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Ground-living predators of the apple fruit moth *Argyresthia conjugella* (Zell.)

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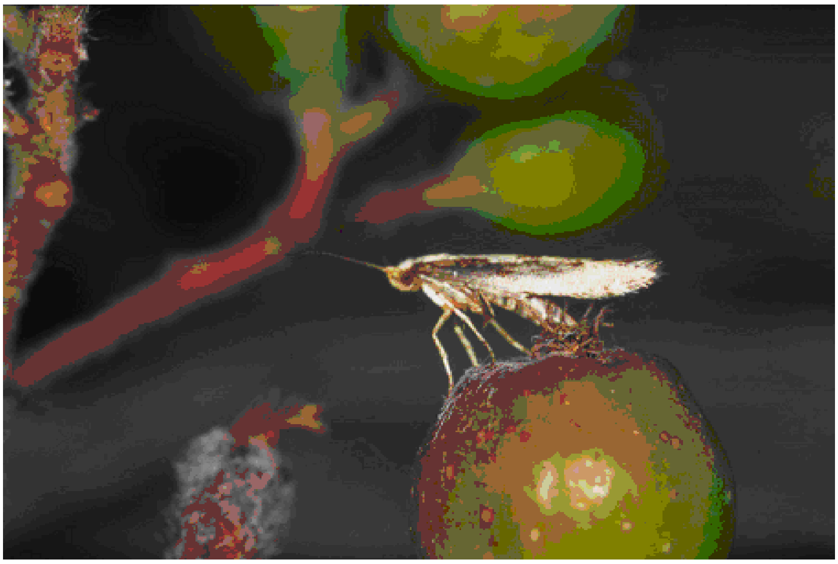

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Ground-living predators of the apple fruit moth, *Argyresthia conjugella* Zell.

Field studies were conducted in two orchards to investigate what type of ground-living predators that prey on the apple fruit moth during hibernation. Two tasks were addressed: 1) hibernation loss of the apple fruit moth was quantified, and 2) effect of the different predator groups were identified. This was done in a spring experiment and an autumn to spring experiment with mesh exclusion cages. The results were analyzed with the GLIMMIX procedure in SAS. The field studies were complemented with feeding tests in laboratory with spiders, ants, staphylinids and carabids that were supposed to detect and eat apple fruit moth pupae.

In spring and autumn, large insects between 5 to 11 mm, were the major predator of the apple fruit moth, while the smaller insects of sizes 0-5 mm, dominated the predation during winter. Small rodents (11-20 mm) had little or no predation effect on the apple fruit moth pupae, probably because the pupae were too small to be detected as a food source. Both ground-beetles (*Pterostichus* sp. and *Harpalus latus*) and staphylinids were able to detect and eat apple fruit moth pupae in the feeding test. Spiders and ants did not eat apple fruit moth pupae in the feeding test.

Keywords: Ground-living predators, apple fruit moth, Argyresthia conjugella, mortality during hibernation, mesh exclusion cage, GLIMMIX, feeding test

Marklevande predatorer till rönnbärsmal, *Argyresthia conjugella* Zell.

Fältstudier genomfördes på två lokaliteter för att undersöka vilken typ av marklevande predatorer som kan upptäcka och konsumera puppor av rönnbärsmal under övervintring. Två faktorer studerades: 1) mortalitet av rönnbärsmal under vinterhalvåret kvantifierades, och 2) effekten av de olika grupperna av predatorer studerades. Uteslutningsburar med olika nätstorlekar användes i ett vårförsök och ett höst- till vårförsök. Resultaten analyserades med GLIMMIX i SAS. Fältstudierna kompletterades med test i laboratorium, där spindlar, myror, jordlöpare och kortvingar observerades medan de attackerade puppor av rönnbärsmalen.

Under vår och höst var större insekter av storlek 5-11 mm den tydligaste gruppen av predatorer, medan mindre insekter (0-5 mm) dominerade predationen under vinterhalvåret. Små däggdjur med storleken 11-20 mm hade ingen eller mycket liten effekt på rönnbärsmalspopulationen, förmodligen beroende på att pupporna var för små för att bli upptäckta som födokälla. Både jordlöpare (såsom *Pterostichus* sp. och *Harpalus latus*) och kortvingar kunde identifiera och äta upp rönnbärsmalspuppor i laboratorietestet. Spindlar och myror däremot var inte intresserade av rönnbärsmalspuppor som födokälla.

Sökord: Marklevande predatorer, rönnbärsmal, mortalitet under övervintring, uteslutningsfälla, födoförsök.

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Introduction

Ecological populations are dynamical systems that fluctuate with time, defined by regulatory factors such as population density and densities of interacting species (Turchin, 1995). Key factors are identified as the main cause in fluctuations of the population from year to year, derived from long term studies (Varley & Gradwell, 1973). Density dependent factors affect a population when its density is high, by a regulatory mechanism that makes the population return to its equilibrium density (Cappucino, 1995). The regulatory mechanisms that stabilizes the population can be of abiotic character such as climate or dispersal; or biotic factors such as predation, parasitism, disease or maternal effects.

The winter moth, *Operophtera brumata* L. has been studied for a very long time, and its population dynamic and the most important mortality factors are well described. The winter moth, like the apple fruit moth, spend a portion of its lifecycle on the ground, where it is exposed to ground-living predators. Pupal predation of the winter moth is the density dependent factor that stabilizes the population, while winter disappearance is the key factor causing population change (Varley & Gradwell, 1973). Winter disappearance cover the loss from all causes between the count of reproductive females up to the count of fully grown larvae. Pupal predation, as the density dependent factor, is the most important mortality factor in the lifecycle of the winter moth, and it is recorded from healthy larvae falling to the ground to the emergence of adult females (East, 1974; Roland, 1990). Other mortality factors for the winter moth are virus, fungus, failed pupation, introduced and native parasites, and larval mortality (East, 1974; Roland, 1990).

Frank (1967b) concluded from mark, release and recapture experiments that 20% of the winter moth were killed by the pupal parasite *Cratichneumon culex* Muell., 40% became victims of the carabid genera *Pterostichus* and *Abax,* and by adults of the staphylinid *Philontus decorus* Gr., and 21% were killed by the shrew *Sorex araneus* and other small mammals. Buckner (1969) on the other hand, concluded from stomach analysis that the shrews *S. araneus* L. and *S. minutus* L. were the cause of more than half of the disappearance of winter moth pupae. East (1974) examined this contradicting results and found through cocoon planting techniques that pupal predation were mainly due to carabids (38%) and staphylinids (30%), while small mammals only accounted for a minor predation (4%).

But in nature, factors seldom act independently of each other, and it is most likely that parasites and predators of the winter moth show synergistic effects (Roland & Embree, 1995). At high densities parasites seem to be the regulating factor and at low densities predation keeps the population down (Kowalski, 1977; Roland, 1990; Roland & Embree, 1995).

The winter moth and the apple fruit moth show some similarity in their biology and lifecycle: Both moths has an annual lifecycle with each developmental stage concentrated at a different time of the year. They hibernate on the ground, where they are exposed to predators and cannot protect themselves. A difference is that the winter moth are in the pupal stage from the end of May to November (Frank, 1967b), while the apple fruit moth hibernate from September to late May (Ahlberg, 1927) (see table 1). Another difference is that the winter moth is almost twice as long as the apple fruit moth. Despite these differences it seems likely that predators of similar sizes to the winter moth also can prey on the apple fruit moth. Edland (1979) found it possible that small mammals and insect predators prey on pupae of the apple fruit moth during hibernation.

Table 1. Lifecycles of the apple fruit moth and the winter moth

		ADULT	EGG	LARVA	PUPA
Winter moth	Period of the year	Nov/Dec-April	April-April/May	April/May-May	May_Nov/Dec
	Location	Flying males, wingless females	In crevices in bark of oak	On oak buds and leaves	In the soil beneath the oak tree
Apple fruit moth	Period of the year	May/June-June/July	June/July-July	July-Aug/Sept	Aug/Sept-May/June
	Location	Flying	On fruit of rowan or apple	In seeds of rowan or in apple fruits	On the ground beneath the tree

Background

Lifecycle of the apple fruit moth

The apple fruit moth *Argyresthia conjugella* Zell. (Hyponomeutidae: Argyresthiinae) emerges as an adult in late May/June. The female oviposits in June/July on the unripe fruit of rowan or apple, shortly after petal fall (Kobro *et.al.* 2003). After approximately two weeks (Ahlberg, 1927) the larva hatches and it immediately eats its way into the fruit. The larva does not leave the fruit until August/September, when it lowers itself down in a silken thread. Depending on the climate, the apple fruit moth hibernate on the ground as a larva or a pupa, during a period of 6-8 months (Ahlberg, 1927).

Appearance

The apple fruit moth is 4 mm long and 13 mm between the wings. The head and the intermediate body are white-yellow, while the outer body and the wings are grey-brown. It has a white-yellow band at the lower part of the wings (see fig. 1). The egg is very small, only 0.5 mm long and 0.3 mm wide and it has a rounded oval shape. The colour is yellow-grey. The larvae is light yellow when hatched. It has 6 eyes on each side of the head and two antennae. It goes through 3-4 juvenile instars before it reaches full size of 6-7 mm (Ahlberg, 1927). The colour changes from light yellow-white, filthy grey to red/orange (see fig. 2).

Fig 2. Fully grown larva of the apple fruit moth

(Photo: M. K. Petersen).

Fig. 3 Pupae of the apple fruit moth

with the cocoon (Photo: M. K. Petersen).

The pupa is shiny yellow-brown, 4-5 mm, and it is surrounded by a cocoon that consists of a thin mesh outer covering and a thick inner one (see fig. 3) (Ahlberg, 1927).

Hosts, parasites and damages

The apple fruit moth is naturally distributed in temperate climates and the actual spreading of the apple fruit moth depends on climatic factors and the occurrence of its primary host the rowan tree, *Sorbus aucuparia* L. (Ahlberg, 1927). The apple fruit moth always prefer the rowan tree to apple (Edland, 1979). When the supply of rowanberries is good, i.e. in masting years, the apple fruit moth reproduces well and the population increases to higher levels. Poor flowering and few oviposition sites lead to attacks on apple in the intermast years and a decreasing population of the apple fruit moth (Sperens, 1997; Kobro *et al.*, 2003). The braconid wasp, *Microgaster politus* Marsh. is the most important parasite of the apple fruit moth (Ahlberg, 1927; Kobro *et al.* 2003). The braconid wasp faces an extremely difficult situation the year after masting, when a small population of the apple fruit moth is spread on a large amount of berries (Edland, 1995). Thus the apple fruit moth population increases much faster than its parasite.

The larva of the apple fruit moth makes tunnels in the apple, in search for the seeds (see fig. 4). The apples get a bitter taste and rot in advance. Sometimes the larva pupate in the cavity with the seeds, but generally the moth leaves the fruit for pupation (Petersen, pers. com). Older studies show that the apple fruit moth has difficulties to develop from apples (Ahlberg, 1927; Edland, 1979), but recent studies proves otherwise (Kobro, 1995). It is even the case that larvae developed from apples are larger than specimens developed in rowan berries (Petersen, pers. com.) The apple fruit moth can reproduce well in apples, and it means that an orchard with a lot of fruit left on the orchard floor can contribute to the pest population the year after (Kobro, 1995).

Fig. 4 Apples with damages from larvae of the apple fruit moth (Photo: M. K. Petersen).

Objectives

The aim of this study is to investigate what type of ground-living predators that prey on the apple fruit moth during hibernation. Two tasks are addressed: 1) quantification of the hibernation loss of the apple fruit moth, and 2) identification of the effect of the different groups of predators. Two questions will be answered: 1) In the long run, can ground-living predators be useful in controlling the apple fruit moth? 2) How can the predators be enhanced?

It is assumed that staphylinids and carabids as well as spiders and small mammals can prey on larvae and pupae of the apple fruit moth, as found for the winter moth. The experimental design on the apple fruit moth is therefore based on similar experiments on winter moth in British Columbia, Canada (Roland, 1990), and in Wytham woods, Berkshire, England (East, 1974).

Material and methods

The experimental sites

The experimental sites are an approximately 25 year old orchard near the Department of Entomology at SLU in Ultuna, Uppsala and an approximately 100-150 year old orchard at the countryside in Östergötland, named Harstorp. In Ultuna the orchard is surrounded by arable land in west and south, and houses and an experimental site in the other two directions. The orchard floor consists of uncut grasses, herbs and shrubs (see fig. 5). The trees have not been pruned for quite a long time.

Fig. 5 The orchard in Ultuna (Photo: M. K. Petersen).

The orchard in Harstorp is surrounded by arable land in west, a countryside road in east, an old cottage in north and a spruce forest in south, and is sloped from west to east. The orchard floor consists of a lawn, or a meadow. There are also some vegetable plots and perennial borders in the orchard (see fig. 6). The soil type is a rather heavy clay, in both Ultuna and Harstorp.

Fig. 6 The orchard in Harstorp, facing south with the spruce forest in the background (Photo: S. Furenhed).

Experimental work

A pilot study with mesh exclusion cages was carried out in the spring 2005. A larger experiment with mesh exclusion cages followed in the autumn 2005 to the spring 2006. In addition, a feeding test with spiders, staphylinids and carabids was carried out in the spring and autumn 2006. The intention is that the result from the feeding test will reveal what predator that caused the injuries recorded on the pupae in the mesh exclusion experiments.

The pilot spring study

To measure the disappearance of the apple fruit moth, plastic mesh exclusion cages were established in the two locations in the spring 2005 in a pilot study. In each location there were six replicates with four treatments each. Each replicate were situated beneath one tree. The treatments differed with the net size; 0.5 mm, 5 mm, 11 mm and 20 mm. The experimental design on the apple fruit moth is based on similar experiments on winter moth in British Columbia, Canada (Roland, 1990), and in Wytham woods, Berkshire, England (East, 1974).

Ten pupae of the apple fruit moth, glued to filter paper, were placed in each cage in the study, for a total of 480 pupae. The pupae had been stored in plastic boxes in a climate chamber at 0°C during the previous winter, and were kindly provided by associate professor Mette K. Petersen. Four cages with varying net sizes were placed under each tree. The cages were placed randomly under the apple trees and approximately 0,5 m from the trunk (see fig. 7). Tent sticks were used to tie the cages to the ground, and some sand were put around each cage to level out, between the bottom of the cage and the soil surface.

The cages were established the 13th of April in Ultuna and the 15th of April 2005 in Harstorp.The pilot study was terminated after four weeks.

Filter paper vs. OH-film

In the pilotstudy it turned out that the filterpapers curved upwards after rain and restricted entrance to the pupae. A pilotproject tested if the edges of OH-film were not curving upwards as the filterpaper did. Four cages of 0,5 mm, 5 mm 11 mm and 20 mm mesh were put under tree four in Harstorp, with ten pupae in each cage. They were placed out the 25th of May and taken in for examination after four weeks. The OH-film did not curv upwards after rain, so in the larger study only OH-film were used. In this OH-film pilotstudy seven pupae out of ten were depredated from the cage with 0,5 mm mesh. The intruders were an earwig and a spider. To prevent this in the larger study (this mesh size was supposed to be a reference group), the 0,5 mm mesh was replaced with an unpenetrable fabric, called 0 mm onwards.

Collection of pupae

In order to obtain pupae for the larger study, rowan-berries were collected from the 15th of August to the 23rd of September and stored in boxes, so that larvae could emerge and pupate. The upper box had holes in the bottom, where a net was glued tight, and another box was placed beneath. A fine fabric was placed under the lid of the upper box, which had a hole for aeration. When the larvae were ready to pupate, they lowered themselves down in a silken thread, from the upper box through the net, and pupated in the lower box (see fig. 7). The boxes were stored in the cellar, at +15°C and at rather high humidity in Harstorp, and in a climate chamber with 17°C and 70 RH at Ultuna.

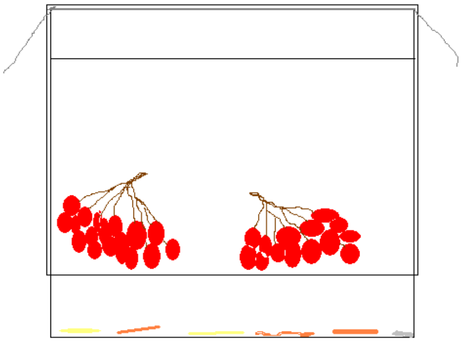

Fig 7. Collection box for pupating larva of the apple fruit moth

(Drawing: S. Furenhed).

The autumn 2005 – spring 2006 study

The autumn to spring study consisted of nine replicates of the four mesh sizes (0, 5, 11 and 20 mm), at the two locations. Each cage contained six pupae. The cages with the pupae were established the 27th of September in Harstorp, and the 29th of September in Ultuna. During the autumn the cages were recorded eight times (every week at the beginning and every second week later in the experiment). After each recording pupae were replaced, so that there were always six undamaged pupae in each cage. During winter there was a break in the recordings, due to a thick snow cover. The study was terminated in the spring 2006, when a final recording was made.

Identification of predators

An attempt to identify the most common predators was done during the autumn, to find out what animals that could actually enter the different net sizes in the cages. Mousetraps were tried for the larger and intermediate mesh cages and insect glue was used for the smaller and intermediate mesh cages. Mousetraps were placed inside extra cages with a netsize of 20x20 mm and placed in the orchards on the 12th of October in Ultuna and on the14th of October in Harstorp. They were placed at some distance from the other cages with pupae. Additional mousetraps in cages with netsize 11x11 mm were placed under the same trees as the first mousetraps, the 19th of October in Ultuna, and the 21st of October in Harstorp. At this time also the cages with insect glue (Tangle-Trap®)[1] were established. Bottoms with the insect glue were taken in for observation after one week.

Feeding test

Possible predators were caught in pitfall traps in Harstorp in April 2006. They were observed in petri dishes for 24-36 hours, while attacking pupae of the apple fruit moth. In each petri dish there were one predator and two pupae, on a moist filter paper.

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[1] The Tanglefoot Company, Grand Rapidos, MI 49504 USA.

Statistic procedures

Results from the spring and the autumn to spring field studies were analyzed with the GLIMMIX procedure in SAS, following a binomial distribution with a logit link. The locations, Harstorp and Ultuna were used as fixed factors as well as the treatment (varying mesh net sizes), and the trees were regarded as random factors. In the autumn to spring study 2005-06 nine recordings were made over time, and they were treated as repeated measurements on each tree.

Results

The GLIMMIX model does not account for the fact that the 20 mm cage also is penetrable for predators that can get into the 11 and 5 mm cages, and that predators that get into the 5 mm cage also can penetrate the 11 mm cage. To be able to detect the true predation effect for the mesh sizes the predation effect from cage 11 mm and 5 mm were subtracted from the 20 mm cage, and the predation effect from the 5 mm cage was subtracted from the 11 mm cage. In this way predator effect from rodents in cage 20 mm is separated from predator effect from large insects in cage 11 mm, and predator effect from small insects in cage 5 mm.

The predation was highest in the 5-11 mm cages ($p < 0.0001$), in both the spring and the autumn study. The treatments differed significantly from each other, except for the treatments 0-5 mm ($p = 0,1203$, DF = 541) and the treatments 11-20 mm ($p = 0,2663$, DF = 541). In the spring study predation in the 5-11 mm cages was 3,4 times higher than in the 0-5 mm cages and 16 times higher than in the 11-20 mm cages (table 2). In the autumn to winter study the same calculations reveal a 1,4 times higher predation in the 5-11 mm cages than in the 0-5 mm cages. This indicates that large insects, that are specific to the 5-11 mm cages, is the overall major predators of the apple fruit moth pupae. The smaller insects, that are connected to the 0- 5 mm cages, is the second most important predator (table 2).

Table 2. Calculated predation in the spring and autumn project.

Predator	*Predation in %*	
	Spring	Autumn
Small insects	7,7	5,1
Large insects	26,2	7,2
Rodents	1,6	0

In the autumn project there are no specific predators linked to the 11-20 mm cages, since the smaller predators cover the entire predation (table 2), but there is some predation in the 11-20 mm cages at day 56, 70 and 77 (see fig 9). In the spring project rodents (in cage 11-20 mm) only stand for a minor predation (table 2).

There was a significant interaction between day and site ($p = 0.0023$, DF = 434), which means that there are a difference in day-degrees between the sites. Harstorp and Ultuna is treated as one locality in all calculations, since site in particular was non-significant ($p = 0.1954$, DF = 16)

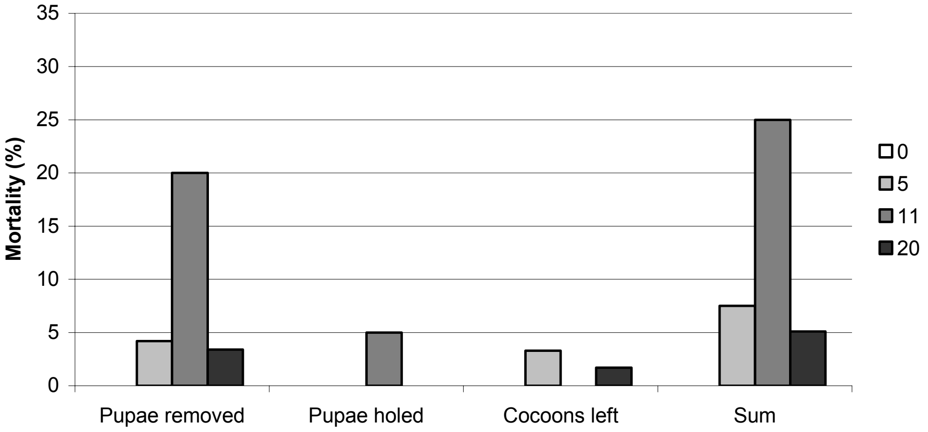

Fig. 8 The spring study 20050413-0513 showed that large insects (treatment 5-11 mm) were the major predators (calculated figures).

The spring study showed that large insects in the 5-11 mm cages, were the major predators (see fig.8).

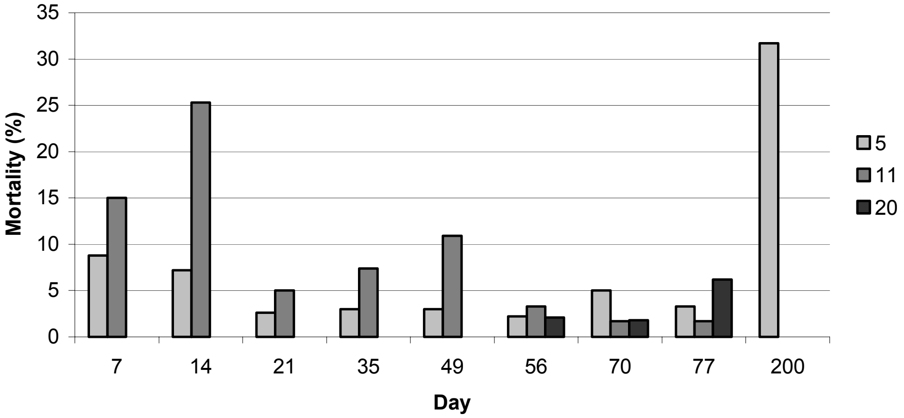

Fig. 9 Calculated mortality (in percent) for the three treatments at the eight recording occasions during the autumn 2005, and the final recording in spring 2006 (day 200).

Mortality varies over time as it is significant (p<0.0001, DF = 431), with decreasing mortality as insect activity decrease with decreasing temperature during the autumn (see fig 9). In the autumn the large insects dominated predation (mesh size 5-11 mm), while during winter (day 200), predation in the 0-5 mm cages was totally superior to the other mesh sizes, indicating that small insects were the major predators (see fig. 9).

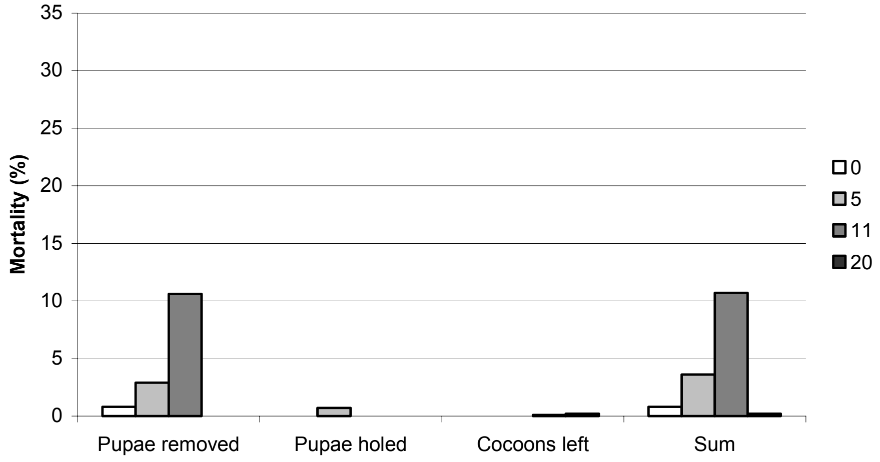

Fig. 10 Calculated mean value of predation (N=8) during autumn 2005, where predation in the 5-11 mm cage is highest.

Of depredated pupae during autumn and winter, almost all were removed compared to the holed or when only the cocoon was left (see fig. 10). Predation in the 5-11 mm cage was highest, indicating that large insects were the major predators, followed by the smaller insects in the 0-5 mm cage (see fig. 10).

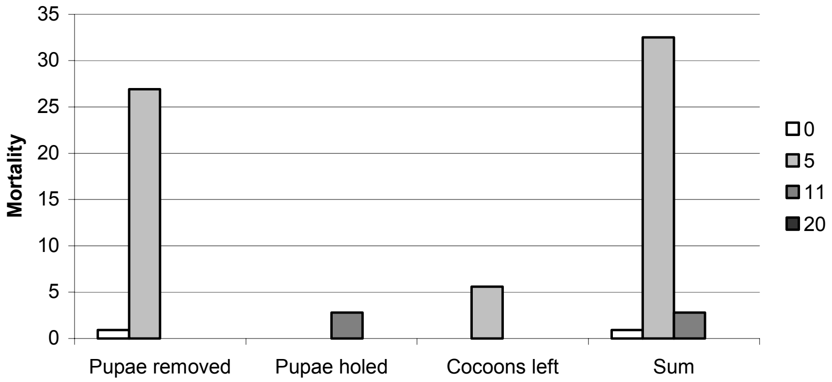

Fig. 11 During the winter 2005-06, cage 5 mm totally dominated predation of the apple fruit moth pupae (calculated values, N=1).

Small insects began to increase predation of the apple fruit moth pupae in december, and they were totally superior in predation during winter (see fig. 11).

In the insect glue experiment I found one carabid, *Pterostichus niger,* a few staphylinids of greater sizes and some earwigs (for a complete record, see appendix 1). Insects were identified using the keys of Mandahl-Barth and Coulianos (2000), Douwes et.al. (1998), Palm (1948) and Lindroth (1986). The spiders were all web spiders and probably too small to be able to prey on pupae of the apple fruit moth (Sandström, pers. com.). Spiders were identified by Sandström (pers. com.). Of small mammals I found three *Apodemus flavicollis,* which could be a possible predator of the apple fruit moth. Mammals were identified from the key Corbet and Ovenden (1981).

Table 3. Results from the feeding test in spring 2006.

	NO. PREDATORS TESTED	NO. PUPAE EATEN WITHIN						SUM
		10 MIN	1 H	2-8 H	8-24 H	24-36 H	36-48 H	
Pterostichus niger	8		1	6	3	2		12
P. cupreus	10		3	5		8	4	20
P. melanarius	9	1		2	5	4	1	13
Harpalus latus	10			1	7	1	6	15
Staphylinidae sp.	4					1		1
S. aeneocephalus	3				2			2
Pardosa sp.	5							0
Dolomedes fimbriatus	1							0
Formica sp.	9							0

The feeding test resulted in several interesting observations. *P. cupreus* were the only species that ate all the pupae they were offered. *Harpalus latus* ate pupae of the apple fruit moth, but after several days. The carabids often completely removed the pupae, ie. both the cocoon and the pupae were eaten. Sometimes the carabids left fragments of the cocoon and the pupal wall Staphylinids ate some pupae, but not in the same extent as the carabids (see table 3). The staphylinids left the cocoon, and made a hole in the pupal wall, from where it suck out the entrails of the pupae. Several other staphylinids ate both the cocoon and the pupa, but left fragments of the pupal wall. The spiders (*Pardosa* sp. and *Dolomedes fimbriatus*) and ants (*Formica* sp.) were not interested in pupae as a food resource (see table 2). Carabids were identified using the key Lindroth (1993) and Lindroth (1986), and with help from Louis Vimarlund at SJV, Linköping and Åke Lindelöw at SLU, Ultuna.

Fig. 12 *Pterostichus* sp. in the feeding test (Photo: J. Sandström).

Fig. 13 *Staphylinus aeneocephalus* in the feeding test (Photo: J. Sandström).

Discussion

This study proposes that large insects (5-11 mm) is the major predator of the apple fruit moth in the pupal stage during spring and autumn. There is a tiny chance that small mammals might be able to penetrate the 5-11 mm cages, although it is not very likely since predation in the 11-20 mm cage is nearly zero. Both in the spring and in the autumn study, predation in the 5-11 mm cages were 3,4 and 1,4 times higher than in the 0-5 mm cages. In the feeding test the carabids were able to detect and eat apple fruit moth pupae to a large extent. East (1974) found that carabids removed 38% and staphylinids 30% of depredated winter moth, which is comparable to my results. During winter, mortality was highest in the 0-5 mm cages, indicating that small insects are the predators. This result is comparable to Roland's (1990), who found that predators of the sizes 0,5-1,5 mm dominated predation of the winter moth, although the winter moth hibernate in the summer season and the apple fruit moth hibernate in the winter. Larvae of the earwig overwinter under an isolationg snow cover, and they might consume pupae of the apple fruit moth during winter (Vimarlund, pers. com.). The 11-20 mm cages had no predation during the autumn and very little in the spring study, so rodents has none or a very small predatory effect. Maybe the pupae are too small to be detected as a food resource by the mammals, compared to the winter moth that is twice as large as the apple fruit moth. Buckner (1969) concluded that the shrews *S. araneus* L. and *S. minutus* L. were the cause of more than half of the disappearance of winter moth pupae, while East (1974) claims that small mammals only caused 4% of the pupal predation of the winter moth, and that seems more likely even in this case.

It was not possible to separate carabids from staphylinids in the feeding test because both carabids and staphylinids left fragments of the cocoon and the pupae, and made similar injuries on the pupae. A lesson from this project is to start with feeding tests, to be able to identify injuries on the pupae in the field. Then I might have been able to classify predators correctly from the injuries on the pupae.

In the future, can ground-living predators be useful in controlling the apple fruit moth, and how can they be enhanced? This study shows that carabids and staphylinids are able to detect and consume pupae of the apple fruit moth. Since predation from groundliving predators were rather low in this study, it is not possible to rely solely on them for controlling the apple fruit moth, but the predators might be a valuable addition to other groups of natural enemies or diseases, and to other organic control methods.

Increased plant diversity may increase the effectiveness of the generalist predators, but decrease that of the specialists. Generalists may also withstand repeated disruptions of their local habitat and are thus likely to be more abundant and play a greater role in pest suppression than specialists do (Picket & Bugg, 1998). Generalist predators can be enhanced by adding organic material to the ground habitat that they use for mating, resting, shelter and alternative prey (Mathews *et al.* 2003). Brown *et al.* (2002) found that organic mulches were more important for apple tree growth than the supply of mineral N, due to lower temperature, higher moisture, reduced competition for weeds and enhanced biological activity. A high abundance of detrivores in the organic mulches, that serves as an alternative food source for the predators, enhance biological control of orchard pests that spend part of their life-cycle on the ground. Compost mulch is reported to increase the abundance of generalist predators such as staphylinids, spiders and carabids (Brown & Tworkoski, 2003). These practices can be useful in organic orchards where addition of mulch has several advantages, eg. as part of a manure program or as weed suppression. Tilling and disking in spring time when weeds are controlled can be a tool to disrupt hibernating pupae, but it also disrupts the predators (Mathews *et al.* 2003).

Sown weed strips is one type of ecological compensation area that increase the biodiversity in the agricultural landscape. Field boundaries, i.e. sown weed strips, are important overwintering sites for beetles, where tussock-forming grasses harbour large communities of beetles (Wratten *et al.* 1998). The strips usually have a width of 3 to 8 m, and should be situated at the border of a field or divide large fields so that the distance between the strips does not exceed 50 to 100 m. The beetles usually invade the field by walking from the field margins, and the carabid densities are enhanced at 30 to 100 m from interplanted vegetation (Nentwig *et al.* 1998 with references). Weed strips should connect other ecological compensation areas such as road sides, hedgerows, dry slopes, field margins, forest remnants and so on, to a network of natural, semi-natural and artificial habitats with high biodiversity. Sown weed strips or grassy strips are known to enhance carabid densities compared to the field center. High carabid densities are found on borage (*Borago officinalis*), bastard clover (*Trifolium hybridum*), white clover (*T. repens*) and alfa-alfa (*Medicago sativa*). Yarrow (*Achillea millefolium*) and wild chamomille (*Matricaria chamomilla*) are excellent hibernation sites during winter and harbour about 250 carabid beetles/m^2 (Nentwig, 1998). This indicates that the weed strips offer suitable conditions for the ground beetles such as a richly structured vegetation, a favorable microclimate, and high prey abundance. In addition, the weed strips protects the beetles from farming operations and prolongates the reproductive period (Wratten *et al.* 1998).

Another possible way to control the apple fruit moth is by habitat manipulation of the orchard surroundings. In southern Europe where *Sorbus* produces a regular crop every year, both the apple fruit moth and its parasite the braconid wasp, are kept at equilibrium densities (Edland, 1995). Under such conditions there is no reason for the apple fruit moth to infest apples, since it always prefer the rowan tree (Edland, 1979). It is possible to create such conditions in northern Europe by planting exotic cultivars of *S. aucuparia,* or *S. austriaca* and *S. mougeotii* that produce large amount of berries each year, and thereby acting as catch crops for the apple fruit moth (Edland, 1995; Bengtsson & Lagerström, 1992). However, is there a risk of building up a larger population of apple fruit moth that goes to the apple trees instead?

Conclusion

Biological control of the apple fruit moth has to be a part of a holistic view on how to handle pests in orchards. The most important measure is to create favorable conditions for natural enemies, such as sown weed strips, hedgerows or other ecological compensation areas, and to keep the apple trees in a good shape with pruning. It is important to remove fallen fruit to avoid building up a pest population in the orchard. It is also possible to plant catch crops that are more attractive for the apple fruit moth than the apple trees. Measures that has several advantages, such as mulching with composted manure, that both add up nutrients, suppress weeds and create a favorable environment for natural enemies, should be used.

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Appendices

Appendix 1.

Treatment	No.	Location	Scientific name	Swedish name	English name
5	2	Ultuna	Formica sp.	stackmyra	wood ant
5	1	Ultuna	Myrmica rubra	rödmyra	ant
5		Ultuna	Centromerus sp.	mattvävarspindel	webspider
5	3	Harstorp	Formica sp.	stackmyra	wood ant
5	5	Harstorp	Myrmica rubra	rödmyra	ant
5	1	Harstorp	Forficula auricularia	tvestjärt	earwig
5	2	Harstorp	Staphylinus sp.	kortvinge	rove beetle
5	5	Harstorp	Pardosa sp.	spindlar	spiders
11	1	Harstorp	Larva of Carabus violaceus	larv av violett jordlöpare	larva
11	1	Harstorp	Pterostichus niger	jordlöpare	ground-beetle
11	1	Harstorp	Pelecopsis elongata	mattvävarspindel	webspider
11	6	Harstorp	Opilionidae	mattvävarspindel	webspider
11	1	Harstorp	Lepthyphantes sp.	mattvävarspindel	webspider
11	3	Ultuna	Linyphiidae sp.	mattvävarspindel	webspider
11	2	Ultuna	Forficula auricularia	tvestjärt	earwig
11	2	Ultuna	Formica sp.	stackmyra	wood ant
20	3	Ultuna	Apodemus flavicollis	större skogsmus	yellow-necked mouse

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2003:1 - Anna-Sara Liman: Intra- and interspecific interactions between heteropteran generalist predators - the effect of behavioural differences and consequences for biological control.
2003:2 - Mattias Forshage: Förändringar i dyngbaggefaunan - Tendenser i abundans och utbredning hos dynglevande bladhorningar och deras släktingar i Sverige sådana de avspeglas i samlingar och litteraturen.
2003:3 - Anna Svedling: Oat sterile dwarf - A molecular method for determination of virus content in individual planthopper vectors.
2003:4 - Zhao Tao: Performance of the pine shoot beetles, *Tomicus piniperda* L. and *T. minor* (Hart.) (Coleoptera: Scolytidae) on their principal and secondary hosts, *Pinus yunnanensis* and *Pinus armandii* in Yunnan, China.
2003:5 - Chen Peng - Is there competition between *Tomicus piniperda* (L.) and *T. minor* (Hart.) (Col. Scolytidae) during shoot-feeding and breeding in China?
2003:6 - Maria Björkman: Induced allelopathic resonses in barley: Effects on the bird cherry-oat aphid (*Rhopalosiphum padi* L.) and the seven-spotted ladybird (*Coccinella septempunctata* L.).
2003:7 - Anna Lindau: Importance of arthropod predation on population dynamics of the willow gall midge *Dasineura marginemtorquens*
2003:8 - Niklas Jönsson: Hermit beetle, *Osmoderma eremita* - Situation and habitat preference on the island Hallands Väderö
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2004:4 - Kristina Browall: Svärmningens påverkan på populationstillväxten av *Varroa destructor* i bisamhällen på Gotland.
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2006:4 - Karin Ström: Species richness correlations between taxa calculated from species-area relationships
2006:5 - Sara Furenhed: Ground-living predators of the apple fruit moth *Argyresthia conjugella* (Zell.)