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Conservation Biological Control Practices

Nabil El-Wakeil, Mahmoud Saleh, Nawal Gaafar and
Huda Elbehery

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Abstract

Natural enemies are subjected to continuous deterioration in populations especially in modern agricultural systems characterized by complete removal of plants after harvesting as well as by insecticide applications. This complete removal of plants gives rise to disappearance of natural enemies after each crop season. Conservation biological control is the protection of NEs against adverse effects of pesticides and incompatible cultural practices and improving their efficiency via providing food sources. During non-crop periods, natural enemies may need of benefit from pollen and nectar. Preservation of natural enemies can be achieved by providing habitat and resources for NEs. This chapter aimed at discussing a suggested strategy for more efficient conservation biological control comprising collection, preservation and releasing the preserved natural enemies on target crops. The collection is mainly conducted before crop harvest and during winter from fruit orchards. Preservation greenhouses are dedicated for natural enemies rather than commercial production of crops. Natural enemies taken from preservation greenhouses are released in target crops during growing season. Different techniques used in collection, preservation and release of natural enemies are reviewed. Such a conservation biological control strategy might contribute to preserve the natural bio-diversity in the agricultural environment and provide natural alternatives to pesticides.

Keywords: natural enemies, biological control, collection, preservation, release, parasitoids, predators, insect pathogens

1. Introduction

Biological control is the regulation of pest populations by the activity of natural enemies (NE) (predators, parasitoids and pathogens) [1]. Natural enemies are periodically released in augmentative biological control of insect and mite pests [2]. In classical biological control, an NE is imported and released in a new area for regulating a specific pest [1]. Released and naturally occurred NEs are subjected to continuous deterioration in populations especially in modern agricultural systems characterized by complete removal of plants after harvesting. This complete removal of plants gives rise to disappearance of natural enemies after each crop season. Conservation biological control is the protection of NEs against adverse effects of pesticides and incompatible cultural practices and improving their efficiency via providing food sources [3–5]. Biological control of arthropod pests has used for a long time traditionally in different crops, therefore it should be used with other compatible integrated pest management methods [6]. Both the area on which it is used and the number of available biological control agents are still expanding [2, 7]. Natural enemies play an important role in limiting potential pest populations [8].

Conservation biological control is one of biological control main branches [8], which can be first realized by reducing the use of pesticides, use of selective pesticides, careful timing and placement of pesticide applications. We have seen what happens when insecticides destroy the natural enemies of potential pests. Insects that were of little economic importance may become destructive pests. When nontoxic control method is used natural enemies are more likely to survive and reduce the populations of pests.

During non-crop periods, natural enemies may need of benefit from pollen, nectar or honeydew (produced by aphids). Many crop plants flower for only short time, so flowering plants along the edges of the field or within the field may be needed for pollen and nectar [9]. Preservation of natural enemies can be achieved by providing habitat and resources for natural enemies [10]. They are generally not active during the winter. Unless they are re-released each year, they must have a suitable environment for overwintering [11, 12]. They usually pass the winter in crop residues, other vegetation or in the soil. Ground cover of fruit orchards, winter crops (like alfalfa and breccias), usually provides shelter for overwintering natural enemies. Adding plants or other food sources for natural enemies must be done with knowledge of the behaviour and biology of the natural enemy and the pest [13–16].

It is widely known that the simplifications of agriculture systems towards monoculturing are mainly responsible for decreasing environmental quality, threatening biodiversity and increasing the possibility of insect outbreaks. Modern crops are often monocultures in highly specialized production units, where not only crop cultivation but also harvest and packaging techniques are specialized [17–19]. The development of farming systems (field or landscape) with greater dependence on ecosystem services, such as biological control of insect pests, should increase the sustainability of agro-ecosystems [20–22]. Farming systems like greenhouses, annual crop systems and other practices that end with removing the whole crop after harvesting, may give rise to elimination of biodiversity, and decreasing the population of natural enemies in the fields or in different agricultural environments [23, 24], as appeared in

Figure 1. Collection and transferring of natural enemies to environmentally controlled habitats could be useful in utilizing these natural enemies until releasing them in the next crop season.



Figure 1. Complete removal of maize may eliminate natural enemies (A) or after roses cutting (B).

Thus, they will try to contribute to preserve the natural biodiversity in the agricultural environment and provide natural alternatives to chemical pesticides. We concentrate here on the effects of conservative biological control on NE biodiversity and cleanliness of environment.

This chapter aims at discussing a suggested strategy for more efficient conservation biological control comprising of three main practices:

1. Collection of natural enemies before the end of crop season.
2. Preservation of collected natural enemies in special greenhouses during non-crop periods
3. Releasing the preserved natural enemies on target crops in the next growing season.

The sequence of these practices is illustrated in **Figure 2**.

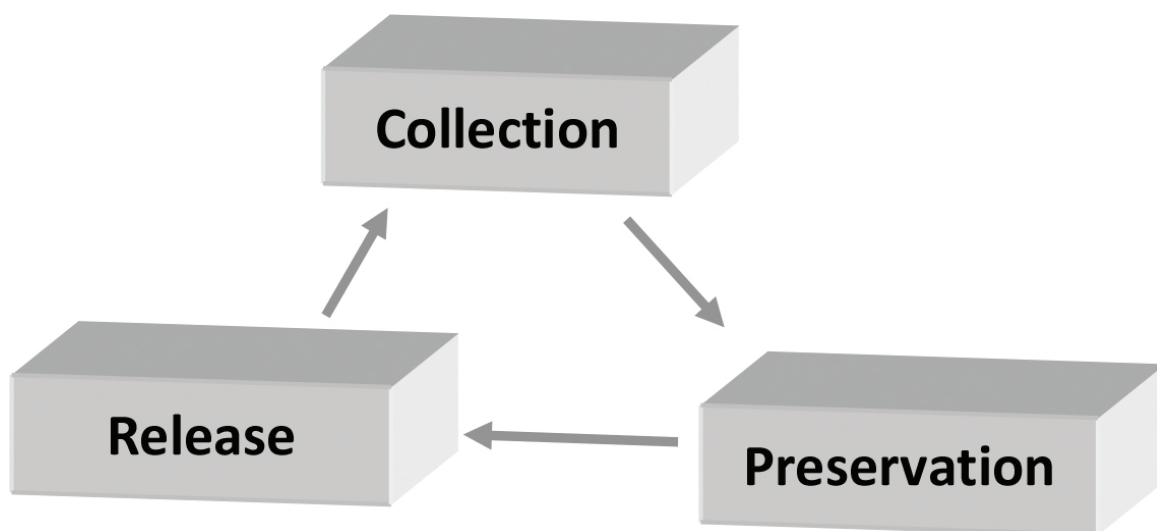


Figure 2. Logical practices diagram of conservation biological control.

2. Collection of natural enemies

The first step of the suggested strategy is collection of NE from fields shortly before the complete removal of plants and disappearance of occurring NEs. At the end of the crop season, the NEs are usually in their top population densities [1].

2.1. Collection time

Summer collection: High numbers of natural enemies may be found during the growing season on areas cultivated with some crops. These crops may not be in need for these natural enemies especially in absence of insect hosts or preys. For example, after heavy infestation of aphids to maize plants, high populations of aphid predators (lacewings and lady beetles) are built up. These predators could be mass collected and directly transferred to the preservation greenhouses or directly to other target crops that are in need for them.

Autumn collection: Before the end of most of annual crops, there are huge numbers of natural enemies which may be lost after harvesting and removing the plants. These NEs could be collected, preserved in greenhouses during non-crop periods then released in the next season.

Winter collection: In cases of permanent crops like fruit orchards and alfa alfa during cold weather in winter, many numbers of natural enemies may be lost as a result of absence of their hosts and preys, especially during non-suitable weather conditions. These natural enemies could be collected and transferred to greenhouses where maintained and improved them in numbers and quality control until release during the next crop season.

2.2. Collection sites

Natural enemies may be abundant in many sites around the year including landscape, fruit orchards, vegetable and field crops and ornamentals and others.

2.3. Collection techniques

Collection techniques differ according to the nature of natural enemies, crop, time and site.

The common collection techniques are vacuum collection, sweeping net, pitfall traps, manual collection etc. Example of collection techniques, sites and crops are assembled in **Table 1**.

Plant	Natural enemies	Pests	Technique	References
Mulberry trees	Parasitoids	<i>Brevipalpus</i> sp.	Parasitoids: Picking infested	Hendawy et al. [25]
	<i>Encarsia citrina</i>	<i>Panonychus ulmi</i>	leaves containing parasitized	
	<i>Anagyrus kamali</i>	<i>Thrips tabaci</i>	insects	
	<i>Metaphycus</i> sp.,	<i>Nezara viridula</i>	Predators: Individuals were collected by	
	<i>Allotropa mecrida</i>	<i>Bemisia tabaci</i>	beating tree	
	<i>Scutellista caerulea</i>	<i>Aphis gossypii</i>	branches in a suitable cloth bag	
	<i>Chartocerus</i> sp.	<i>Icerya aegyptiaca</i>		

Plant	Natural enemies	Pests	Technique	References
	Predators	<i>I. purchase</i>		
	<i>Orius</i> sp.	<i>I. seychellarum</i>		
	<i>Coranus</i> sp.	<i>Ceroplastes rusci</i>		
	<i>Coccinella undecimpunctata</i>	<i>Coccus hesperidum</i>		
	<i>Cydonia</i> sp.	<i>Saissetia oleae</i>		
	<i>Mantis religiosa</i>			
Tomatoes	<i>Nesidiocoris tenuis</i>	<i>Tuta absoluta</i>	Sweeping net	Sayed [26]
	<i>Chrysoperla carnea</i>	<i>Phthorimaea operculella</i>		
		<i>Bemisia tabaci</i>		
Clover	<i>Bracon</i> sp.	<i>Phthorimaea</i>	Tomato or potato leaves were	ELbehy [27]
Tomatoes	<i>Coccinella</i>	<i>operculella</i>	collected in jars and kept in the	
Maize	<i>undecimpunctata</i>	<i>Spodoptera. littoralis</i>	laboratory until parasitoids	
Potatoes	<i>Hypera postica</i>	<i>Agrotis ipsilon</i>	emergence	
	<i>Apanteles</i> spp.	<i>Tuta absoluta</i>		
Mango trees	<i>Amblyseius</i> spp.	<i>Aulacaspis</i>	Infested small branches were	Mohamed and
	<i>Oligonychus mangiferus</i>	<i>tubercularis</i>	collected in cloth bags and the predators	Nabil [28]
	<i>Brevipalpus obovatus</i>	<i>Kilifia acuminata</i>	were counted	
	<i>Cunaxa capreolus</i>			
Pineapple	<i>Pheidole megacephala</i>	Mealybugs	Infested small branches were	González-
	<i>Ochetellus glaber</i>	<i>Dysmicoccus brevipes</i>	collected in cloth bags and the predators	Hernández et al.
	<i>Lobodiplosis pseudococci</i>	<i>D. neobrevipes</i>	were counted in the laboratory	[29]
	<i>Nephus bilucernarius</i>			
	<i>Sticholotis ruficeps</i>			
	<i>Anagyrus ananatis</i>			
Sugarcane	<i>Tritaxys milias</i>	<i>Anoplognathus</i> spp.	Direct collection of insect individuals:	Sallam et al. [30]
	<i>Cuphocera javana</i>	<i>Dermolepida</i>	Insect larvae were collected and	
	<i>Palexorista</i> sp.	<i>albohirtum</i>	reared in the laboratory until emergence of	
	<i>Dicamptus fuscicornis</i>	<i>Lepidiota laevis</i>	parasitoids	
	<i>Zelomorpha</i> sp.	<i>Athetis recluse</i>		
	<i>Brachymeria</i> sp.	<i>Leucania loreyi</i>		
	<i>Lissopimpla scutata</i>	<i>L. stenographa</i>		
	<i>Lissopimpla</i>	<i>Nodaria cornicalis</i>		
	<i>Zosteria</i> sp.	<i>Oncopera</i> sp.		

Plant	Natural enemies	Pests	Technique	References
Pine trees	Predators:	<i>Chrysomphalus</i>	Parasitoids: Picking 20 leaves containing parasitized insects/tree Predators: Individuals were collected by beating tree branches in a suitable bags	González-Hernández et al. [29]
	<i>Chilocorus</i>	<i>aonidum</i>		
	<i>bipustulatus</i>	<i>Fiorinia fioriniae</i>		
	<i>Cydoni avicina</i>	<i>Lepidosaphues beckii</i>		
	<i>Pharoscyrnus</i>	<i>Parlatoria proteus</i>		
	<i>varius</i>	<i>Cenopalpus fewstrii</i>		
	<i>Paederus alferii</i>	<i>Coccus hesperidum</i>		
	<i>Calidomantis savignyi</i>	<i>Chrysomphalus aonidum</i>		
	<i>Embusa</i>	<i>Aspidiotus nerii</i>		
	<i>hedenberchii</i>	<i>Leucaspis pini</i>		
	<i>Hypsicorypha</i>	<i>L. pusilla</i>		
	<i>gracilis</i>			
	<i>Iris oratoria</i>			
	Parasitoids:			
	<i>Aphytis</i> spp.			
<i>Encarsia</i> spp.				
Pigeonpea (<i>Cajanus cajan</i>)	<i>C. septempunctata</i> <i>Andrallus spinidens</i> <i>Rhynocoris fuscipes</i> <i>Componotus</i> sp. <i>Mantis religiosa</i>	<i>Aphis fabae</i> <i>Oxyrachis tarandus</i> <i>Odontotermes obesus</i> <i>Nezara viridula</i> <i>Melanoplus bivittatus</i> <i>Sphenoptera indica</i>	Sweeping net	Sayed [26]
Abandoned orchards and Wild plants	<i>Lestodiplosis aonidiellae</i> <i>Ablerus perspicuosus</i> <i>Coccophagoides moeris</i> <i>Chilocorus bipustulatus</i> <i>Cybocephalus fodori-minor</i> <i>Rhyzobius lophanthae</i> <i>Aphytis</i> spp. <i>Encarsia berlesei</i>	<i>Aonidiella aurantii</i> <i>Parlatoria oleae</i> <i>Lepidosaphes ulmi</i> <i>Pseudaulacaspis pentagona</i>	Picking up: Scale insect-infested plant parts were examined for collecting predators. Aspirator: Adult NEs were collected using an aspirator and dropped into jars.	Erler and Tunç [31]

Table 1. Examples of collection techniques of natural enemies.

Collection techniques depend on many factors like pest species, host plant, type of natural enemy, habit, time, weather and others.

2.3.1. *Picking up infested plant leaves*

Plant leaves are picked up and transferred in cloth bags to the preservation greenhouses where emerged natural enemies could be classified and maintained. Infested leaves containing parasitized insects of mulberry trees were picked up and transferred to the laboratory; then the parasitoids were counted after their emergence [25]. Leaves of tomatoes or potatoes infested with leaf feeders *Phthorimaea operculella*, *Spodoptera littoralis*, *Tuta absoluta* and *Agrotis ipsilon* were collected then the parasitoids were counted after their emergence [26]. Immature predators were collected and transferred to the laboratory together with the plant material infested by their prey scale insects for rearing to the adult stage [27].

2.3.2. *Beating tree branches in cloth bags*

Leaves and/or branches (shoots) are picked up from trees and beaten in cloth or paper bags; then they were transferred to preservation greenhouses. Hendawy et al. [25] used this method for sampling predators and parasitoids of mealybug on mulberry trees. Small branches of pine trees were beaten in cloth bags and transferred in the laboratory for surveying mealybug natural enemies [28]. Also mango trees were sampled by the same methods for monitoring the natural enemies of *Aulacaspis tubercularis* and *Kilifia acuminata* [29]. Infested small branches were collected in cloth bags and predators were counted in the laboratory [27, 28].

2.3.3. *Sweeping net technique*

Sweeping net technique is a common technique for collecting parasitoids and predators such as Chrysopid, Syrphid and Coccinellid species from vegetable and field crop plants. Sayed [30], ELbeherly [26], and Badr [31] used the sweeping net in tomato or potato fields, usually by 50 double strikes by walking diagonally across the experimental plots.

2.3.4. *Direct collection of insect individuals*

Parasitized caterpillars or white grubs infesting roots are directly collected and transferred to preservation greenhouses where emerged parasitoids could be classified and maintained until their releases in the next season. Sallam et al. [32] collected white grubs infesting sugarcane roots and reared until parasitoid emergence. Larvae of armyworms were collected in sugarcane fields and were taken to the laboratory and fed on pieces of cane leaves until parasitoid emergence.

2.3.5. *Aspirator devices*

Aspirator or vacuum devices are used for collecting flying natural enemies from trees, orchards, vegetable and field crops. Adult parasitoids and predators were collected using an aspirator and dropped into a jar. Erler and Tunç [27] used aspirator devices for collecting the predacious mites from orchards and wild trees.

3. Preservation of natural enemies

Preservation greenhouses are dedicated for natural enemies rather than commercial production of crops. Preservation practices represent the cornerstone of conservation biological control. Preservation practices could be applied individually or in combination to maintain and improve efficiency of collected natural enemies. The currently applied practices for preservation of natural enemies in different fields are summarized in **Table 2**.

Crop	Natural enemy	Pest	Practice	References
Sweet pepper, ornamental crops	Syrphids lacewings hoverflies Predatory mites, <i>Orius laevigatus</i> , <i>O. majusculus</i> <i>O. insidiosus</i>	White flies, thrips, aphids	1 Plants providing pollen and plant sap as food sources for natural enemies like sweet alyssum, coriander, <i>Ricinus communis</i> and flowering ornamental	Bozsik [33]; Coll and Guershon [34]; Symondson et al. [35]; Pineda and Marcos-Garcia [36]; Igarashi et al. [37] Waite et al. [38]
Cucumber, chrysanthemum	predatory mites <i>Amblyseius swirskii</i> and <i>Euseius scutalis</i> ,	Thrips, whitefly	2 Spraying or dusting artificial or natural food supplements onto the crop. i.e. corn pollen, apple pollen, <i>Typha latifolia</i> pollen	van Rijn et al. [39]; Hulshof et al. [40]; Wade et al. [41] Nomikou et al. [42]; Adar et al. [43, 44]; Delisle [45]
Cereal crops	Aphid parasitoids	Cereal aphids	3 Introducing non-crop plants harbouring the prey species	Arno et al. [46]; Frank [47]; Huang et al. [17]
Chrysanthemum	Phytoseiid predatory mites	Spider mite	4 Applying yeast and sugars for astigmatic mites that are suitable prey for phytoseiid predatory mites	Messelink et al. [48–50]
Sweet pepper	Predatory mites <i>P. persimilis</i>	Spider mite	5 Artificial field rearing sachets containing bran, sugars, starch, yeast and/or saprophytic fungi, for feeding preys	Kühne [51]; Sampson [52]; Wright [53]; Baxter et al. [54]; Bolckmans et al. [55]
Sweet pepper	predatory mites <i>P. persimilis</i>	spider mites	6 Inoculating plants with low levels of pests early in the season and release predators afterwards to help their establishment.	Markkula and Tiittanen [56]; Messelink et al. [57]
Ornamentals	<i>Orius insidiosus</i>	thrips	7 Mixed diet of prey, or mixes of prey and non-prey food sources	Butler and O'Neil [58]
Rose plants	predatory mites	Spider mites	8 Providing oviposition sites and shelters:	Walter [59]; Parolin et al. [60]

Crop	Natural enemy	Pest	Practice	References
			Sweet pepper was used by predatory mites for oviposition.	
Tomato, sweet pepper	General mired predators, <i>Orius</i> spp., lacewings	whitefly, leaf miners, <i>T.absoluta</i>	9 Planting suitable non-crop plants near fields that help natural enemies to migrate into fields	Thierry et al. [61]; Bosco et al. [62]; Perdakis et al. [1]; Ingegno et al. [63]
Cotton, wheat, tomato	<i>Orius</i> spp., lacewings, lady beetles	Aphids, thrips, leaf-feeders	10 Induced plant responses that attract and/or retain natural enemies	Pare and Tumlinson [64]; Turlings and Wäckers [65]; El-Wakeil et al. [66, 67]
Different crops	Aphid parasitoids, chrysopids	aphids	11 Applying semiochemicals for increasing efficacy of natural enemies	Glinwood et al. [68]; Kunkel and Cottrell [69]; Simpson et al. [70]; Kaplan [71]
Wheat	<i>Orius</i> spp., lacewings, lady beetles	Aphids, thrips, leaf-feeders	12 Mitigation of pesticide side-effects by selecting pesticides that are compatible with natural enemies	El-Wakeil et al. [72, 73]

Table 2. Examples of preservation practices of natural enemies in different crops.

Practices of preservation of natural enemies are many and vary according the types of natural enemies, the target pests, the plants and the ecological conditions.

3.1. Plant-provided food

Many plants can provide food sources for natural enemies like nectar, pollen and plant sap but the effect of these food sources depends on the type of predator/parasitoid. Specialist natural enemies reproduce only in the presence of their specific prey/host species. However, most other natural enemies are feeding on both plant resources and prey [34]. Wäckers et al. [9] stated that adults of parasitoids and gall midges can increase their longevity, flight activity and oviposition by feeding on nectar. General predators consume multiple prey types and may feed also on nectar and pollen provided by plants [9, 13, 34, 35, 37, 74]. Adding some flowering plants like sweet alyssum and coriander to a sweet pepper crop resulted in higher densities of hoverflies [36]. Plants that produce a lot of pollen, like *Ricinus communis*, provided more pollen to predatory mites [75]. Flowering alyssum provided food resources for the predatory bugs *Orius laevigatus* and *Orius majusculus* during times of prey scarcity [76–78]. Flowering ornamental pepper can support and increase populations of *Orius insidiosus* in ornamental crops [38]. Another approach can be to select crop varieties with increased levels of plant-provide food resources [79]. Thus, the availability of plant-provided food can be a driving force in biocontrol success program [80].

3.2. Food sprays

Artificial or natural food supplements can be sprayed or dusted onto the crop to support natural enemies in crops where nectar and pollen are absent or only present at low densities [41]. For example, pollen sprays can serve as food for predatory mites and enhance their efficacy against thrips and whiteflies on cucumber [39, 42]. Corn pollen is also suitable for increasing populations of *Amblyseius swirskii* and *Euseius scutalis*. These pollens could be mechanically collected in large quantities [43, 44]. Other types of pollen are commercially available for pollination, such as apple pollen and date palm pollen. Application of pollen on chrysanthemum plants increases the establishment of many natural enemies [45]. Studies with predatory mites showed that adding *Typha latifolia* pollen to a crop clearly enhanced the biological control of thrips, even though the pollen is edible for thrips itself [39, 40]. The development of inexpensive alternative food sources is one of the major opportunities and challenges for enhancing biological control in different crop [50].

3.3. Introducing non-crop plants harbouring the prey species

The use of alternative prey/host plant species for the preservation of released natural enemies in many crops has been of interest for biological control of insect pests [17]. A widely applied system in different crops has been the use of monocotyledonous plants with cereal aphids that serve as alternative hosts for parasitoids of aphids that attack the dicotyledon crop [17, 47]. Prey/host plants can also be established on the edges of the field to bridge non-crop periods and contribute to the preservation of natural enemies [46]. Some alternative prey species that are not harmful to the crop may support their natural enemies [11, 81–84]. Woody habitats (hedgerows, field margins) often provide a more moderate microclimate than the centre of fields, protecting natural enemies against extreme temperature variations [14, 85, 86].

3.4. Applying artificial food for natural enemies

The application of yeast and sugars in chrysanthemum maintained populations of astigmatic mites that are suitable prey for phytoseiid predatory mites [48, 49].

3.5. Artificial field rearing units

Rearing natural enemies in controlled conditions has been developed into artificial rearing units for some natural enemies. For example, rearing sachets containing bran with saprophytic fungi for feeding astigmatic mites (prey) were used for rearing predatory mites [51, 52]. Many modifications with different types of preys, predatory mites, food sources for astigmatic mites such as sugars, starch, yeast and types of sachets have been developed [53–55]. Such units may produce predatory mites for 3–6 weeks [54]. This could be optimized by balancing the rate of predator, prey and food in the rearing unit [55].

3.6. Inoculation with low pest levels

A risky method to support natural enemies is the release low levels of pest species into crops. Inoculating plants with a low level of spider mites early in the growing season and release

predators afterwards enhanced the establishment of predatory mites in the crop [56]. Currently, this method is mainly used in sweet pepper crops [50, 57]. Thus, allowing low levels of pests, in numbers insufficient to cause crop damage, might contribute to natural enemies preservation.

3.7. Supplementing mixed diet for natural enemies

The population of natural enemies in crops can be increased by providing mixed diets of prey and/or non-prey food sources. Survival and reproduction of *O. insidiosus* were enhanced when aphids with thrips were supplemented as a prey source [58]. Supplementing thrips with pollen increased egg production of *O. laevigatus* and predation rates of thrips larvae [87]. Thus, supplementing diets of single pest species for predators with alternative prey or food may increase predator population and enhance biological control.

3.8. Providing oviposition sites and shelters

Suitable oviposition sites are essential for reproduction of many predators. *Orius* spp. and *Mimulus pygmaeus* lay their eggs into soft plant parts and ovipositional acceptance of the host plant depends on the morphological characteristics such as epidermal thickness or trichome density [88–90]. The hard plant parts are not very suitable for oviposition behaviour of predators and may disrupt their establishment [91]. Cutting soft stems of flowers may remove a potential new generation of natural enemies from the fields [50]. The same problem can also occur on tomato with the de-leaving practice that has a strong negative effect on the development of mixed predator populations [92, 93] and *Encarsia formosa* by removing parasitized whitefly scales [94]. These problems may be solved by adapting the de-leaving strategy or providing host plants with suitable oviposition sites for natural enemies.

A number of plants are considered as refuges for natural enemies [59, 95]. For example, the vein axils of sweet pepper plants are used by predatory mites for oviposition which reduced cannibalism and increased survival by providing such suitable microclimate [59]. Adding *Viburnum tinus* and *Vitis riparia* plants in roses enhanced mite control by predatory mites [60].

3.9. Planting suitable non-crop plants near fields

Mirid predators often migrate from non-crop plants into tomato fields, where they add to the control whiteflies, leaf miners and *T. absoluta* [1, 63, 96]. The natural existence of predatory bugs in tomato fields seems to be strongly related to the surrounding landscape. Migration of *Orius* spp. from neighbouring wild plants into sweet pepper fields may compete with populations of released *O. laevigatus* [62]. Many studies suggested that preservation biological control of predators can be enhanced by planting suitable non-crop plants near fields either to support migration into the crop or to provide a shelter when field crops are harvested and plants removed [1]. Field surroundings may also contribute to the migration of parasitoids into fields [97]. Providing overwintering shelters may enhance lacewings by providing diapausing adults with artificial overwintering chambers in greenhouses [61]. These methods may contribute to early establishment of natural enemies in new season in the spring.

3.10. Induced plant responses

Induced plant resistance against insects includes direct traits, such as the production of toxins and feeding deterrents that reduce survival, host preference, fecundity or developmental rate of pests and indirect traits, which attract and/or retain natural enemies [64, 65]. The latter contains traits such as the plant producing volatiles and floral nectar [98]. Insect-induced plant volatiles help natural enemies to detect their prey/hosts in a crop [23, 64, 99], whereas floral nectar production is increased in response to insect attack, guiding natural enemies to find their prey/hosts [100]. Preservation of natural enemies might be enhanced in different crops by breeding varieties that produce more volatiles and nectar [65, 101].

3.11. Applying semiochemicals

Behaviour of natural enemies is directed by semiochemicals. Attraction of natural enemies with synthetic compounds, similar to plant volatiles, is being tested in crops [71]. Natural enemies may also respond to odours that are produced by their prey/host species, such as sex pheromones or alarm pheromones. Sex pheromones are used either to monitor or mass trapping pest populations. However, volatiles for improving natural enemy performance are so far not applied in many crops. Glinwood et al. [68] mentioned that pheromones could be used to treat clusters of aphid infested plants in fields, which might increase efficacy of released parasitoids. Lures may also be used to attract released natural enemies in order to help them establish. Applying attractants in combination with food sprays may promote oviposition of released chrysopid predators into the target crop [69]. Hexane extract of corn borer larvae was applied on corn plants to enhance performance of larval parasitoid *Bracon brevicornis* adults against the corn borers *Ostrinia nubilalis* and *Sesamia cretica* [102].

3.12. Pesticide side-effects

Preservation of natural enemies should not be combined with pesticides, as most pesticides have lethal effects on NEs. Mitigation of side-effects on preservation of natural enemies can be realized by selecting pesticides that are compatible as possible with natural enemies.

Finally, with transfer of collected natural enemies into greenhouse with environmentally safe conditions, where these natural enemies can be fed on the pollen and nectar of flowering crops (clover and alfalfa), these plants will provide shelter for the natural enemies. This procedure will be continued until the next crop season, where the proper site and time of release.

Balzan and Moonen [103] mentioned that studying field margin vegetation enhances biological control agents in addition to crop damage suppression from many insect pests in tomato fields. They suggested that these habitats may be important during early crop colonization by natural enemies. These results indicate that the inclusion of flower strips enhances the preservation of arthropod functional diversity in ephemeral crops, and that diverse mechanisms are important for controlling different pests. However, the efficiency of habitat management is likely to be better when it is complemented with the preservation of diverse seminatural vegetation in the pre-existing field margin. Therefore, the field margin should be considered and evaluated before the inundative release strategy [1, 74, 104, 105].

4. Release of natural enemies

Release techniques are varied according the type of biocontrol agents, host plants, weather conditions. For example, egg parasitoids are released as parasitized egg patches; larval parasitoids are released as adults. Predators are usually released in the pupal stage. Timing, rate and frequency of release are determined according to the nature of the target pests, natural enemies and crops. Pathogens like entomopathogenic nematodes could be applied as sprays or injection [22, 106, 107]. Examples of cases of NE field releasing are summarized in **Table 3**.

Crop	Natural enemy	Pest	Release technique	References
Tomatoes	Egg parasitoids <i>Trichogramma</i> (29 starins)	<i>Tuta absoluta</i>	Paper cardboard or strips containing about 400 parasitized eggs of <i>Ephistia kuehniella</i> ready to emerge	Alomar and Albajes [108]; Cônoli et al. [109]; Chailleux et al. [110, 111]; El-Arnaouty et al. [112]; Balzan and Moonen [103]
Cabbages	<i>Trichogramma</i>	<i>Pieris rapae</i>	Releasing <i>Trichogramma</i> to control <i>Pieris rapae</i>	Abbas [113]
Olive fields	<i>Trichogramma evanescens</i>	<i>Prays oleae</i>	a dose of 3000 wasps/card x 3 cards/tree was applied (8 releases)	Agamy [114]
Grape orchards	<i>Trichogramma evanescens</i>	<i>Lobesia botrana</i>	50 and 75 cards/ ha, each card contain 1000 parasitoids (5 release)	Ibrahim [115]
Cotton	<i>Trichogramma</i>	Bollworms	Releasing <i>Trichogramma</i> in cards, each contain 1000 parasitoid for several times	El-Wakeil [66]; Abdel-Hafez et al. [116]; Andrade et al. [117] Saad et al. [118]
Sugarcane fields	<i>Trichogramma</i>	<i>Chilo agamemnon</i>	30,000–120,000 parasitoids per Feddan were released (5 releases)	Abbas [119] Tohamy [120]
Rice	<i>Trichogramma</i>	<i>Chilo suppressalis</i>	Investigating performance of 4 Chinese <i>Trichogramma</i> species on <i>C. suppressalis</i>	Jiang et al. [121]; Yuan et al. [122]
Maize	Larval parasitoids <i>Bracon</i> spp	Corn borers	Larval and pupal parasitoids are released in the pupal stage on special carriers like talc powder	Zaki et al. [102] Loni et al. [123]; Ferracini et al. [124]; Zappalà et al. [125]; Biondi et al. [126, 127]
Tomatoes		<i>Tuta absoluta</i>		

Crop	Natural enemy	Pest	Release technique	References
Tomatoes	Whitefly parasitoids <i>Encarsia</i> spp. and/or <i>Eretmocer</i> spp.	Whitefly	237,000 <i>Eretmocer</i> <i>siphonini</i> are released as parasitized pupae shortly before adult emergence	Abd-Rabou and Abou-Setta [128]; van Lenteren and Martin [129]; Gerling et al. [97] Abd-Rabou [130] Simmons and Abd-Rabou [131]
Tomato and cotton fields	<i>Eretmocer</i> <i>mundus</i>	<i>Bemisia tabaci</i> , <i>B. argentifolii</i>	<i>Eretmocer</i> <i>mundus</i> were released into cotton and tomato fields	Hoelmer [132]; Joyce et al. [133]; Gabarra et al. [134]
Cabbage, Faba bean, Oleander	Aphid parasitoids <i>Diaeretiella</i> <i>rapae</i>	<i>Brevicoryne</i> <i>brassicae</i> , <i>Aphis</i> <i>craccivora</i>	20 parasitoids/200 aphids per cage	Saleh [135]
Different orchards	Scale insect parasitoids <i>Coccophagus</i> <i>scutellaris</i>	Soft scale insects	About 953,000 <i>Coccophagus</i> <i>scutellaris</i> were released as parasitized individuals for controlling soft scale insects	Abd-Rabou [136–139]
Ornamental plants	Mealybug parasitoids <i>Anagyrus kamali</i> and <i>Gyranusoidea indica</i>	<i>M. hirsutus</i>	300,000 parasitoids in parasitized individual stage were released	Awadallah et al. [140]; Roltsch et al. [141]
Tomatoes	Insect predators <i>Nesidiocoris tenuis</i> <i>M. pygmaeus</i>	<i>Tuta absoluta</i> , whitefly	Predators release in pupal stages to control both insects	Gabarra et al. [142]
Tomatoes and Pepper	Predacious mites phytoseiid predator	Spider mites whiteflies	Predators release in pupal stages	El-Laithy [143]; Messelink et al. [49, 57]
Maize	Combination Trichogramma Entomopathogenic nematodes	Corn borers	20 and 30 cards (1000 parasitized eggs/ card)/ acre (3 releases) The infested plants were sprayed with (500 and 1000 IJs/ml) of <i>S. carpocapsae</i> and <i>H. bacteriophora</i>	El-Sherif et al. [144]; Kfir [145]; Saleh et al. 1995 [158]; Ragab et al. [146]; El-Wakeil and Hussein [22]
Date palms	Entomopathogenic nematodes	Red palm weevil	Spraying EPNs around infested tree trunks	Saleh et al. [147]

Table 3. Release techniques regularly used for various natural enemies in different crops.

4.1. Egg parasitoids

The common techniques of releasing egg parasitoids are paper cards or strips holding the parasitized eggs. Cardboard strips containing parasitized eggs in tubes were released in tomatoes for controlling *T. absoluta* [110, 112]. *Trichogramma buesi* was released against *Pieris rapae* eggs in cabbage fields [113]. A dose of 3000 *Trichogramma evanescens* wasps/card x three cards/tree was applied; each card contains three different ages of *Trichogramma* to keep searching adults continuously; 8–11 releases were performed per year at 2-week intervals against *Prays oleae* in olive fields [114, 148, 149]. Five releases of *Trichogramma* at two release levels (50 and 75 cards/ha, each contains 1000 parasitoids) were released in grape orchards for controlling *Lobesia botrana* [90, 115]. Over 100,000 parasitoids per Feddan were released against *Chilo agamemnon* in sugarcane fields; five releases were applied during season [120, 145].

Bollworms are causing highly infested boll in cotton; *Trichogramma* were applied for control them. Different releasing *Trichogramma* in cards, each contain 1000 parasitoid for several times [66, 116–118, 150, 151]. Four *Trichogramma* species (*T. japonicum*, *T. chilonis*, *T. dendrolimi* and *T. ostriniae*) was evaluated against *Chilo suppressalis* in rice fields. *T. chilonis* parasitized more eggs, while *T. dendrolimi* and *T. japonicum* performed the best [121, 122].

4.2. Larval parasitoids

Larval and pupal parasitoids are released in the pupal stage. Parasitized pupae just before emergence are carried on special carriers like talc powder and distributed in the target fields. Releasing *Bracon* spp to control corn borer larvae is one of the effective methods for controlling such insects [102]. Two ectoparasitoid species *Bracon* sp. and *Necremnus* sp. were released in tomatoes [152]. *Necremnus* sp. *Nrartynes* and other braconid species have already been proved to be potential key biocontrol agents of *T. absoluta* in tomato field [123–127].

4.3. White fly parasitoids

Encarsia spp. or *Eretmocerus* spp. are released as parasitized pupae shortly before adult emergence [153, 154]. Additional *Encarsia* species have been released against *Bemisia tabaci*; reached to 65% parasitized whiteflies [97, 130, 155]. Simmons and Abd-Rabou [131] confirmed that inundative releases of parasitoid *Eretmocerus mundus* against *B. tabaci* into tomato and cotton fields increased parasitization rates. Findings from their research may be useful in the enhancement and preservation of parasitoids of *Bemisia* [132, 133].

4.4. Aphid parasitoids

Aphid parasitoids are released as parasitized mummies of aphid host. Semi-field experiments were carried out to evaluate the performance of releasing parasitoid species *Diaeretiella rapae* for controlling *Brevicoryne brassicae*, *Aphis craccivora* and *Aphis nerii* infesting cabbage, faba bean and oleander plants. The highest percentage of parasitism was 92.20, 83.20 and 79.30% for *D. rapae* at 20 parasitoids/200aphids per cage in semi-field test *B. brassicae*, *A. craccivora* and *A. nerii*, respectively. The maximum numbers of mummies in the field were 185.60, 166.4 and 158.6

for *D. rapae* at 20 parasitoids per cage and minimum of 124.60, 97.40 and 83.0 mummies at five adults per cage [135].

4.5. Parasitoids of scale insects

Parasitoids of scale insects are released as parasitized host individuals. About 953,000 of *Coccophagus scutellaris* as parasitized individuals were released and evaluated for controlling soft scale insects *Ceroplastes rusci* on citrus, *Ceroplastes floridensis* on citrus, *Coccus hesperidum* on guava, *Pulvinaria floccifera* on mango, *Pulvinaria psidii* on mango, *Saissetia coffeae* on olive and *Saissetia oleae* on olive. The population of parasitoid *C. scutellaris* showed a significant correlation with the build-up of the population of the soft scale insects population in all of the release orchards studied [136–139].

4.6. Mealybug parasitoids

Parasitoids of mealybug are released as parasitized host individuals. *Anagyrus kamali* and *Gyranusoidea indica* were released at ten sites on ornamental plants. 300,000 parasitoids of *A. kamali* were released to control *Maconellicoccus hirsutus*. Population density of *M. hirsutus* was reduced by approximately 95% and *A. kamali* was the predominant parasitoid [140, 141].

4.7. Predators of *T. absoluta* and *B. tabaci*

General predators (lacewings and lady beetles) are released in the pupal stage with the suitable carriers. These general predators are used commercially for regulating many insect and mite pests. *Nesidiocoris tenuis* and *M. pygmaeus* were also released and caused a significantly reducing *T. absoluta* [155] and *B. tabaci* populations [142, 156].

4.8. Predacious mites

Individuals of predacious mites carried on special materials are released for regulating spider mites and whiteflies in tomato and pepper in the greenhouses [49, 57].

4.9. Combination entomopathogenic nematodes (EPNs) and egg parasitoid

Natural enemies may be released in integration with each other to regulate one or set of insect pests. Entomopathogenic nematodes (EPNs) and *Trichogramma* were used for *S. cretica*, *C. agamemnon* and *O. nubilalis*, respectively, in corn fields. The infested plants *S. cretica* were sprayed one time with 500 and 1000 IJs/ml of *Steinernema carpocapsae* and *Heterorhabditis bacteriophora*. Three releases of *T. evanescens* were conducted to control *C. agamemnon* and *O. nubilalis* [22].

4.10. Entomopathogenic nematods application

Entomopathogenic nematods are injected in tunnels made by the red palm weevil larvae or sprayed around the trunks of infested trees to control the pest adults [147].

4.11. Evaluation of released natural enemies

Evaluation of preservation biological control practices varies according to the pest, natural enemy species and target crops. Evaluation items include crop assessment, crop damage, pest and natural enemy populations. These evaluation criteria may include natural enemy efficiency and persistence in the target fields, predation rates, parasitization rates and pest population reduction. For field experiments, the standard equation of Henderson and Tilton [157] will be used. This equation is applicable for evaluating insect and natural enemy population, damage level and yield.

5. Conclusion

Populations of natural enemies are subjected to continuous deterioration especially in modern agricultural systems characterized by complete removal of plants after harvesting. Conservation biological control is the protection of NEs against adverse effects of pesticides and incompatible cultural practices and improving their efficiency via providing food sources. During non-crop periods, natural enemies may be in need of benefit from pollen and nectar. Preservation of natural enemies can be achieved by providing habitat and resources for natural enemies. This chapter aimed at discussing a suggested strategy for more efficient conservation biological control comprising (1) collection of natural enemies before the end of crop season, (2) preservation of collected natural enemies in special greenhouses during non-crop periods and (3) releasing the preserved natural enemies on target crops in the next growing season. The collection is mainly conducted before crop harvest but also could be done during the growing summer season and during winter from fruit orchards and permanent crops. Collection of natural enemies may be done in annual crops, fruit and vegetable orchards, landscape, abandoned plants and bushes.

Preservation greenhouses are dedicated for natural enemies rather than commercial production of crops. Practices of preservation of natural enemies vary according to the types of natural enemies, the target pests, the plants and the ecological conditions. Many plants can provide food sources for natural enemies like nectar, pollen and plant sap but the effect of these food sources depends on the type of predator/parasitoid. Artificial or natural food supplements can be sprayed or dusted onto the crop to support natural enemies in crops where nectar and pollen are absent or only present at low densities. Introducing plants harbouring the prey species is essential for the preservation of natural enemies. The application of yeast and sugars in chrysanthemum maintained populations of astigmatic mites that are suitable prey for predatory mites.

Natural enemies taken from preservation greenhouses are released in target crops during crop growing season. Releasing technique, rate of release, timing and frequency of release depend on the type of target pest, the crop, the natural enemies, weather condition and others. The present chapter contains many cases of releasing NE for pest regulation. The common techniques of releasing egg parasitoids are paper cards or strips holding the parasitized eggs. Larval and pupal parasitoids are released in the pupal stage. Parasitized pupae just before

emergence are carried on special carriers like talc powder and distributed in the target fields. White fly parasitoids are released as parasitized pupae shortly before adult emergence. Aphid parasitoids are released as parasitized mummies of aphid host. Such a conservation biological control strategy might contribute to preserve the natural biodiversity in the agricultural environment and provide alternatives to chemical pesticides.

Author details

Nabil El-Wakeil*, Mahmoud Saleh, Nawal Gaafar and Huda Elbehery

*Address all correspondence to: nabil.elwakeil@yahoo.com; nm.elwakeil@nrc.sci.eg

Pests and Plant Protection Department, National Research Centre, Dokki, Cairo, Egypt

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