere with the wellbeing of human beings, are generally known as pests. For the purpose of this paper, however, the authors pragmatically consider any organisms that, against human interests, interfere with the functioning of ecological systems and/or compete with humans for resources that are extracted from the system. Moreover, ectoparasites that directly or indirectly, as disease vectors, affect human health are also included. The status of pests depends on the socio-economic environment where they interfere with human interests. On the other hand, pest organisms are affected by a wide collection of natural enemies. Among them are arthropod predators, parasites and micro-organisms or microbial control agents. In the evaluation of biological control for pest control, frequent reference is made to arthropod natural enemies. Moreover, when evaluating biological control in an ecosystem management context, the authors focus on crop pest management and on the general mode of action of natural enemies and explore opportunities for their use without referring to specific taxonomic groups.

Biological control is the action of parasites, predators, or pathogens in maintaining other organisms population density at a lower average than would occur in their absence. Serious pest problems occurring in the mid-to late nineteenth century and progress in medical entomology stimulated the interest in pest control techniques. By the turn of the nineteenth century major approaches to pest control, including biological control, were well established and further developed until World War II when synthetic pesticides became the prominent control option. The drawbacks of unilateral reliance on synthetic pesticides lead to the development of integrated pest management (IPM). Initially, biological control was seen as an IPM control component, but reached the status of a key component in the past decades. Further development of IPM went from a single species pest control towards the study and management of agricultural systems including multi-species pest assemblages. Although considered as a key component, apparently few attempts have been made to develop biological control for use in complex ecological systems and hierarchically organized institutions of decision-makers and end users.

During the last decades ecologists increasingly recognized the limits of reductionistic approaches and strongly recommend the addition of synthetic to analytic approaches. The ecosystem, initially vaguely defined as a system including both organisms and chemical-physical components, became the subject of study and management. It is now seen as a biotic and functional system or unit that can be qualified with sustainability, stability and resilience criteria. Ecologists recognize the limits of traditional experimental approaches to ecosystem study and management and propose the use of adaptive management, i.e. a cyclic process for continually improving management policies and practices based on lessons learnt from operational activities. In the recent decades, objectives and methods of ecosystem management have received the attention of many ecologists, and biological control has already been discussed as a tool for ecosystem management.

From agricultural standpoint, biological control evolved from a single-pest control option into a key component of integrated pest management (IPM) in complex agricultural systems, while, from an ecological standpoint, it appears to develop into an ecosystem management tool. Thus, the historical development is important in our attempt to build biological control into an ecosystem context where modern agricultural and ecology sciences appear to converge. The first part provides additional insights into historical development and briefly reflects on selected case studies of biological control. These two elements are the basis for reviewing biological control as both a single pest control option and subsequently, as an ecosystem management tool.

2. Biological control of arthropod pests

2.1. History of the biological control concept

The problem of pest control may have arisen with the development of agriculture about 10'000 years ago, but there appear to be no reports on biological control until the use of Pharaoh's ants, *Monomorium pharaonis* (L.) against stored product insect in China. It was favored by a tradition of interest in entomology, e.g. silkworms, and by a philosophical view of the world that early recognized the importance of food webs and natural control of populations. Individual examples of the use of natural enemies to control pests by natural enemies have existed for centuries, but biological control emerged as a scientific method only in the late nineteenth century.

During the agricultural revolution peaking in the mid - to late nineteenth century European countries and their colonies experienced some of the worst pest outbreaks including the invasion of Europe by the grape phylloxera. At the same time, progress was made in medical entomology, including the role of arthropod vectors in disease transmission, and awareness at the importance of parasites, predators, and pathogens in the limitations of insect numbers, lead to suggestions for their practical use.

At the end of the 19th century, complete and permanent control of a major pest, the cottony-cushion scale, *Icerya purchasi* Mask. in California by the introduction of the coccinellid predator *Rodolia cardinalis* (Muls.) demonstrated the applicability of the approach This result quickly produced a widespread enthusiasm for biological control, and many biological control projects have been concluded until World War II. Moreover, the search for other pest control methods was intensified and new control techniques were implemented.

The pressures of World War II caused the development of synthetic organic pesticides. The chemicals were so poisonous that there seemed to be no need to continue carrying out many of the old pest control practices, and many of them were simply disregarded and discontinued. In the period following 1945, when pesticide use was extremely popular, chemical control was considered the basic control option and biological control was viewed as secondary or unnecessary.

Dr. Robert van den Bosch was among the entomologists who observed that unilateral reliance on synthetic chemicals resulted soon to problems. According to him, the earliest hint of impending disaster was the development of *pest resistance* resulting from natural selection that produces individuals with improved chance of survival and breeding under pesticide pressure. Another problem was described as *target pest resurgence*. After spraying for pest control, growers noticed that pest populations would sometimes drop drastically and then suddenly surge to higher levels than before. Pest recurrence occurred because broad spectrum pesticides killed natural enemies of the pest as well as the pest itself.

Surviving natural enemies reacting to food shortage emigrated or went into a reproductive lapse, while surviving pests on the other hand, would be able to do better than ever before. The third problem was referred to as *induced secondary pest outbreak*. This occurred when a plant feeding species, previously not known as an important pest, suddenly erupted to damaging levels. This eruption was usually the result of the pesticides destruction of natural enemies, which until then had kept the new pest under effective biological control. Other drawbacks of heavy dependence on synthetic pesticides were described as environmental contamination and had negative effects on the health of workers and consumers. However, these drawbacks are not discussed in this paper. Focus is on the three problems mentioned previously because they show consequences of directing control measures against single pest species resulting to changes in their genetic make-up as well as to unforeseen responses of agroecosystems.

The drawbacks of unilateral reliance on synthetic chemicals lead to the development and implementation of integrated pest management (IPM) programs. In 1967, a panel of experts for the Food and Agriculture Organization of the United Nations (FAO) defined IPM as a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury.

Initially, biological control may have been seen as one of many pest control components; in the past decades, it became a key IPM component. In recent decades a change has gradually taken place with respect to this perception of priorities, and the concept of IPM based on biological control has arisen. Under this concept, biological control agents are seen as essential and of first priority in building pest control systems.

Biological control generally falls into one of three categories, but the differences are not always clear cut and overlapping occurs. *Classical biological control* involves the planned relocation of natural enemies of insect pests and weeds from one locality to another. Other methods include measures taken to increase natural enemy action by *augmentation of natural enemies* through inoculative or inundative releases as well as natural enemy conservation. *Inundative biological control* refers to a technique that involves the release of large numbers of natural enemies for pest control, and the releases act as a biotic pesticide.

Inoculative releases relies on the effect that comes from the accumulative action by the progeny produced over several generations following the release of relatively small numbers of natural enemies. *Conservation of natural enemies* refers to an enhancement of biological control through modification of the environment in such way that any adverse environmental effects would be eliminated or mitigated, or simply to alter the environment better to suit certain particular needs or responses of the natural enemies which were previously unsatisfied.

Natural control involves the combined actions of the whole environment in the maintenance of characteristic population densities. Various authors have referred to the existence of these characteristic densities by the use of the term balance that contains many different ideas, different mechanisms, and different characteristics. In 1964, Drs. C.B. Huffaker and P.S.

Messenger stated that ‘to understand the limitations and potentialities of natural enemies that affect the biological control of insect pests we must relate their action to all forces of environment affecting either their own success or that of the species they attack. Thus it is necessary to consider all factors which contribute to the abundance of organisms’. The understanding of population dynamics for assessing the role of natural enemies remains an important research objective, but the introduction of systems analysis into population ecology and ecosystem science has substantially improved possibilities to achieve this objective. With respect to biological control, however, a difference is made between understanding and control. In the light of experiences in other natural sciences, ecologists are advice to separate objectives of science and decision-making.

Traditionally, agroecosystems have exclusively been viewed as producers of goods, and biological control was seen as an approach to control organisms causing damage and economic losses to growers. This viewpoint has changed in the past decade. First, Dr. G. Daily pointed out that ecosystems provide a wide array of conditions and processes through which ecosystems, and their biodiversity, confer benefit on humanity. The control of the majority of potential pest species can be seen as a stabilizing process within ecosystem services. Biodiversity is key pest control component, and biological control may be seen as a way to manage biodiversity. Second, according to a report of the 'Ecological Society of America committee on the scientific basis for ecosystem' sustainability must be the primary objective of ecosystem management, and levels of commodity and amenity provisions adjusted to meet that goal. Dr. Robert Goodland has defined sustainability as used in this paper. These ideas can be generalized to adjust and coordinate ecosystem services in general to obtain sustainability enhancement.

To illustrate the three biological control versions, case studies are selected that reflect the authors' research interests and appear appropriate to highlight some limitations of the single-species approach. The selection, however, does not reflect achievements reached in the different projects neither with respect to methodology nor to implementation.

2.2. Classical biological control or introduction of natural enemies

Classical biological control involves the planned relocation of natural enemies of insect pests and weeds from one locality to another. Normally, the method has been used to combat pests that invaded agroecosystems geographically or ecologically isolated from the ecosystems in which the invading organisms evolved. Partial or complete control is sought by exploiting the within-species variability of natural enemy species that may appear as subspecies or ecotypes. Rather than introducing one species, some biological pest control programs involved the introduction of several species.

2.2.1. Classical biological control in silviculture: the Winter Moth

One of the most interesting cases of biological control in forests is that of the Winter Moth *Operophtera brumata* L. in Canada. Around 1930, the pest was accidentally introduced into Nova Scotia where it attacked a number of broad-leave trees but caused most damage to forests and apple orchards. Of the six parasitoids that were introduced from Europe and released in the mid 1950s only two became established, the tachinid *Cycenis albicans* (Fall.) and the ichneumonid *Agrypon flaveolatum* Grav..

Following the releases, the populations of *O. brumata* on oak gradually declined and thereafter, fluctuated at low densities, while there are still defoliations on apple trees. Both parasitoids may contribute to the level of control, but *C. albicans* appears to be the most important, presumably because of its density-dependent response to damaged leaves. Noteworthy, *C. albicans* has an insignificant effect on *O. brumata* in Britain where populations are controlled by a complex of pupal predators in the soil.

2.2.2. Classical biological control in agriculture: the Cassava Mealybug

The Cassava Mealybug *Phenacoccus manihoti* Matile-Ferrero invaded West Africa from South America in the early 1970s. In the early 1980s, it was found in much of tropical Africa and greatly reduced the yields of cassava, a staple food for 200 Mio people. The parasitoid, *Epidinocaris lopezi* (De Santis) was found in South America and brought to Africa where it proved to be a highly effective Cassava Mealybug control agent. A multitrophic system simulation model was developed, validated and used to evaluate yield losses caused by the *P. manihoti* and other biotic as well as abiotic constraints. Moreover, the model was used to assess the contribution of *E. lopezi* and other natural control factors to *P. manihoti* control.

Noteworthy, the model predicted the influence of soil fertility on plant growth patterns and the outcome *of P. manihoti – E. lopezi* population interactions. Field experiments confirmed model predictions that nutrient depleted soils had a profound influence on plants, mealybugs, parasitoids and their interactions. Nutrient poor soils impinged upon plant growth and impacted the quality of the mealybug host population in such a way that parasitoid population development was impaired. As a consequence, biological control by *E. lopezi* could not be sustained on depleted soils. A massive rearing and release program, with 100 release sites in a 1.7 Mio km^2 area covering 25 countries, was established and the pest was soon under control in nearly all parts of Africa.

2.3. Augmentation of natural enemies

Augmentation refers to actions taken to increase the populations or beneficial effects of natural enemies. This can be achieved by inundative or inoculative releases of natural enemies.

2.3.1. Inundative release of *Phytoseiulus persimilis* A.H. for Two-Spotted Spider Mite control

The Two-Spotted Spider Mite *Tetranychus urticae* Koch was among the first greenhouse pests to become resistant to a number of synthetic pesticides. A wide range of host plants and the potential to build-up high population densities are among the major factors for soon reaching the status of occasionally important greenhouse pest. *P. persimilis* imported from South America in the late 1950s proved to be efficient biological control agent. A survey completed in 1993 showed that small-scale commercial production and application of biological control in greenhouses was started in 1968.

Thereafter, the area treated and the number of companies producing *P. persimilis* steadily increased. The selection of the appropriate strain for a particular environment, such as protected crops in temperate or Mediterranean areas, the adequate quantity of released predators, and the use of compatible methods for the control of other pests are indispensable. Noteworthy, pathogens and selective pesticides have shown not to interfere with the activity of *P. persimilis*, and hence, are considered as compatible control techniques. Under Mediterranean conditions, the use of habitat management strategies including irrigation to reduce temperature is often required for making efficient use of *P. persimilis.* Moreover, corrective measures are sometimes undertaken to lower prey densities before releasing the predator.

The strategies are based on both empirical work and on detailed predator-prey population studies. In fact, acarine systems can easily be manipulated, and thus have been used as experimental systems for fundamental studies in population ecology. For example, studies on the influence of spatial complexity on the persistence of a predator-prey system have considerably influenced the way ecologists evaluate spatial qualities in population interactions. Until 1995, 19 models on various acarine predator-prey population systems have been published, emphasizing different aspects of population ecology and developed for different purposes.

2.3.2. Inundative releases of *Encarsia formosa* Gahan for Greenhouse Whitefly control

The Greenhouse Whitefly *Trialeurodes vaporariorum* (Westw.) and the Tobacco Whitefly *Bemisia tabaci* (Gennadius) are serious pests on several host plants in greenhouses, but here, focus is given to *T. vaporariorum* control by the parasitoid *E. formosa*. Noteworthy, *E. formosa* was found in the1920s in the UK. Within a few years, a research station in England was annually supplying 1.5 Mio individuals to 800 nurseries in Britain. After World War II the distribution was discontinued, but was revived in the 1970s when enormous outbreaks of *T. vaporariorum* took place in Europe. As in the case of *P. persimilis*, there has been thereafter a steady increase in the area treated in the number of companies producing it.

The diminished costs of natural enemies have lead to multiple inundative releases whether pests are present or not. In general, however, the use of *E. formosa* is a component of crop-specific IPM programs that include other control methods. Among them are *T. urticae* control by *P. persimilis,* leafminer control by *Diglyphus isaea* (Walker), *Thrips* control by *Orius* spp. and application of compatible insecticides, acaricides as well as fungicides.The use of *E. formosa* is considered as a successful biological control method in Central and Northern Europe but has some limitations in Mediterranean protected crops, where high temperatures impair parasitoid activities. To achieve satisfactory levels of control, growers are recommended to release twice the number used by their colleagues further north.

2.4. Conservation of natural enemies (habitat management)

In general, conservation means premeditated action for protecting and maintaining natural enemies. The approach specifically refers to the manipulation of the environment to enhance the survival and the physiological and/or behavioral performance of natural enemies and to increase their effectiveness. Among other environmental components, crop management practices are seen as opportunities for natural enemy conservation.

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Biographical Sketches

Dr. Gianni Gilioli is Assistant Professor of Agricultural Entomology at the University of Reggio di Calabria, Italy. He received his PhD in 1995 at the University of Parma (Italy) after completing his research project on analysis and modelling of single species spatio-temporal population dynamics at the Natural History Museum. From 1995 to 1998 he was a Postdoctoral Fellow at the Department of Mathematics at the University of Parma. Since 1998, Dr. Gilioli is a visiting scientist at the Nairobi (Kenya) based International Centre of Insect Physiology and Ecology (ICIPE). He relies on a systems approach and is interested in developing and implementing mathematical models representing the dynamics of populations and ecosystems. These models are being used in the areas of Integrated Management of Pests in agriculture and forestry as well as in comprehensive integrated human health and natural resource management. Currently, Dr. Gilioli is participating in ICIPE's efforts to design and implement adaptive population and ecosystem management schemes in Kenya and Ethiopia.

Dr. Johann Baumgärtner is Head of the Population Ecology and Ecosystem Science Department at the Nairobi (Kenya) based International Centre of Insect Physiology and Ecology (ICIPE) and Associate Director of the planned Centre for Analysis of Sustainable Agricultural Systems (CASAS) at Kensington, California, USA. He received a diploma as Agricultural Engineer (1972) and a PhD in Technical Sciences (1976) at the Swiss Federal Institute of Technology (ETH, Zurich, Switzerland). He joined ICIPE in 1997 after holding the positions of Research Assistant and Research Adjunct at the ETH, and Commissioner for Ecological Performances at the Agricultural Bureau of the Grisons (Chur, Switzerland). Dr. Baumgärtner relies on a system approach to population systems as well as ecosystems. He supervises work at ICIPE's Animal Health, Human Health, Environmental Health and Plant Health research Divisions. His current most important research projects are the design and implementation of adaptive population and ecosystem management schemes in Kenya and Ethiopia.

Prof. Vincenzo Vacante is Full Professor of Agricultural Entomology at the University of Reggio di Calabria (Italy). He received his degree in Biology in 1976 at the University of Catania (Italy). He was visiting scientist at the University of Gent (Belgium), at the Zoologisch Museum of Amsterdam (The Netherlands), and collaborator of scientists from the Hebrew University in Rehovot (Israel), the Institut National de Recherche Agronomique (INRA) at Antibes (France) and the Commission of the European Community. Moreover, he was the convenor of the working group 'Integrated control in Citrus and Fruit Crops' of the International Organization of Biological Control (IOBC). Prof. Vacante is interested in Biological Control and relies on it as a key pest control technique in Integrated Pest Management schemes for greenhouses and citrus orchards. He participates in research at the International Centre of Insect Physiology and Ecology (ICIPE) on adaptive population and ecosystems schemes in Kenya and Ethiopia.