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Bembidion spp.

- condition and fecundity in relation to cropping system and landscape parameters

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ABSTRACT

In this study the condition and fecundity of a genus of the polyphagous predator, *Bembidion*. is investigated in respect to landscape complexity and farming practice. The beetles where collected during 1999 from five pairs of conventional and organic farms in central east Sweden (in the area around Uppsala). The farms within each pair were situated close to each other and had similar size and landscape structure. The condition was measured as the percent fat in *Bembidion* captured during spring and fecundity was studied in laboratory were the amount of eggs were counted and the egg volume measured. On organic farms there were correlations between number of eggs and crop diversity and between eggs and landscape heterogeneity. On the conventional farms there were correlations between fat and landscape heterogeneity and also between fat and perimeter-to-area ratio. There was also a correlation between egg volume and perimeter-to-area ratio on conventional farms. The results indicate that it is possible to improve the condition and fecundity of *Bembidion*, and thereby increase the predation of pest aphids.

INTRODUCTION

Generalist predators are important in the preventive work to avoid pest attacks because they are present in the fields during the aphids establishment phase. Östman et. al. showed an 300 kg/ha increase in yield in the presence of natural enemies due to decreased aphid populations. They also showed that predation during the establishment phase was higher on organic farms than on conventional farms, but also that predation was higher with in fields with a large proportion of edges or on farms with a large proportion of perennial crops.

In this study the interaction between the aphid pest, the bird cherry-oat aphid (*Rhopalosiphum padi* L.) and one group (*Bembidion)* of their natural enemies was investigated. One tribe, *Bembidion* sp, of ground beetles (Carabidae) has been studied in the laboratory using beetles collected from farms with different management regimes and a gradient of landscape features. The aim was to assess the condition of the beetles. Condition is measured with respect to two different analyses: (1) egg production using beetles collected during the summer, and (2) content of body fat, from beetles collected in the spring (April and May). The laboratory methods for the studies on *Bembidion* sp were developed by Wallin et. al. (1992) and Petersen et. al. (1996). In this study we also tested the correlation between the number of aphid days and the condition of the carabids.

The relationship between the condition of the *Bembidion* and differences in the landscape structure and the farm management were investigated. The carabids disperse by walking and the studied species of *Bembidion* are small carabids (mostly <5 mm) with a rather low dispersal rate. This is interesting because our hypothesis is that habitat quality in the form of the design of the landscape is mostly interesting for species with a low dispersal capacity. In a study of *P. cupreus*, (Bomarco 1998), it was shown that fecundity and body size is correlated with landscape heterogeneity. For of another large carabid *P. melanarius* (Östman 2001b) the beetle's condition was better on organic farms and the most important landscape factor was perimeter to area ratio.

This study is part of a larger project "Biodiversity and natural enemies in the agriculture; habitat quality, dispersal capacity and landscape complexity". One of the aims of the project was to understand the influence of the surrounding landscape on the biodiversity and abundance of natural enemies of pest insects on farms in the agroecosystem. Another goal is to understand what the fragmentation and landscape mosaic means for the dynamics of organisms with different dispersal capacity. The population growth of pest insects, such as aphids, may be different on different farms due to the abundance of natural enemies. One important aspect of natural enemy population dynamics is the availability of resources that can contribute to increased survival and fecundity thereby resulting in high numbers of enemies that can, in turn, attack insect pests.

Biology of the species

***Bembidion* (Col.: Carabidae)**

Bembidion is the genus in the family of carabids with the largest number of species. They have a uniform appearance and size (2,5 -8,5 mm) with long antennae and legs (Lindroth 1945). Their movements are rapid but *Bembidion* have a rather poor dispersal capacity since they move mostly by walking (Wallin 1985). Most of the species are hygrophilous and most of *Bembidion* can be associated with a particular soil type (evergreen.edu, 1997). They are polyphagous predators which mean that they have an advantage over aphid specific predators in that they are already present in the field when the first vermin arrive (Ekbom & Wiktelius, 1985). This makes them rather dependent on a favourable environment in their habitat. The species are only partly macropterous, brachypterous wing morphs dominate, this means that most of the species in the genus have only rudimentary wings (Thurin et al. 1977). All species in the genus also have about the same manner of living (Lindroth 1945).

Figure 1. *B. lampros*

Bembidion lampros (Herbst, 1784) is the most common species of coleopterans in arable land (Lindroth, 1945) and also one of the most investigated species. It is a day-active spring-breeder, which prefers sun-exposed warm parts of the field (Wallin, 1985 and Pietraszko et al. 1981). The adult beetle of *B. lampros* is 3.0-4.4 mm long. They hibernate as adults aggregated (Kaufmann, 1986) in the field edges. In early spring they move out into the fields to find prey and to reproduce (Wallin, 1985; Petersen, 1999). In field they reproduce from May to July, with a peak in May/June and with an average of 10 eggs per female (Petersen, 1998). According to Petersen (1998) they start egg-laying 100° DD (Day degrees over a threshold of 9°C, air temperature) and eggs develop in the ovaries immediately after they leave their over-wintering sites. The larvae appear in the soil surface from June to August (Wallin, 1989), and pupation takes place in an oblong chamber beneath the soil surface (Langor & Larson, 1983). The new generation (teneral adults) is usually fully developed before harvest and soil tillage in the autumn (July to September) (Wallin, 1989). The mortality in the juvenile stage is high, in some studies about 34 %, and therefore an important factor in the population dynamics (Petersen, 1998). *Bembidion* *lampros* is univoltine, they reproduce only one period in their lifetime (Wallin, 1989) but according to Mitchell, 1963, they can live more than one year in England. *Bembidion* is diurnal, and prey on cereal aphids (Chiverton, 1986), eggs from different vermin flies, for example frit fly eggs *(Ocinella frit* L.), Collembola, and other arthropods (Mitchell, 1963). They are dimorphic with respect to wing length (Turin et al.1977). Wallin (1985) reported that spring-breeders use the field edges primarily as hibernation sites.

Bembidion properans (Stephans, 1828) can only be differentiated from *B. lampros* using a microscope. The two species have a golden metallic sheen and are common in gardens, fields and grassland. *B. lampros* is distinguished from *B. properans* by having very few pits on the external elytral striae. (http://www.ladybird-survey.pwp.blueyonder.co.uk/grbeetrec.htm#bembidion)

Bembidion guttula *(Fabricius, 1792)* is a small black ground beetle with red spots at apex of the elytra. It's a widespread hygrophilous species, also common on poorly drained agricultural soils. *B. guttula* is a generalist epigeic predator of cereal aphids. (http://www.ulstermuseum.org.uk/carabids/7262.html)

Bembidion quadrimaculata (Linneaus, 1761) this is a species with macropterous wing morphs (Thiele, 1977).

Rhopalosiphum padi (Bird Cherry-Oat Aphid)
The aphids belong to a large family including over 4400 species in 493 genera (Blackman et. al., 1994). They are most common in the northern temperate regions, where they are considered one of the most important pests to agricultural crops. In Sweden the Bird Cherry-Oat Aphid is prevalent among the aphids (Minks et. al., 1987). They reproduce through parthenogenesis, which means that they are viviparous without fertilization. This gives them an enormous reproduction capacity. One female may give rise to over three millions of new aphids during a year. (Wiktelius, 1992)
The bird cherry-oat aphid is a host alternating species, feeding on the sap of bird cherry (Prunus padus) leaves in autumn and in spring and the sap of grasses or cereals during summer. In Sweden *R. padi* hibernates as diapausing eggs, which are laid on bird cherry in the autumn. In April the eggs hatch, and *R. padi* will stay for two or three generations on the bird cherry tree before they migrate. Migration is triggered by the change in food quality (decreasing content of soluble nitrogen in tree leaves) and increased crowding. The last generation in the spring on the trees is alate (winged) and migrates to cereals and other grasslands where wingless morphs then dominate. During the summer host parthenogenesis is the only mode of reproduction. When the cereals reach the onset of heading, the content of nitrogen in leaves has declined and the aphids have become crowded. Therefore they are stimulated to again produce alates, which migrate to other grasslands. The population in cereals usually crashes as winged adults begin the summer migration. Later in the season, as the day length shortens and temperatures become lower the production of the sexuparae is triggered. This is the morph that produces the alate males and gynoparae. The gynoparae is in turn the morph, when she is back on the bird cherry tree, that gives birth to the sexual females, the oviparae. The male is the very last to be produced by the sexuparae, and returns to the bird cherry where they mate with the oviparae. The sexuparae are triggered to produce males by a combination of three factors –temperature, photoperiod and their age. (Wiktelius, 1992; Minks et al, 1987)

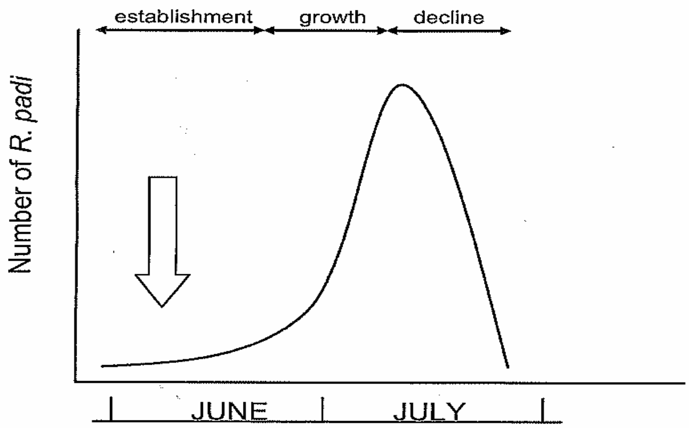

Figure 2. Population development of the bird cherry-oat aphid in cereal fields. The arrow indicates when generalist predators can be most effective; during the aphid establishment phase.

According to Hallqvist (1991) *R. padi* can be responsible for about a 15 % decrease in yield in Sweden or yield losses up to 600 kg/ha. If the number of migrant *R. padi* leaving overwintering sites is low then few aphids will reach the fields, and aphid damage on yield will be negligible. The phases in population development are described in figure 2.

MATERIAL AND METHODS

Sampling sites

Five pairs of farms, one organic and one conventional in each pair, were studied. These farms are located in the area around Uppsala and from these farms beetles were collected in the summer of 1999. The pairs were chosen in 1996 according to the Bray-Curtis dissimilarity index (Krebs 1989), based on landscape structure, land use, crop rotation and size/shape of the farms. The paired farms had to be similar in size and within a distance from two to ten km from each other. For further details on how the pairing was done see Weibull et al., 2000.

Landscape parameters

On each of the farms a field of spring barley was chosen and the landscape surrounding these fields was characterised using four parameters: mean field perimeter-to area ratio (PA), percentage winter crop (PWC), crop diversity (CD), landscape heterogeneity (LH). The mean field perimeter-to-area ratio is the mean ratio of the perimeter of cultivated fields to the area of the fields. Cultivated fields were all fields that were used for crops, ley (harvested grass or clover), or pasture. Percentage winter crop is the percentage area of wintergreen crops to total cultivated area. Crop diversity was calculated as a Shannon habitat diversity index of the proportion cereals, ley, pasture, fallow, or other crops of the total cultivated area. These three parameters were measured for all cultivated fields within 400 m of the sampling sites. Landscape heterogeneity was calculated as the mean of the Shannon habitat diversity indices for four 400 m by 400 m squares randomly chosen from a grid covering the farm. Habitat categories were arable land, other open areas, mixed forest, clear-cuts, deciduous forest, water, habitat islands, and areas with buildings. (Östman et al., 2001a)

Farming practices

For each farm we noted the general use of pesticides, fertilizers, and soil management practices at the farm (Table 1). Pesticide use was divided into use of insecticides and herbicides; no fungicides were used on any of the fields. Fertilizer use was divided into no extra fertilizer applied but with nitrogen-fixing crops plowed into the soil (green manure), animal manure, or inorganic fertilizer. Soil management was divided into only harrowing, or harrowing and tillage (moldboard plowing or chisel plowing). Pesticides, fertilizers, tillage, and cultivation were used most for annual crops (cereals and oilseed rape). For other arable fields (ley, pasture, and fallow) there was usually no pesticide use, tillage, or cultivation, and fertilizer use was usually the same as on the annual crops. (Östman et al., 2001b)

Table 1. General farming practices at the different farms. Conv denotes conventional farms and org indicates organic farms. The organic farms were organically managed since at least 1992. The recommended doses for Diklorprop-P was 1,2 l/ha, MCPA 1,5 l/ha and for Tribenuronmetyl 1,5 kg/ha. Rate of application for inorganic fertilizers is 300-400 kg/ha, for liquid manure 15 000 kg/ha, and solid manure 20 000 kg/ha. Farms where no extra fertilizer was applied had green manure, i.e. nitrogen fixing plants are ploughed down into the soil. No fungicides were used. Crops are annual crops in descending order of area used at the farm. Bold style indicates crop where the traps were placed. (Östman et al., 2001b)

Farm	Insectcide use	Herbicide use	Fertilizer	Cultivation	Crops
1 org	No	No	None	Moldboard ploughing, Harrowing	**Barley**, rye-wheat, Oats
1 conv	No	Tribenuron-metyl	NP 26-6	Harrowing	Winter wheat, **spring wheat**, barley, oats
2 org	No	No	Liquid manure	Moldboard ploughing, Harrowing	**Barley**, oats, rape-seed, rye-wheat, sunflower
2 conv	Pirimicarb (0,2 kg/ha)	Diklorprop-P	NP 26-6	Chisel ploughing, Harrowing	Winter wheat, oats, **spring wheat**, peas, barley
3 org	No	No	None	Moldboard ploughing, Harrowing	**Oats, barley**, rye-wheat, peas
3 conv	No	MCPA	N 34, PK 13-13	Moldboard ploughing, Harrowing	**Barley**, oats, **spring wheat**, winter wheat
4 org	No	No	Solid manure	Moldboard ploughing, Harrowing	**Barley**, spring wheat, **rye-wheat**, oats
4 conv	No	Diklorprop-P, Tribenuron-metyl	N 34	Moldboard ploughing, Harrowing	**Barley, spring wheat**, winter wheat, oats
5 org	No	No	Liquid manure	Harrowing	Peas, **spring wheat**, barley, oats, rape-seed, rye-wheat
5 conv	Pirimicarb (0,2 kg/ha) Lambdacyhalothrin (0,3 kg/ha)	Diklorprop-P, MCPA	NPS 26-4-4, NS 27-3	Moldboard ploughing, Harrowing	Winter wheat, **spring wheat**, barley, oats

Sampling of aphids

The number of aphids was measured between the 4 June and the 30 June using a D-VAC (Ø= 34 cm) in the open field (unsprayed parts of the fields). We took three samples per sampling occasion and field, each sample consisted of five (4–14 June) or three (17–30 June) suctions of about five seconds. To account for confounding effects of crop plant macronutrient concentration (Dean 1974) we measured the macronutrient (N, P, and K) concentration from ten plants per field, collected on 17 June.

During the exponential growth phase we determined *R. padi* population growth rates 11–24 June (or until plant heading). We estimated *R. padi* population growth rate, r, by linear regression between day and natural logarithm of the number of aphids per tiller. Aphid damage to the crop depends on both duration and magnitude of aphid attack, therefore we calculated the cumulative number of aphid-days from 11 June until the *R. padi* population began to decline. We estimated the numbers of aphid-days between two samples as (N_0*e $^{r_s t}$dt, where N_0 = number of aphids in the first sample, r_s = *R. padi* population growth rate between two samples, and t = days between two samples). See also Östman et al., 2001a for further information.

Sampling of natural enemies
Sampling was conducted between 28 April and 3 August 1999. At each farm five pitfall traps were placed in the field or at the edges of the chosen spring cereal field. Moistened crumpled paper was placed at the bottom of the pitfall trap to prevent cannibalism and bird predation. The traps were emptied every third or fourth day during this period.

Measuring condition of natural enemies
Fat extraction
Bembidion that were collected between April and the middle of May were frozen in less than 24 hours from the time that the pitfall was emptied. They were later dried at 60°C for about 48 hours and weighed individually. Fat was extracted by incubating each specimen in a solution of 2 ml chloroform and methanol (1:1) for 48 hours. The carabids were kept in glass vials covered with plastic wrap and tinfoil to avoid evaporation. After extraction the beetles were dried at 60°C for 48 hours and weighed again. Fat content was calculated as amount of fat extracted divided by dry weight before extraction; (dry weight – dry weight after fat extraction)/dry weight. The method is described in Petersen, 1999b.

Egg laying capacity
The traps were emptied every third or fourth day. The following day all *Bembidion* were sorted and placed one by one in plastic cups. Females were distinguished from males by examining the front tarsae (Wallin, 1987). The cups had a bottom of plaster of Paris mixed with activated charcoal (about 4:1) (Petersen, 1998). The cups were covered with perforated lids to prevent the beetles from escaping. The beetles were watered and fed with fly maggots dyed red *ad libitum* two or three times a week. The coloured maggots made it possible to separate white eggs produced by food ingested in the field from red eggs produced from laboratory food, red maggots (Bommarco, 1998, van Dijk et al. 1992). The maggots were purchased already dyed from a fishing-bait store. The beetles were held outdoors in the shadow, so that they were exposed to natural, fluctuating temperature. The cups were searched for eggs two or three times a week. The eggs were removed and the length and width was measured. The volume was calculated using the following formula; volume = (length* width^2 *π). When the beetles began to produce pink eggs or approximately two weeks had passed without any eggs, the beetles were killed by freezing. The frozen beetles were examined at the end of the experiment to determine the species.

Statistics
The analyses of the data were performed by SAS 6.12 for PC. To analyze the effects of farming practice and landscape parameters on the residuals an analysis of covariance (ANCOVA) was performed (Östman, et al., 2001b).

We also performed an ANOVA analysis of variation with fixed factors (pairs of farms, as replicates and organic or conventional farm as treatment) and the correlation with landscape variables and aphid days where investigated. Linear regression was performed using Excel.

RESULTS AND DISCUSSION

Landscape parameters

In table 2 you can see the actual value of the different landscape parameters on the different farms. We found a correlation between perimeter-to-area ratio and percent winter crops (table 3).

Table 2. Landscape parameter values at the farms.

Farm	Perimeter-to-area ratio (m/ha)	Crop diversity	Percent wintergreen crops	Landscape heterogeneity
1o	267	1,44	0,53	0,70
1c	241	1,27	0,66	0,75
2o	321	1,50	0,49	0,36
2c	229	0,81	0,03	0,83
3o	366	0,69	0,62	0,93
3c	370	1,09	0,53	1,03
4o	519	0,99	0,90	1,00
4c	431	0,68	0,58	0,93
5o	155	1,33	0,47	0,84
5c	148	0,80	0,21	0,42

There were no significant differences between organic and conventional farms for any of the landscape parameters (mean values in table 4). There was a significant difference between pairs for the perimeter to area ratio (F=17.86, p=0.004, df=4,5). Pairs 1 and 2 did not differ from each other but all other combinations of pairs were significantly different. This means that the pairs represented a range of landscape parameters, but there were no systematic differences between organic and conventional farms.

Table 3. Correlations between landscape parameters. r = Pearson correlation Coefficients, N=10.

	Perimeter-to-area ratio (m/ha)	Crop diversity	Percent wintergreen crops	Landscape heterogeneity
Perimeter-to-area ratio (m/ha)		-0,26	0,68 *	0,54
Crop diversity			0,25	-0,38
Percent wintergreen crops				0,39
Landscape heterogeneity				

**p<0,05. Transformed data for percent wintergreen crops - arcsin square root.*

Table 4 Mean values of the landscape parameters in respect to the different farming systems.

	Organic	Conventional
PA	326	284
CD	1,19	0,93
PWC	0,60	0,40
LH	0,76	0,79

The parameters were measured in an area of 400*400 m and it bigamy be too large for the small carabid Bemidion but the parameters were chosen for a larger carabid studied by Östman. The correlation between percent winter green crops and perimeter-to-area ratio is not unexpected as a field with a lot of edges (in the area of the 400*400 m) also have a higher percent winter green crops (the edges are green during the winters) in its vicinity. The best would have been if there hadn't been any correlations at all.

Sampling of aphids and natural enemies

The total number of *Bembidion* sp captured in the pitfall traps during the spring is shown in figure 3; *B. lampros* strongly dominate in farm pair numbers 1, 2 and 5. Pair number 3 and 4 are the pairs of farms with the highest amount of edges (perimeter-to-area ratio), the lowest index of crop diversity, high percent wintergreen crops and also the highest landscape heterogeneity, and those farms are also where the diversity seems to be higher. This can also be because of different soil types. The other three species were present at lower levels, *B. properans* was not found on farms 1c, 4c and 5o. *Bembidion quadrimaculata* was not present among the captured beetles from farms 1c, 2o and pair number 5. *Bembidion. guttula* is only missing in the collection from farm 2c.

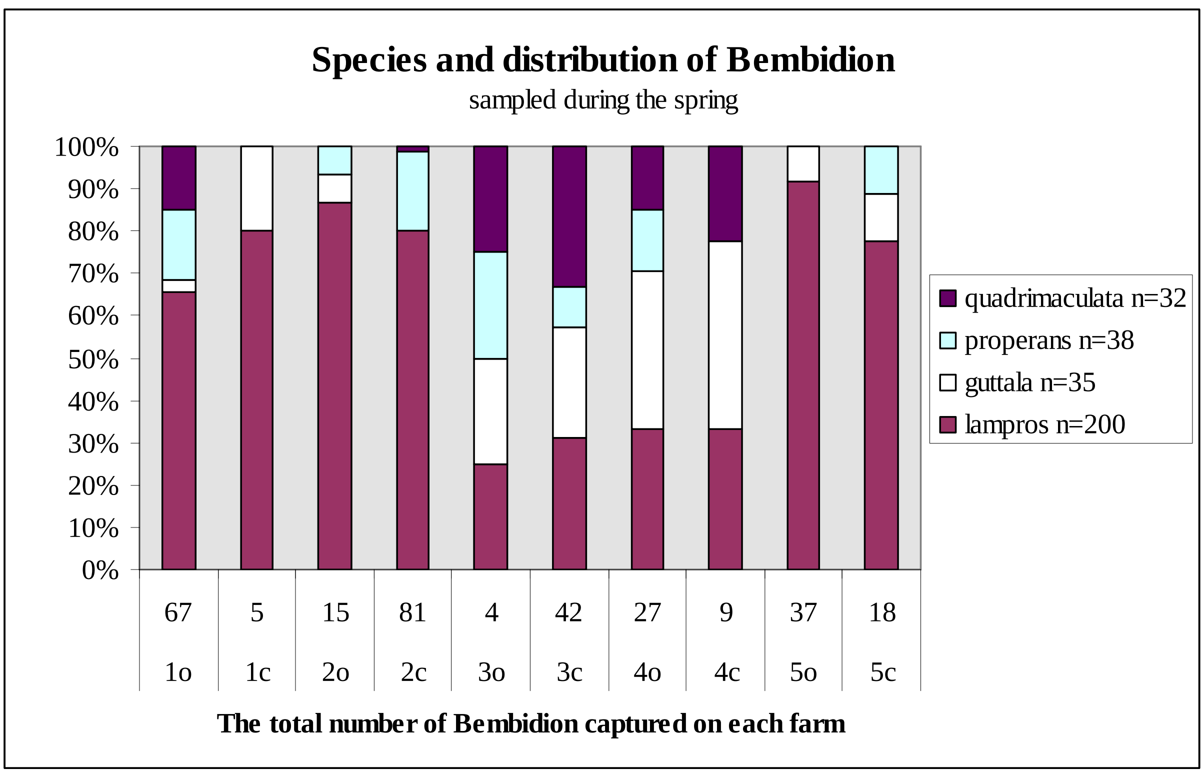

Figure 3. The mixture of species and total number of Bembidion captured on each farm during spring.

In figure 4 you can see the weight of the different species captured during spring and how much it differs between them. *Bembidion lampros* and *B. properans* are the heaviest species and the difference between them and the smaller species *B. guttala and B. quadrimaculata* is almost 30 % . This is why we chose to do statistics on percent fat instead of the total amount of fat.

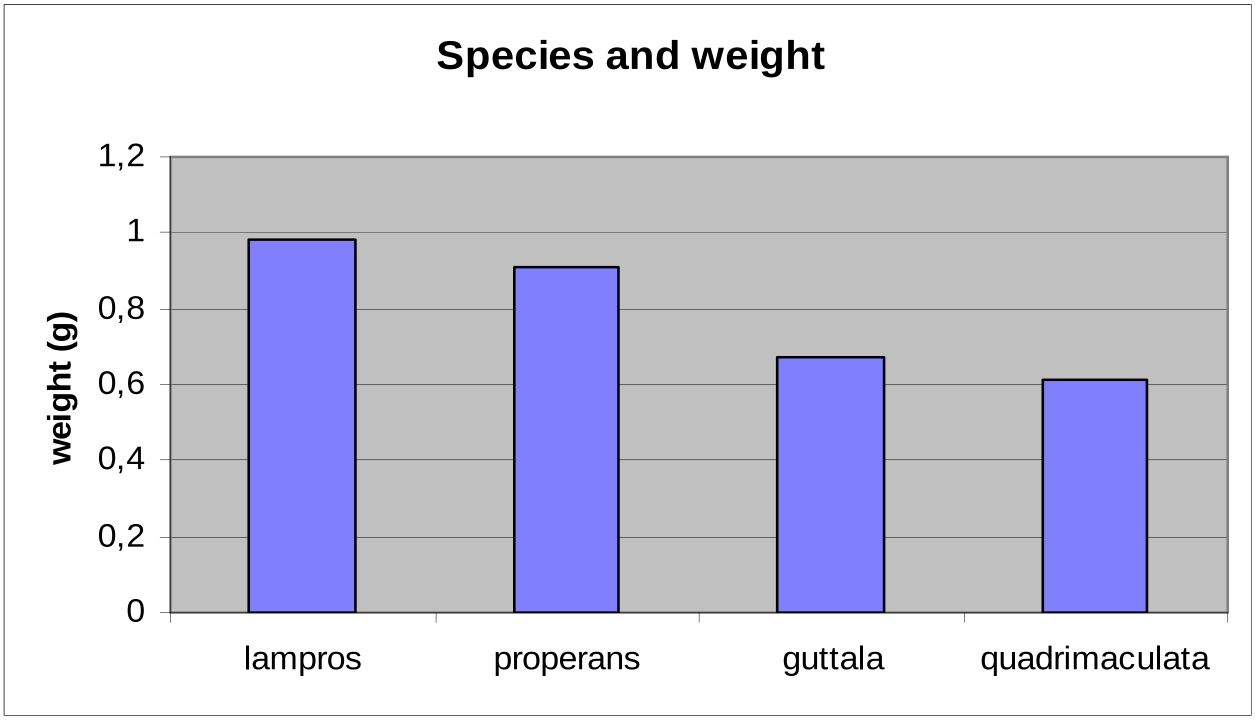

Figure 4. The size (g) of the different species captured during spring.

The total number of females of *Bembidion* captured in the pitfall traps during summertime is shown in figure 5 (totally 115 individuals); *B. lampros* dominate but not as much as it did during springtime.

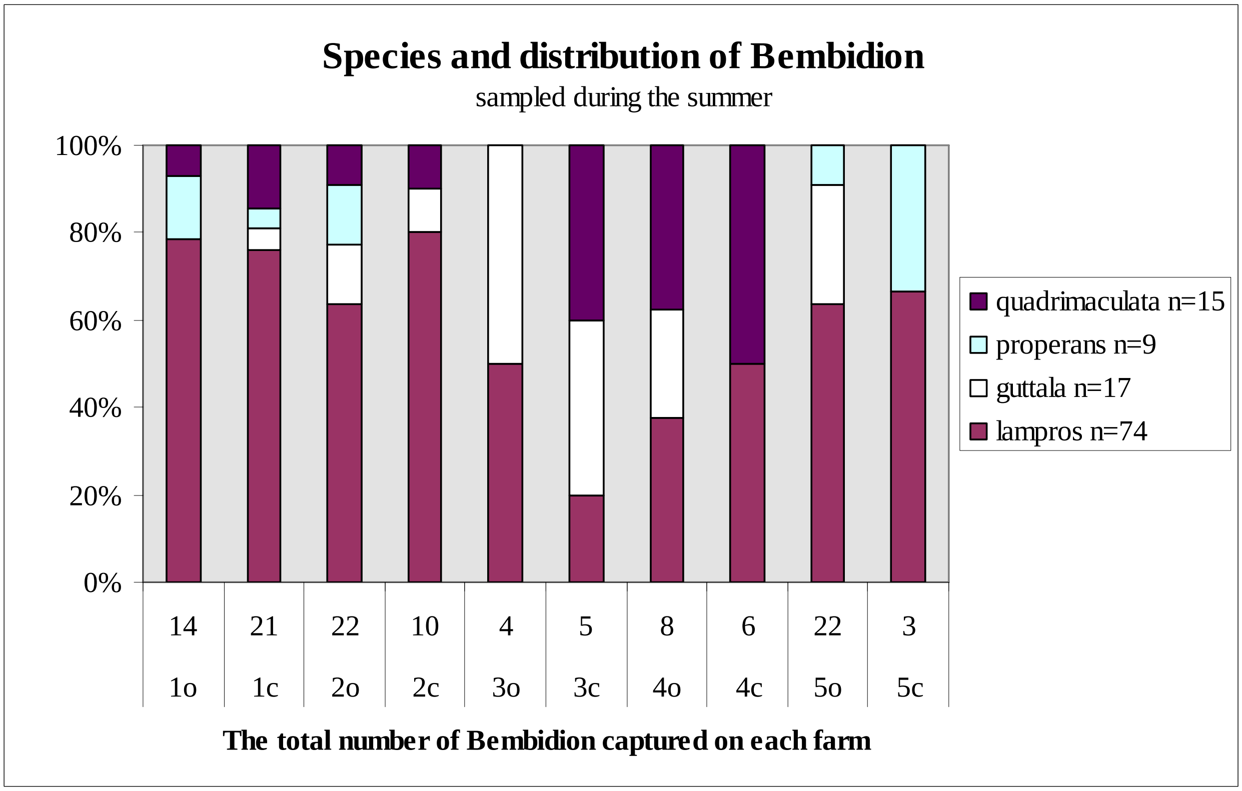

Figure 5. The mixture of species and total number of Bembidion captured on each farm during summertime.

In figure 6 the total catch is summarized for each farm, it varies from 8 to 91, totally 420 individuals captured. On farm 3 organic very few *Bembidion* were captured.

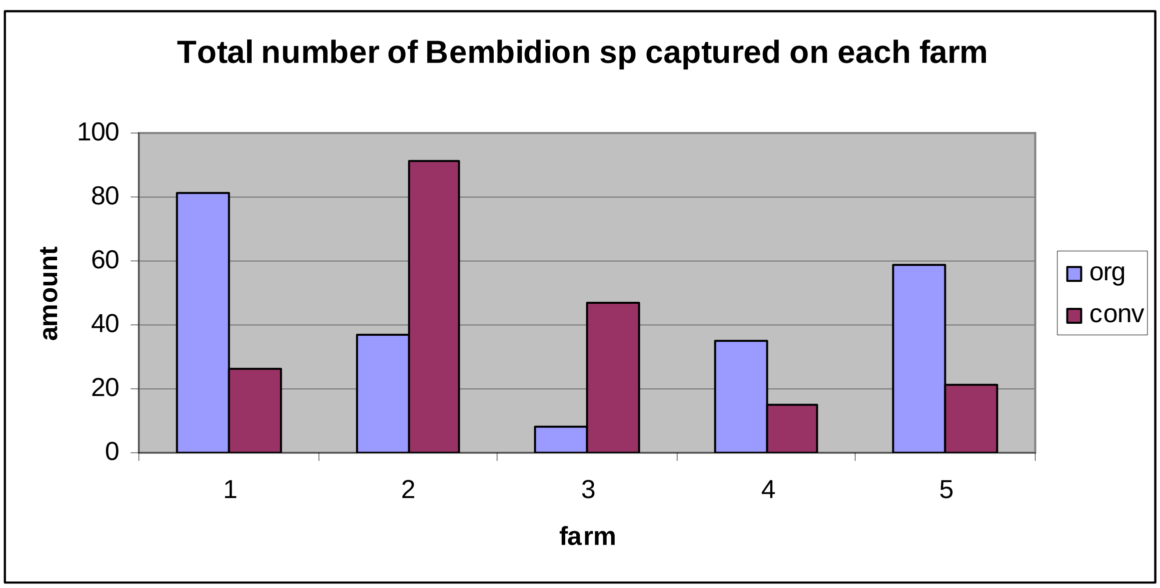

Figure 6. The total number of *Bembidion* sp. captured on each farm, spring and summer captures are pooled.

The number of aphid days was higher on conventional farms (mean value 185 aphid days) than on organic farms (mean value 54 aphid days), as shown in figure 7. Aphid days were chosen because the decrease in yield depends both on population size and the duration of the attack.

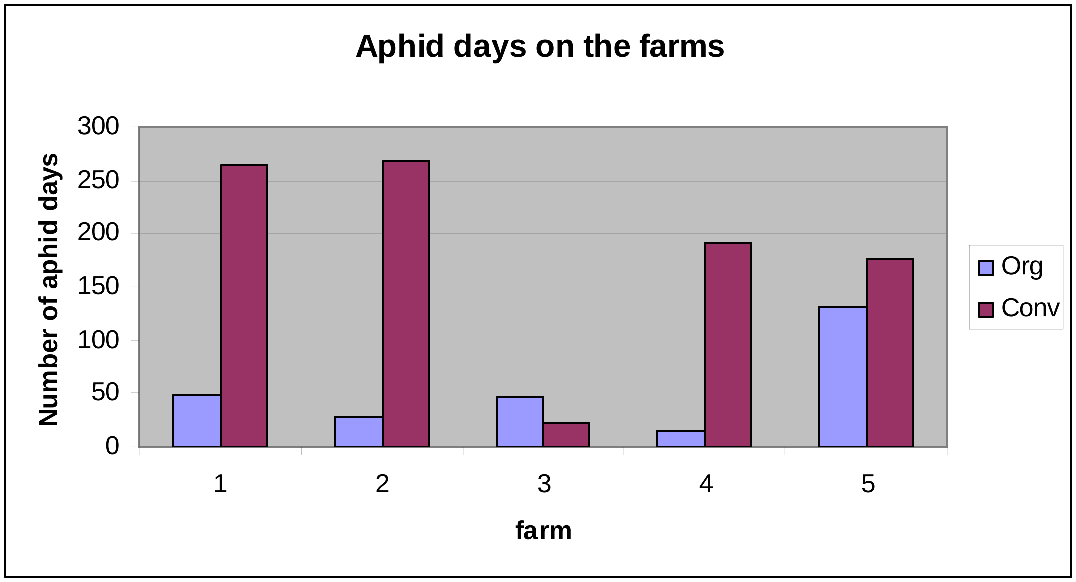

Figure 7. The number of aphid days in presence of predators.

Measuring condition of natural enemies

Fat content

There were no significant differences between the farms concerning fat content. Neither were there any significant differences between farming systems (figure 8). As shown in figure 9 the results for *B. lampros*, are more or less the same. The variation (standard error) is probably high mostly because of the difference in species and sex, for example the *Bembidion* on farm 3c have the highest amount of fat but it is also there we captured most of *B. quadrimaculata*, which is the species with the highest fat percent (figure 10).

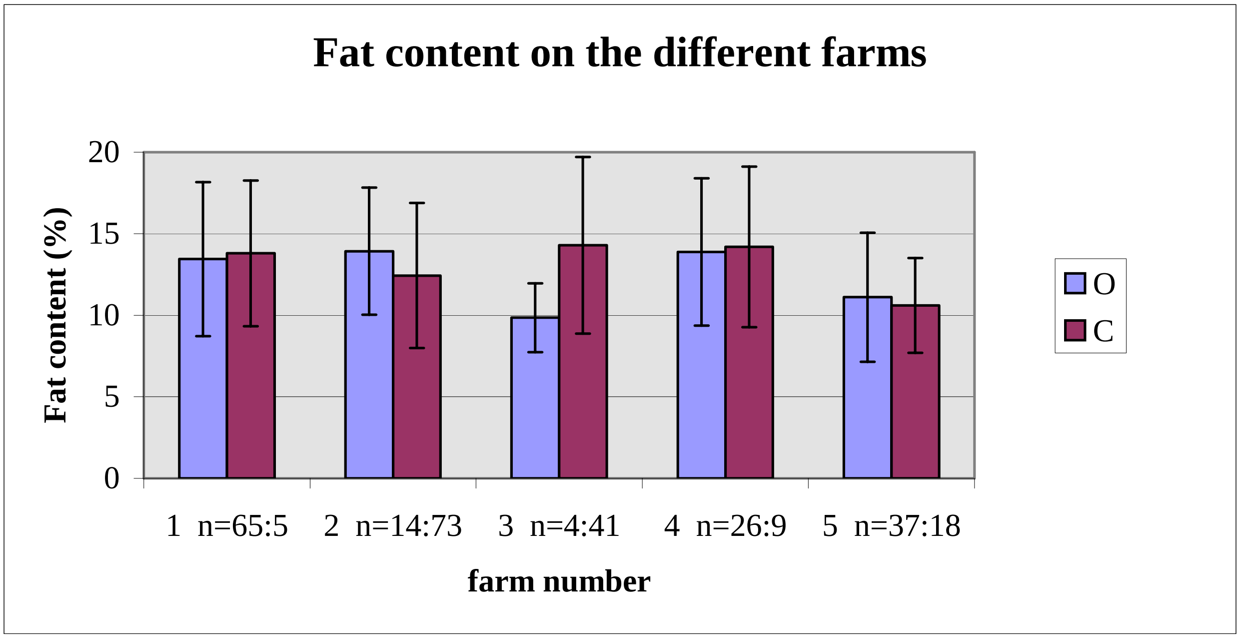

Figure 8. Average of fat content (%) on the different farms, five organic (O) and five conventional (C). The number of individuals is stated below (n).

Petersen, 1999, measured fat content in *B. lampros,* collected during spring in the area around Copenhagen, Denmark, the fat content were 23 % and were reduced to 7 % when they died by starvation, and the climate during hibernation affected the ability to survive starvation. This means that the beetles collected in this study were food limited and the winter in the area around Uppsala harsher than in the Copenhagen area.

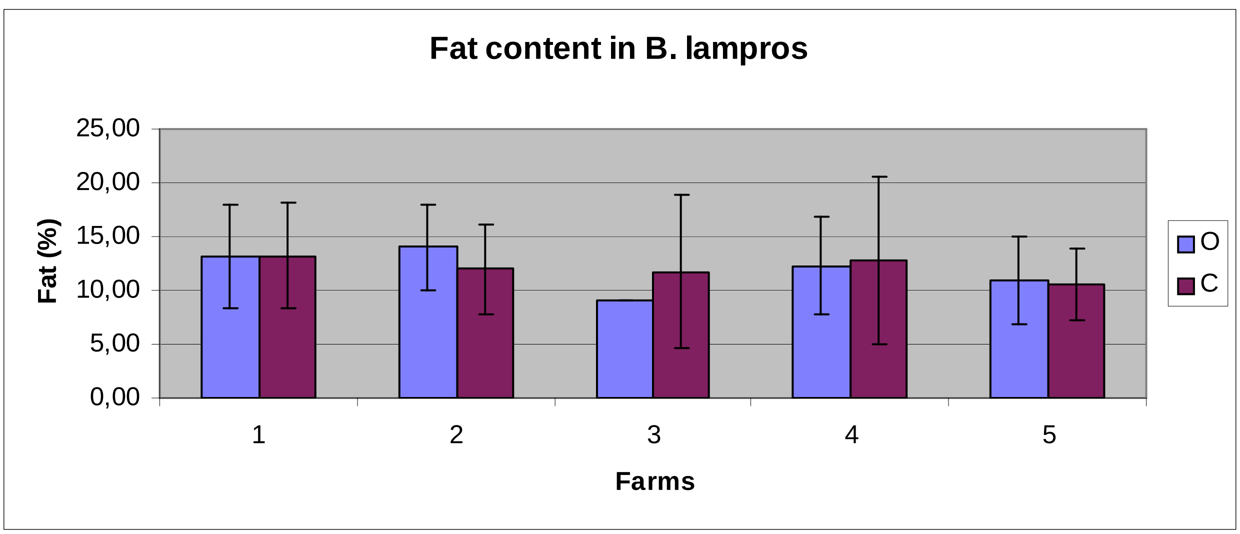

Figure 9. The fat content (%) measured in *Bembidion lampros* on the farms, one organic (O) and one conventional (C) in each pair of farms.

As shown in figure 10, for all of the different species except *B. properans* (only a few females of *properans* means that the results are non significant) the females have a larger content of fat during the spring. We can also see in the figure that there are fewer females than males captured in the pitfall traps during the spring. *B. guttala* and *B. quadrimaculata* have the highest amount of fat and as shown in figure 4 they have the smallest body weight.

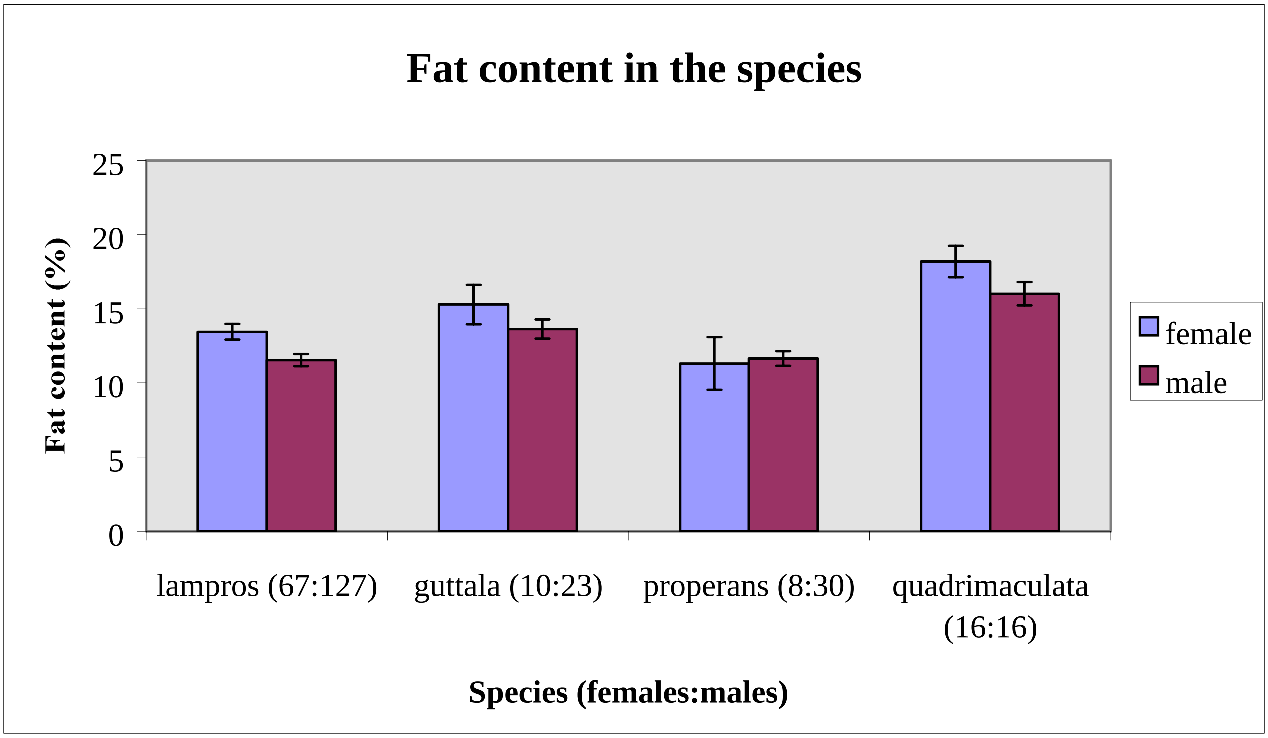

Figure 10. Average of fat in the different species and the standard error.

The results in table 5 show that on the conventional farms there was a positive correlation between the amounts of fat in the spring-collected *Bembidion* and field perimeter-to area ratio (PA) and also to landscape heterogeneity (LH), but this was not found for the organic farms. The correlations and linear regressions are shown in figure 11 and 12, as can be seen there, the trend on the organic farms also tends to be in the same direction for field perimeter-to area ratio (PA) but concerning landscape heterogeneity there is no such tendency at the organic farms. We could not see any correlation between fat and aphid days, crop diversity or percent winter crop for any of the farming systems.

Table 5. Correlation between the fat content and the parameters of landscape. Five farms are organic and five are conventional

Parameter	Percent fat (%)	
farming system	Org	Conv
Aphid days	-0,53 P=0,35	-0,32 p=0,60
Perimeter to area	-0,31 P=0,61	0,89 p=0,04*
Crop diversity	0,62 P=0,27	0,30 p=0,63
Percent winter crop[1]	0,39 p=0,51	0,69 p=0,19
Landscape heterogeneity	-0,46 p=0,44	0,93 p=0,02*

[1]*Transformed data for PWC - arcsin square root.*

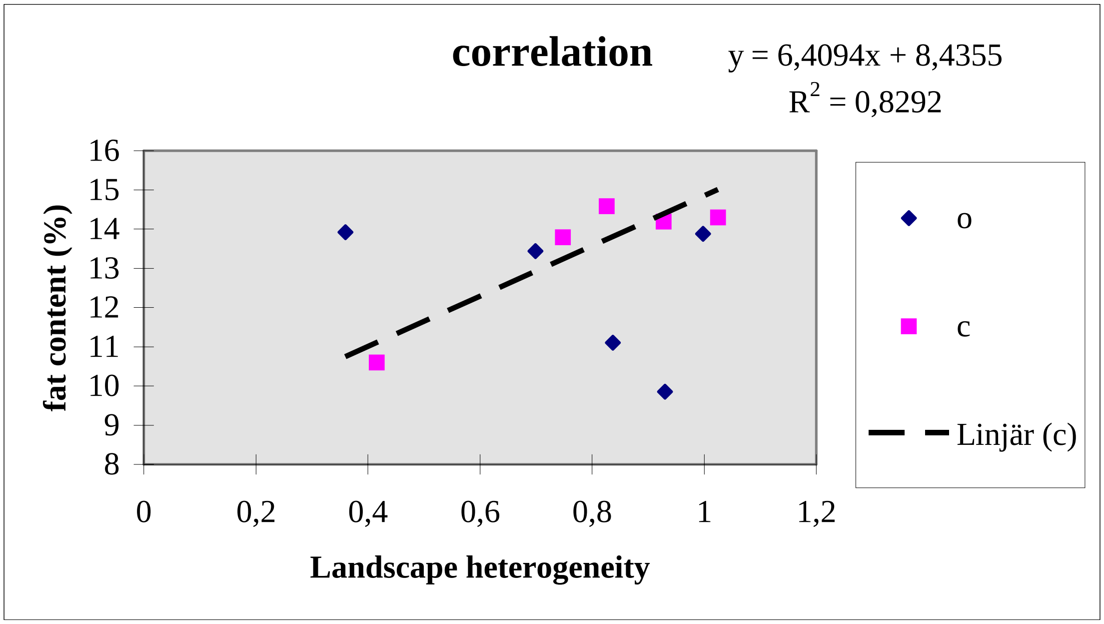

Figure 11. Correlation between the fat content (%) and the landscape heterogeneity.

The results shown in figure 11 means that the fat content on conventional farms increases when the landscape heterogeneity is higher. The R^2-value shows that it's quite valid on conventional farms.

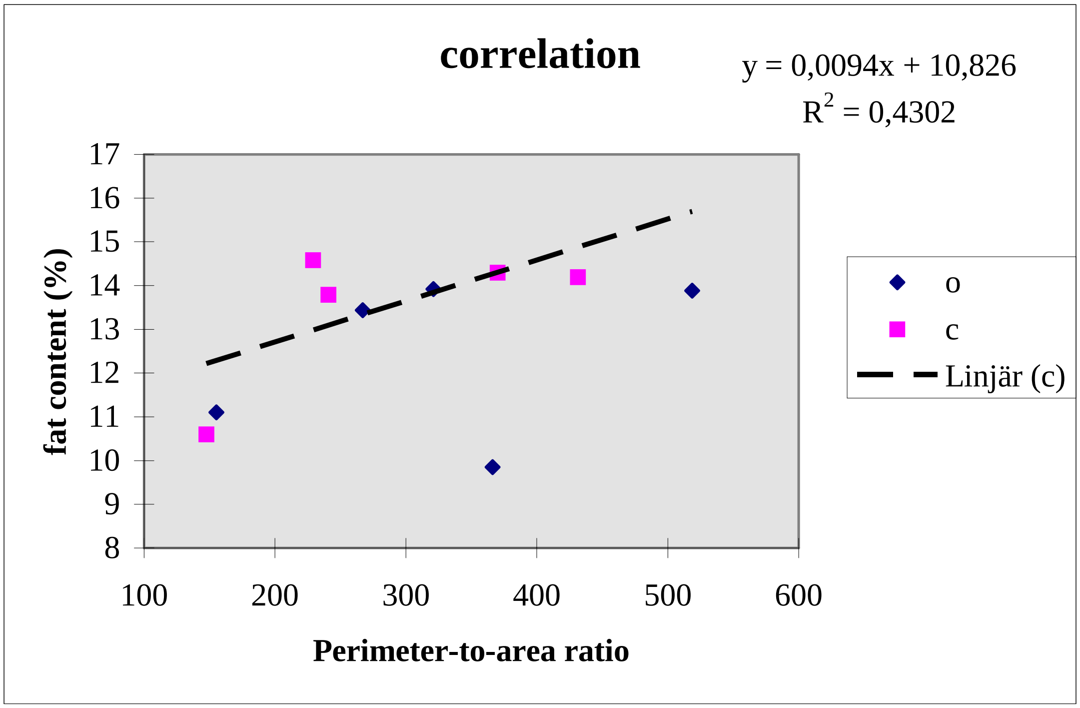

Figure 12. Correlation between the fat content (%) and the perimeter-to-area ratio.

As shown in figure 12, there is only a weak correlation between percent fat and perimeter-to-area ratio (PA) on conventional farms. This means that the condition of *Bembidion* is better on fields with high proportion edges. Östman 2001b also showed a correlation between PA and the condition of several larger carabid beetles.

Egg laying capacity

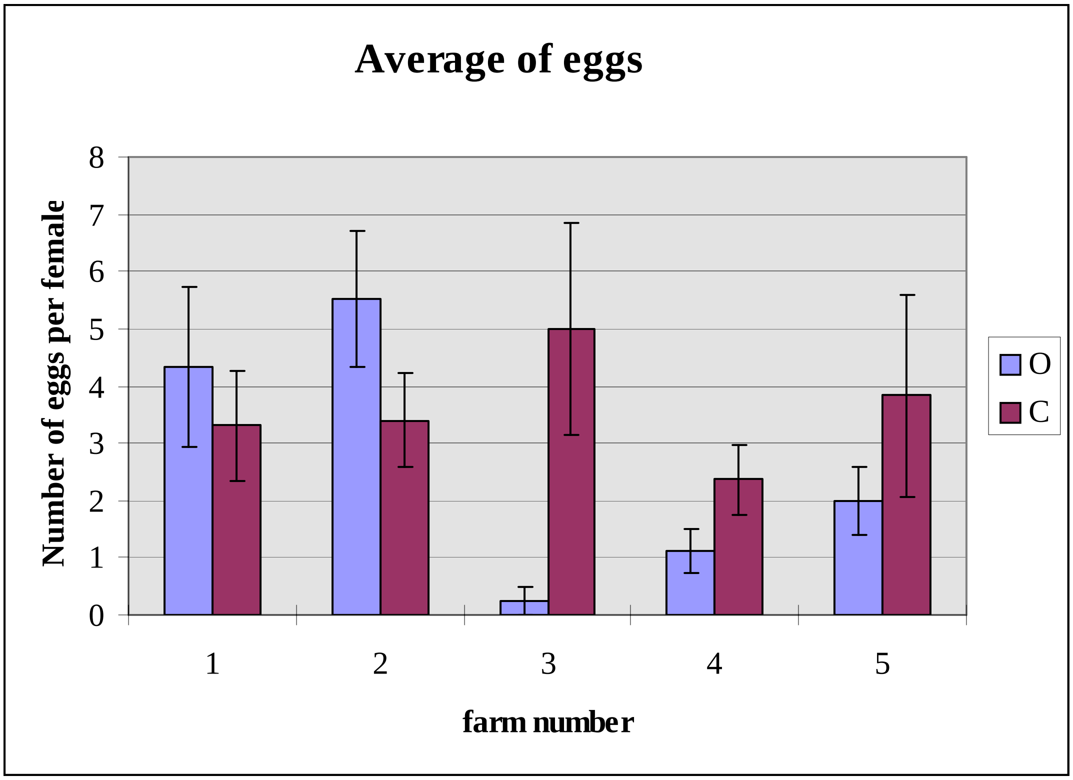

Figure 13. Average number of eggs laid by beetles from the different farms

The result of egg laying capacity among different farms and farming methods are shown in figure 13. There were no significant differences between the farms nor the farming systems. Correlations between egg laying capacity or egg volume and the fat content, the landscape parameters and abundance of aphids are shown in table 6. Correlations were found for organic farms between mean number of eggs and crop diversity (CD) and landscape heterogeneity (LH), and on conventional farms between egg volume and perimeter-to-area ratio (PA). As seen in figure 14 the number of egg laying females was low (3-15), below ten on all farms except 1org, 1conv, 2org and 5org.

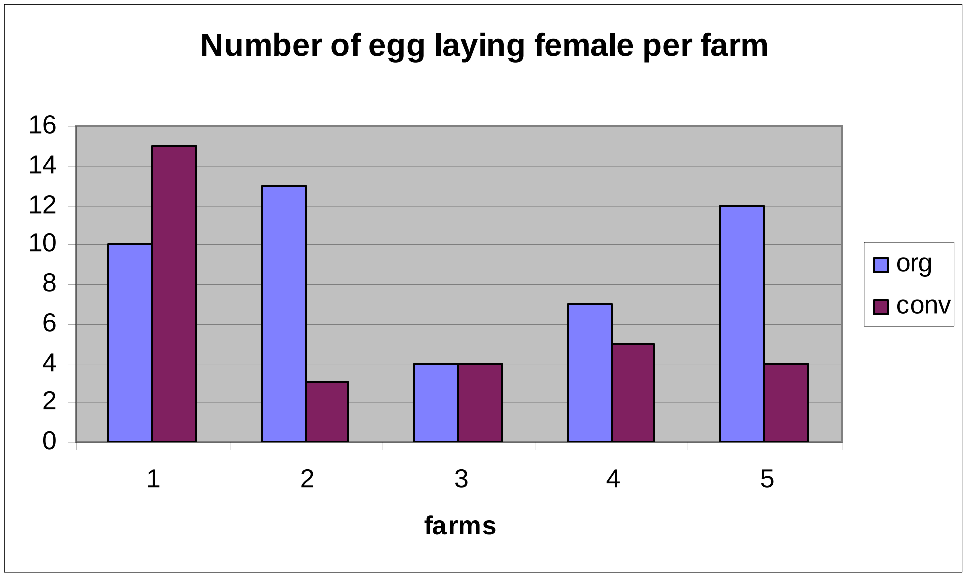

Figure 14. The number of egg laying females per farm.

Table 6. Correlation between the mean number of eggs and the volume of eggs, and the fat content, abundance of aphids and the landscape's parameters.

Parameter	Mean number of eggs		Egg volume	
farming system	O	C	O	C
Perimeter to area	-0,33 p=0,58	-0,16 p=0,80	-0,37 p=0,54	-0,89 p=0,04*
Crop diversity	0,90 p=0,04*	0,45 p=0,44	-0,36 p=0,55	0,15 p=0,82
Percent winter crop	-0,40 p=0,50	0,05 p=0,93	-0,69 p=0,20	-0,68 p=0,21
Landscape heterogeneity	-0,93 p=0,02*	0,09 p=0,89	-0,08 p=0,89	-0,60 p=0,28
Aphid days	-0,14 p=0,82	-0,73 p=0,16	0,31 p=0,62	0,70 p=0,19

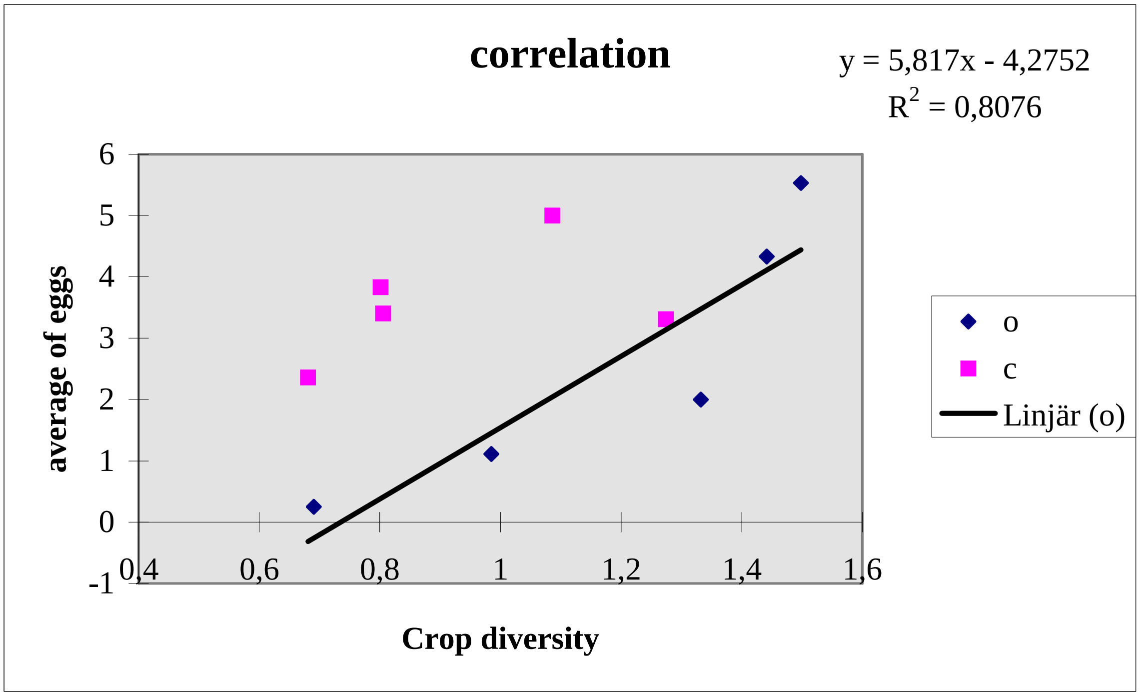

Figure 15. Correlation between numbers of eggs produced and crop diversity (CD).

The results in figure 15 show a quite strong correlation between the number of eggs and crop diversity, with higher fecundity on organic farms with many different crops in the neighbourhood.

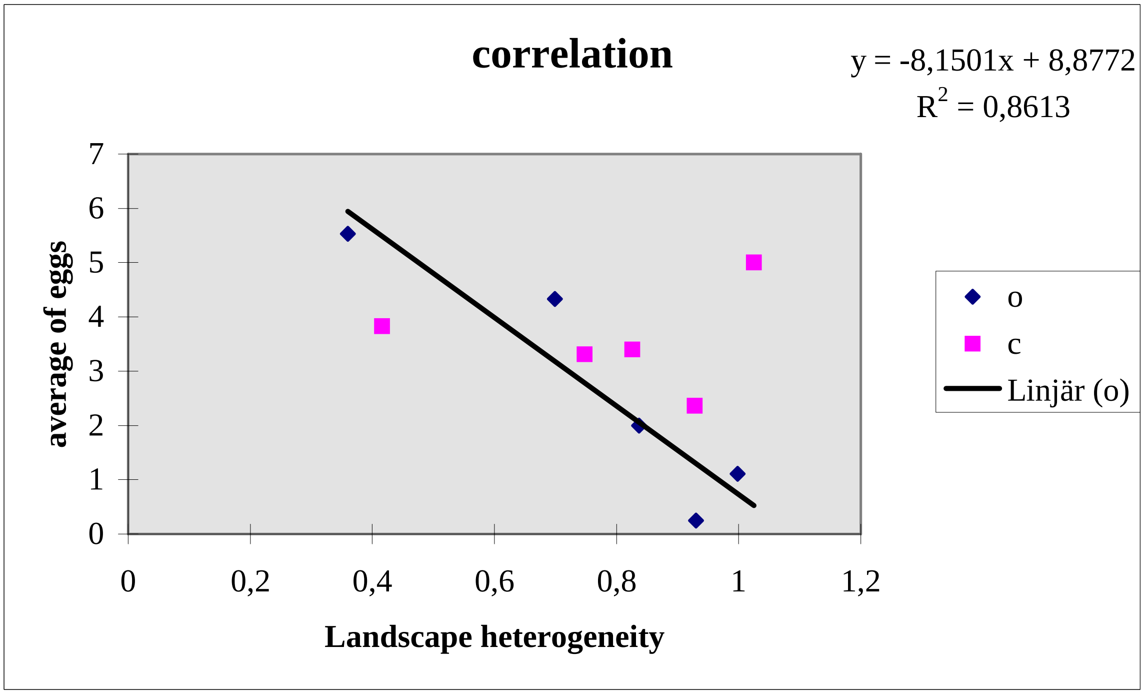

Figure 16. Correlation between number of eggs and landscape heterogeneity (LH).

In figure 16 the correlation between average of eggs and landscape heterogeneity (LH) is shown and is a quite strong negative correlation for organic farms, the fecundity is lower in varied landscapes. In figure 17 the correlation between egg volume and perimeter-to-area ratio on conventional farms is shown, this means that the volumes of the eggs are decreasing as the perimeter-to-area ratio increases (fields with a high proportion of edges). But the slope of the regression suggests that this might no be of biological significance. Table 7 shows that there is no correlation between volume of eggs and the number of eggs either.

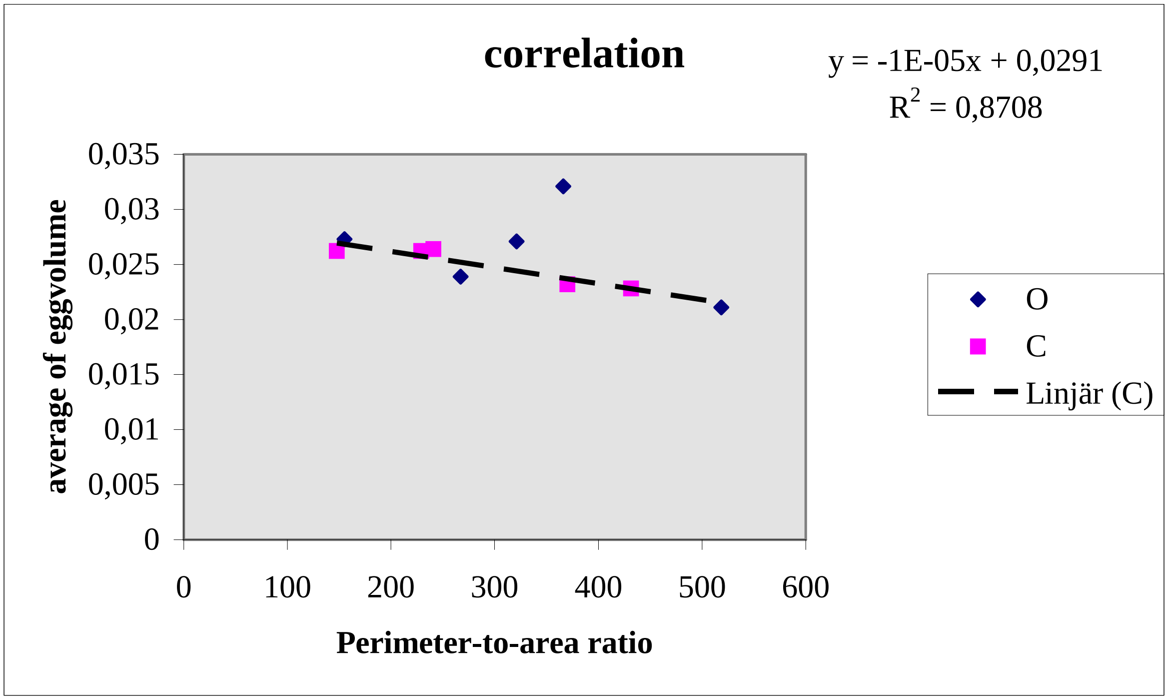

Figure 17. Correlation between average of eggvolume and perimeter-to area ratio (PA).

Table 7. Correlation between volume of eggs and number of eggs.

Organic	Conventional
-0,23 p=0,71	-0,05 p=0,93

CONCLUSIONS AND FUTURE STRATEGIES

On organic farms there were correlations between number of eggs and crop diversity (positive) and between eggs and landscape heterogeneity (negative). On the conventional farms there were positive correlations between fat and landscape heterogeneity and also between fat and perimeter-to-area ratio. There was also a negative correlation between egg volume and perimeter-to-area ratio on conventional farms. The results indicate that it is possible to improve the condition and fecundity of *Bembidion* sp., and thereby increase the predation of pest aphids.

In the future, studies similar to this one should include a large number of species, because it is important to consider the whole population of natural enemies to see what the effects would be for a certain strategy, for example in the development of landscape structures. Such a study also should continue for several years, because otherwise it is not known if the results are relevant to years with aphids or not, Östman (2005) states that the studied year has an effect on the condition for a couple of carabid species. It is also important to have enough individuals to be able to get satisfactory degrees of freedom for the statistics, especially when dealing with many parameters. Concerning landscape parameters it would have been interesting to include the proportion of annual crops and size of the field, because Öberg, 2007, found that wolf spiders (which move mostly by walking, just like *Bembidion*) had better condition in large fields of annual crops.
It would also be interesting to do a literature study to cover as many natural enemies as possible concerning farming system and landscape parameters.

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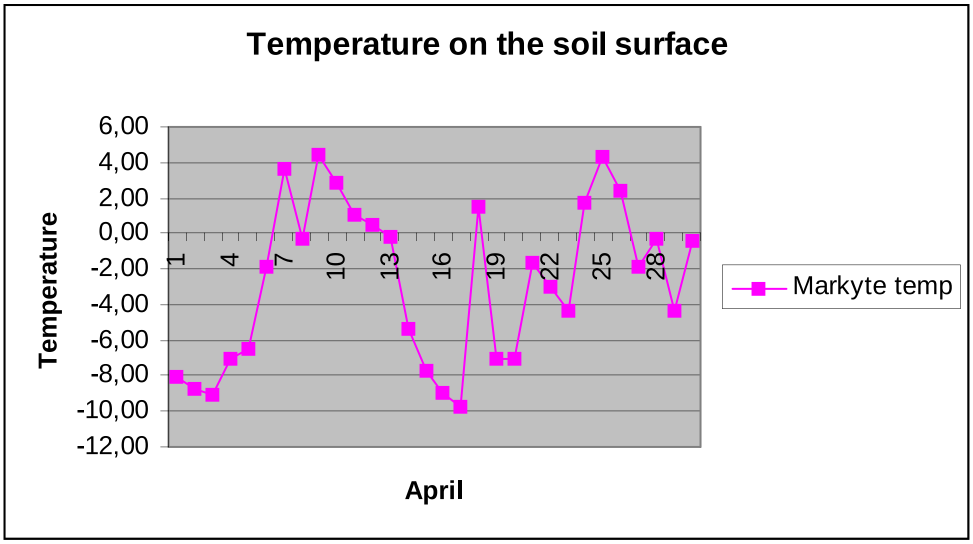
http://www.evergreen.edu/

APPENDIX 1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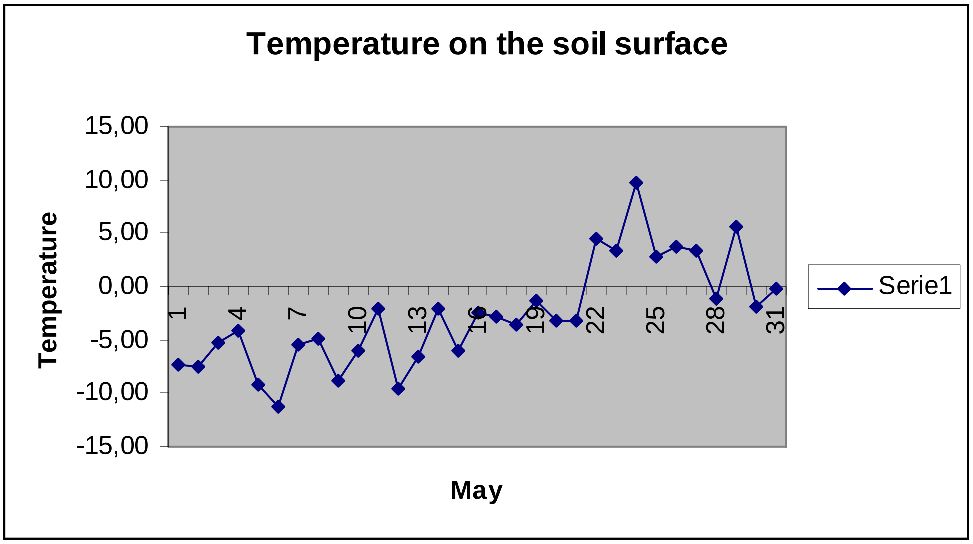
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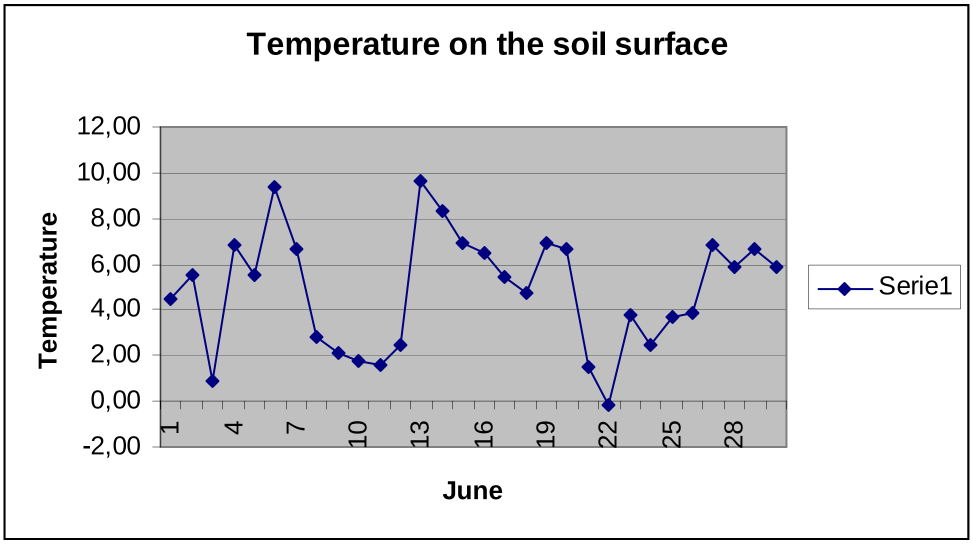
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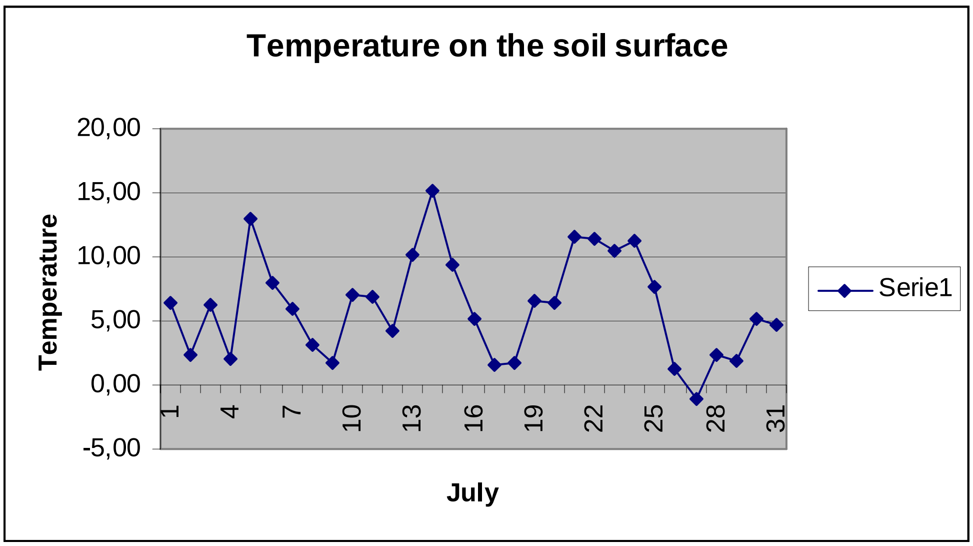
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