THE ROLE OF MIDFIELD ISLETS IN PEST CONTROL

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Preface

This Master’s thesis is Sabine Sigfridsson’s degree project in Geography at the Department of Physical Geography and Quaternary Geology, Stockholm University. The Master’s thesis comprises 30 credits (one term of full-time studies).

Supervisors have been Sara Cousins and Matti Ermold at the Department of Physical Geography and Quaternary Geology, Stockholm University. Examiner has been Britta Sannel at the Department of Physical Geography and Quaternary Geology, Stockholm University.

The author is responsible for the contents of this thesis.

Stockholm, 31 January 2013

Lars-Ove Westerberg
Director of studies
Abstract

During last century rising populations and changed market preferences have led to large structural changes in agriculture in the developed world. Most conventional cultivation methods involve the production of few monoculture crops within a homogenous landscape, where pesticides and inorganic fertilizers are used to increase yields. The cereal aphid *Rhopalosiphum padi* (L.) is a pest in cereals resulting in large economic losses for farmers throughout Europe, and are currently removed with chemical pest control. However, the pesticides also affect existing ecosystem services like potentially pest-controlling insects as well as the surrounding environment negatively. According to previous studies higher landscape diversity leads to a higher diversity of natural enemies to pest insects, but no study has investigated if the pest control is enhanced around non-crop remnants such as midfield islets (MI). This thesis investigates (i) if MI will reduce the number of aphids in crop field, (ii) if larger MI will be more effective than smaller MI by having higher aphid predation rate, and (iii) if larger MI will provide a more effective reduction of pest insects over a longer distance from edge. To assess the potential for pest control, aphids were glued on papers and placed at ground level in crop fields and around MI in nine fields. The collected data was processed statistically, and the result demonstrates that MI play an important role by providing habitats for natural enemies to pests. The increased size of MI have a positive effect of number of aphids consumed around MI, however the distance from edge was not significance. This study highlights the value of MI in crop fields as an existing ecosystem service in biological pest control. The naturally occurring predators are able to reduce *R.padi* and thereby minimize the need for insecticide applications.

Key words

Agriculture, aphid interaction, biological pest control, bird cherry-oat aphid, cereal aphids, ecosystem services, landscape diversity, midfield islets, natural enemies, non-crop habitats, predators, *Prunus padus, Rhopalosiphum padi*
Abstrakt

Ökat befolkningstryck och större efterfrågan av jordbruksprodukter på marknaden har det senaste seklet lett till stora förändringar i västvärldens jordbrukslandskap. Odlingslandskapet är idag homogent och monokulturellt där besprutningsmedel används för att ge större avkastning i produktionen. Skadeinsekten havrebladlöss (Rhopalosiphum padi) angriper vägrödor vilket leder till stora ekonomiska förluster för bönder runtom i Europa. Pesticider används för att reducera angreppen men påverkar även miljön negativt samt existerande ekosystemtjänster, såsom naturliga fiender som biologiskt kan begränsa skadeinsekters angrepp. Tidigare studier visar att heterogena landskap har en hög biologisk mångfald, men ingen studie har undersökt åkerholmars (ÅH) eventuella potential för biologisk bekämpning av skadeinsekter i säd. Denna studie undersöker därför (i) om ÅH leder till ökad reducering av havrebladlöss i säd, (ii) om större ÅH är mer effektiva än mindre i frågan om pestreducering, samt (iii) om större ÅH begränsar lusangrepp längre ut i fält från ÅH:s kant än mindre holmar. Studiens hypoteser testades genom experiment utförda i nio fält med vårgrödor där löss klistrades på etiketter som placerades ut i omgivande fält. Dessa samlades in efter tjugo fyra timmar för att studera antal löss konsumerade i relation till ÅH. Det insamlade materialet är bearbetat statistiskt och resultatet visar att ÅH spelar en betydande ekologisk roll för naturliga fiender till skadeinsekten havrebladlöss. Fler löss konsumerades runt större ÅH än de med mindre yta eller i de fält utan ÅH. Däremot har avståndet från ÅH en mindre betydelse, vilket indikerar att pestreduceringen är mest effektiv nära stora ÅH. Denna studie synliggör värden av existerande ÅH som inhyster nyttoinsekter i jordbrukslandskapet, samt att heterogena landskap har högre potential för en mer naturlig skadedjursbekämpning. Naturliga fiender är därmed en existerande ekosystemtjänst som kan begränsa bladlusangreppen (R. padi), som i sin tur ger möjligheten att reducera användandet av bekämpningsmedel, vilket för oss närmare miljömålet ”en giftfri miljö”.

Nyckelord

Biodiversitet, biologisk bekämpningsstrategi, ekosystemtjänster, havrebladlöss, heterogent landskap, hägg, jordbruk, landskapsekologi, lusreducering, naturliga fiender, nyttoinsekter, predatorer, Prunus padus, Rhopalosiphum padi, skadeinsekter, åkerholmar.
TABLE OF CONTENTS

Abstract ............................................................................................................................................... 2
Key words ............................................................................................................................................ 2
Abstrakt ............................................................................................................................................... 3
Nyckelord............................................................................................................................................. 3
INTRODUCTION ....................................................................................................................................... 6
The aims of the study .......................................................................................................................... 9
METHOD ................................................................................................................................................ 10
Study sites ......................................................................................................................................... 10
Sampling design ................................................................................................................................. 12
Data analysis ...................................................................................................................................... 15
RESULTS ................................................................................................................................................. 16
DISCUSSION ........................................................................................................................................ 17
CONCLUSION ....................................................................................................................................... 20
FUTURE CHALLENGES........................................................................................................................ 21
ACKNOWLEDGMENTS ........................................................................................................................... 22
BIBLIOGRAPHY ....................................................................................................................................... 23
APPENDIX .............................................................................................................................................. 29
Appendix 1: ........................................................................................................................................ 29
   Bird cherry-oat aphid (Rhopalosiphum padi) ................................................................................ 29
Appendix 2: ........................................................................................................................................ 31
   Natural enemies ............................................................................................................................ 31
Appendix 3: ........................................................................................................................................ 32
   Information about the study sites on Selaön ................................................................................ 32
Appendix 4: ........................................................................................................................................ 33
   Illustrations of the field work ........................................................................................................ 33
Appendix 5: ........................................................................................................................................ 35
   Pictures of the midfield islets in the study site of Selaön ............................................................. 35
Appendix 6: ........................................................................................................................................ 40
   Raw data ........................................................................................................................................ 40
INTRODUCTION

The rising population and a growing demand for food and products has led to an increased production, following the conversion of forest and wetlands into farmlands (Tilman, et al., 2001; Robinson & Sutherland, 2002; Zhang, et al., 2007). After Second World War there have been large structural changes in agriculture in the developed world where effectiveness and quantity are in focus, and pesticides and inorganic fertilizers are used to increase yields and outputs (Östman, 2002; Gurr, et al., 2003; Sveriges National Atlas, 2011). Intensified agricultural production have negative effects, such as increasing use of pesticide which has led to an evolution of pesticide resistance among pests and nutrient leaching (Vitousek, et al., 1997; Ffrench-Constant, et al., 2000). The landscape change has led to removal of non-crop habitats and enlargement of field sizes, which has caused a rapid decline of farmland biodiversity affecting the functioning of natural pest control as a broad spectrum of natural enemies lives in non-crop habitats (Ives, et al., 2000; Benton, et al., 2003). Landscapes with high proportions of forest, road verges, hedgerows, field margins, tree lines, ditches or wetlands are referred to as non-crop habitats, heterogenic or complex landscapes (Wilby & Thomas, 2002; Bianchi, et al., 2006). Another remnant habitat is midfield islets (MI), which are landscape structural elements that are situated within a field of crops (Cousins & Lindborg, 2008). During the last sixty years many MI have been destroyed to make the production of crops more effective. The ones remaining have not been managed for a long time but since 1995 all MI are protected by regulations. Nowadays it is not allowed to remove or destroy MI (Cousins & Lindborg, 2008; Naturvårdsverket, 1995). Many farmers view MI as a problem as it takes longer time to manage the fields (Jonsson, 2012 personal communication). However, previous studies have shown that MI promotes a rich flora (Cousins & Eriksson, 2001; Cousins & Lindborg, 2008), and may therefore consider as an important habitat for pest controlling insects.

In general two different farming systems are in use in Sweden today, conventional or organic farming (Sveriges National Atlas, 2011). Within conventional farming chemical pest control is the dominant form of management against insect pests in order to sustain and increase the yield (Östman, et al., 2001; Östman, 2002). Organic farming differs from conventional farming by using crop rotation, choosing plants and animal species that are adapted to local conditions and which are resistant to diseases. These activities limit the use of chemical pesticides and synthetic fertilizers, and limit the food additives and livestock antibiotics use and prohibit the use of genetically modified organisms (European Commission, 2012). During
the last decades both politicians and consumers have called for food produced in an environmentally sound manner (Östman, 2002). For instance the European Commission highlight the issue regarding extensive farming versus valuable habitats in Europe, where inappropriate agricultural practices and land use can have an adverse impact on natural resources as soil, water, air, wildlife etcetera (European Commission, 2012a). EU have therefore elaborated an agri-environmental scheme (AES), which compensate farmers for additional costs and loss of income if they protect and enhance the environment in adopting sustainable farming techniques that go beyond legal obligations (European Commission, 2012b). Sweden have implemented an environmental scheme called "Landsbygdsprogrammet" (Rural Development Program) where economic support pays farmers whom applies measures to improve the environment (Jordbruksverket, 2011). Since 2007 over 2 billion SEK is paid annually, in general to organic farming and management of pastures and hayfields. Furthermore, one of the National Environmental Goals in Sweden is to minimize pesticides in the landscapes and achieve a non-toxic landscape, by reducing emissions of metals and other substances that can harm human health and biodiversity (Naturvårdsverket, 2011).

A study by Tscharntke et al. (2002) and Bianchi et al. (2006) highlight that diversified landscapes with crop rotation and non-crop habitats hold most potential for conservation biodiversity and sustainable pest control function. Biological pest control is a way to use the available ecosystem services (Niklasson & Nilsson, 2005; Mills, 2007). Ecosystem services benefits humans and include for instance pollination, decomposition, water purification by natural processes and natural control of insect pests that damage plants or spread human diseases (Millenium Ecosystem Assessment, 2005; Bianchi, et al., 2006; Mills, 2007). Bianchi and colleagues (2006, p. 1716) state that the benefits to farmers in a diversified landscape is increased when “(i) the natural enemy population are higher and more diverse, (ii) natural enemies substantially colonize arable fields, (iii) they significantly reduce pest densities, (iv) thereby reducing damage levels and (v) increasing yield or quality and (vi) benefits outweigh costs.”

The bird cherry-oat aphid *Rhopalosiphum padi* (L.) (*R.padi*) is a major aphid pest in spring-sown cereals in Sweden and throughout Europe, resulting in large economic losses for farmers (Östman, et al., 2001). In general the pest infests spring cereals in Sweden, but also winter cereals in other parts of Europe (Leather, et al., 1989; Östman, 2002). Moreover the pest causes damages to the cereals due to its ability to transmit virus diseases in temperate
climate, in particular barley yellow dwarf virus (BYDV), also called red leaf (Leather, et al., 1989; Alberta, 2012). The abundance of *R.padi* varies highly between years, at least in Northern Europe (Östman, et al., 2001; Östman, 2002). The reason for the fluctuations in aphid abundance between years is still unknown, but a season with high abundance of aphids, (a so-called “aphid-year”) results in yield loss and an increased use in pesticides (insecticides) (Wiktelius, et al., 1990; Östman, et al., 2001). “Aphid-years”, and consequently extensive weed control, usually arises every 3 to 5 years in central Sweden and more often in southern Sweden (Jordbruksverket, 2012a). The pesticides do not only affect the aphid’s establishment, but also natural enemies like spiders, ladybirds and ground beetles which are important in biological pest control (Ekbom, 2004). Cultivation methods such as harrowing and plowing are necessary, but frequently disturb annual ecosystems which can make it difficult for the natural enemies to remain in the field (Öberg, 2007). The farmers are therefore dependent on the pest predators’ ability to recolonize the fields from non-crop habitats.

Previous studies show that many natural enemies are more abundant near field edges, woody habitats, hedgerows, road verges etcetera compared to the field center (Ekbom, 1996; Thies & Tscharntke, 1999; Bianchi, et al., 2006). In the studies by Östman et al. (2001) and Bianchi et al. (2006) lower aphid abundance was found in complex landscapes. Bianchi et al. (2006) also found that the non-crop habitats were negative to *R.padi* and appeal to natural enemies only, in other words a higher abundance of natural enemies was found in non-crop habitats. Parasitoids and predators generally act at smaller spatial scales than herbivores thus the natural enemies are therefore more susceptible to habitat fragmentation than the pest (Cronin, 2004; Bianchi, et al., 2006). Large-scale landscapes with monoculture crops may only support an impoverished parasitoid community and therefore run an increased risk of pest outbreaks when parasites are released from natural enemy control. However, other studies show that both predators and pest species are favored by non-crop habitats (Roschewitz, et al., 2005; Thies, et al., 2005). The landscape complexity may seem to stimulate pest suppression in particular cases, but the low number of studies on the role of non-crop habitats in biological pest control, and the lack of proper statistical analysis, prohibits drawing general conclusions on this issue (Bianchi, et al., 2006).

The study by Östman (2002) showed that natural enemies had a greater impact on *R.padi* establishment in organic farms than in conventional farms. The study further showed that irrespective of farming system landscapes including abundant field margins and non-crop habitats are associated with low *R-padi* establishment. The landscape shape is important for
the natural enemies’ present in cereals, and therefore affects the aphid’s establishment phase in the fields. However, another study show that the natural enemies effect on the cereal aphids in the heterogenic landscapes is substantial during the establishment phase of the pest, but even more important in homogenous landscapes after the pest have established in the fields (Östman, et al., 2001a). One explanation may be that the predators have access to other prey in complex landscapes. However, early predation of pest insects can suppress the establishment of the cereal aphids and the yield loss (Åkerberg, 1988). A study by Östman et al (2001a) show that the number of aphids are less if natural enemies are available in field, and that the yield loss decrease with existing predators in the agricultural landscape.

Depending on level of diet specialization pest predators can broadly be divided into generalist and specialists (Symondson et al., 2002; Winqvist, 2011). Spiders and ground beetles are some of the most abundant generalist predatory insects within arable crops. They are recognized as important contributors to conservation biological control (Östman, et al., 2001a; Ekbom, 2004). Generalist predators seem to be more efficient than specialist predators for pest suppression in frequently disturbed habitats such as crop fields (Öberg, 2007). This is because the generalists can be present in the fields before pests appear as they consume alternative preys (Ekbom, 1996; Östman, 2002). Therefore generalists play an important role as biological agents as they prey on the pest insects before they can cause damage. As they have the possibility to predate on the pest even at low abundance results that they prevent the establishment of pest insects (Östman, 2002; Lang, 2003; Winqvist, 2011). Previous studies have shown that higher abundance of polyphagia (generalists) predators, decrease the aphid establishment (Chiverton, 1986; 1987; Åkerberg, 1988). No notable correlation between the specialists and infest of the pest was shown. However, the importance of generalist and specialist predators for biological control of cereal aphids is not well known (Winqvist, 2011).

Further information on the bird cherry-oat aphid (*R.padi*) is possible to find in appendix 1, and facts about natural enemies to the *R.Padi* you find in appendix 2.

**The aims of the study**

To my knowledge no study has investigated if the pest control is enhanced round midfield islets (MI), an exception is the study by Thomas et al (1991) which investigated the role of created MI on arthropods. Identification of the key factors that drive natural pest control at the landscape scale may provide insight into the unexplained variation in natural enemy and
herbivore densities in time and space (Bianchi, et al., 2006). The lack of knowledge of the role of existing MI in pest control and the spatial movements around the MI are therefore important to study thus I put forward these hypotheses:

a) Midfield islets will lead to a reduced number of pest insects (aphids) in crop fields because the islets harbor more natural enemies than fields without midfield islets

b) Larger midfield islets will be more effective, than smaller midfield islets, which means they have less pest insects (aphids) in the surrounding crop field

c) Larger midfield islets will provide a more effective reduction of pest insects over a longer distance from edge into the crop field

METHOD

Study sites
The study was conducted in south eastern Sweden, an area that is described as the temperate zone with a mean annual temperature of 5-6 C° (SMHI, 2009), and 600-700 mm precipitation (SMHI, 2009a). Four farms on Selaön, a large island in Lake Mälaren about 80 kilometers to the west of Stockholm (59°23’N, 17°13’E), were selected, see figure 1. The *R.padi* in general damage spring crops, such as oat and grain (Jordbruksverket, 2012a), therefore the experiment was done only in fields with spring crops. According to Östman (2012 personal communication) fields with crops sown at the same time should have the same predators. The study includes five fields with cultivated grain, two oat fields, one field with broad beans and one with flax, see table 3 in appendix 3. All farms were managed conventionally which means regular use of inorganic fertilizers and pesticides. No of the four farms used insecticides against the *R.padi* during the season although some of the fields in the study site were above the economic threshold. The economic threshold is dynamic and rates the actual price for the seed which differ from year to year, and contrast the costs for weed control to decide if use of pesticides is financially sustainable (Arvidsson, 2012 personal communication; Jordbruksverket, 2012c). However, all farms used the pesticide (herbicide) Ariane S for weed control in the field with oat and grain before the experiment in June 2012. The flax was processed with a triple mix of herbicides; Gratil, MCPA and Ally 50 ST (see table 3 in appendix 3). The herbicides used are most likely not affecting the natural enemies directly, but may have an indirect impact when the fauna become unilateral and the diet for the natural enemies is less abundant (Arvidsson, 2012 personal communication).
The timing of the experiment was in accordance to Östman (2002), when the aphids are most active. To account for temporal variability the experiment was repeated two times, week 24 in June and week 27 in July year 2012. Moreover a pilot study in May (week 20) was carried out but is excluded in the analysis due to a change in the experimental set-up design. Jordbruksverket (2012b) make prognoses every year early in spring by counting eggs on the Bird Cherry Trees (*Prunus padus*). The prognosis in spring 2012 showed that it was higher risk of abundant aphids in field during the season than in several years, and the risk of red leaf (BYDV) was considered high. The prognosis said that winged aphids appeared in the crop fields during week 20-21 in June in the area where the experiment was carried out (Jordbruksverket, 2012b). The aphids migrated from the Swedish *Prunus padus* or were brought with winds from countries around the Baltic Sea. Week 23, 20 % of the fields were above economic threshold and the aphids increased in both fields of grain and oat until week 28-29 when the *R.padi* population collapsed. Pea aphids established in broad beans week 24 and decreased week 29. In other words “natural *R.padi*” was established both in oat and grain fields and pea-aphids in the field with broad beans during the timing of the experiment. However, no aphids were established in the field with flax. According to Jordbruksverket (2012b) year 2012 was an aphid year, but the weather led to an adverse year for the aphids when wind and rain affected them later on in season (Arvidsson, 2012 personal communication). The weather was similar both weeks during the experiments (June and July) on Selaön. It was sunny or cloudy, with moderate wind and no rain. However, June had a colder mean temperature around 12-15 C° compared to a mean temperature of 16-20 C° in July (Berglund , 2012 personal communication).
Figure 1. Study site Selaön, a large island in Lake Mälaren about 80 kilometers to the west of Stockholm (59°23’N, 17°13’E). Fields without midfield islets, medium-sized islets and large midfield islets are shown in the figure as well as the surrounding landscape in terms of water bodies, forest, agricultural fields and urban areas.

Sampling design

The Rhopalosiphum padi (R.padi) were obtained at the department of Ecology in Swedish University of Agricultural Sciences in conjunction to the three different experiments in a time scale. The aphids were cultured in a lab in greenhouse-conditions and transported by car on a plant wrapped in plastic. The aphids were glued the same day, in the afternoon, as they were obtained. I have used a similar method developed by Östman (2002) placing two living R.padi aphids on small pieces (1x1 centimeters) of self-adhesive labels anchored by a map-pin. Living aphids was used because some predators, for instance the wolf spider Lycosids (see appendix 2) use the hunt strategy “sit-and-wait” and react to vibrations and visual cues.
(Öberg, 2007). The labels with the glued aphids were placed on a piece of Styrofoam and transported to the study site the next day. The glued aphids were placed faced-down into the soil on the ground to let ground dwelling arthropod predators detect them, essential ground-living generalist and specialist predators (Östman, et al., 2001a; Östman, 2002). The remaining aphids were counted after twenty four hours to include both day- and night active predators to estimate predation rate of predatory arthropods (Winqvist, 2011 personal communication; Östman, 2012 personal communication). See set-up design in appendix 4. Glinwood (2012 personal communication) argues that aphids do not live more than a couple of hours without food and liquid in field, but survive longer time in indoor environment. However, I saw that the majority of the aphids were still alive when they were placed into the fields, and some of the remaining aphids were still alive when the glued aphids were collected the next day.

In order to account for landscape variation I replicated the experiment three times at the landscape scale, leading to a total of nine locations, see figure 1 and 2. The fields were grouped into three categories; fields with no midfield islet (NMI), fields with medium-sized midfield islets (MMI) and fields with large midfield islets (LMI), see figure 1, 2 and table 3 in appendix 3. MMI are categorized as MI less than 1000 m², and LMI larger than 1000 m². Naturvårdsverket (1995) classifies MI as remnants less than 5000 m², but due to lack of locations with large MI with spring crops on Selaön one LMI above 5000 m² was used. The vegetation on all the MI were more or less wooded, see photos in appendix 5. The surrounded vegetation-type was relatively similar for all locations (mixed deciduous and coniferous forest), except to some locations having water cover. The percentage of land covers in a 500 meter buffer zone around the study area was analyzed using the terrain map in GIS, for further information see appendix 3.

I placed ten labels pieces at a transect from the edge of the MI and in the center of the fields similar to Östman (2002), see figure 2. All MI were situated approximately in the middle of the field, and were at least 100 meters (m) from the edge of the field, similar the set up in Cousins and Lindborg’s study (2008). The transects in the fields without MI were also placed at least 100 m from the edge of the field, see figure 2. Every midfield-location had three different transects, and to create a substantial difference in distance a logarithmic sample design was used (Ewers & Didham, 2006). The first label was placed in 0 m from the edge of the midfield islet, the second 10 centimeters (cm) from the edge and then the following 20, 40, 80, 160, 320, 640, 1280 cm from the edge ending at 2560 cm away from the MI. In the
fields without MI the glued *R. padi* were placed in a transect every 2.5 m. At each location there were 30 labels, with 60 aphids. Hence 270 labels and 540 aphids were used in total during each experiment. I used sticks in the beginning and in the end of the transect to show the farmers were the experiment were placed, and the farmers drove around the transects with their vehicles.

![Diagram](image)

**Figure 2.** Landscape set up to test the role of Midfield islets (MI) in pest control by varying the size of MI and fields without any MI. The brown lines illustrates how the three transects were placed with ten papers with glued aphids in a logarithmic scale from the MI. The dots illustrate the four pitfall traps placed in each location. The transects and the pitfall traps in fields without MI were placed in between two sticks in the middle of the crop fields. The figure is not according to scale.

The experiment also included to collect insects to investigate the abundance of natural enemies around the MI and in the fields. Four pitfall traps were placed in each location and the samples were emptied after twenty-four hours, in conformity with the glued aphids (Östman, 2002; Ekbom, 2004; Högfeldt, 2011 personal communication), see figure 2. The ground-living predators were trapped with pitfall traps; a plastic cup (500 ml volume) buried 20 cm in the ground containing water and detergent. The plastic cup was placed into the ground and covered with a tile to avoid trapping mammals, rain etc. The tile was placed on a couple of stones which surrounded the cup to let the insects enter the pitfall trap, see figure 10 in appendix 4. The insects were sorted as spiders, carabids, ladybirds and rove beetles, and
were counted and weighed which give an estimation of abundance and body mass of the predators. For further explanations and for pictures of the experiment design, see appendix 4.

Data analysis

To analyze the effects of the midfield islets (MI) in pest control, a linear mixed model was performed (Quinn & Keogh, 2002; Bradley & Nachtsheim, 2009; Winqvist, 2011). ANOVA is used to increase statistical power and to find significant variances between variables (McKillup, 2005; Tabachnick & Fidell, 2007). After that two models with different terms (one including site as random term, and the other one excluding site as random term), were compared with help of an ANOVA by looking at the P-value and AIC-values, a spatial autocorrelation was found and the method mixed model was chosen (Jones & J. Nachtsheim, 2009; Zuur, et al., 2009). The aphid lice consumed was used as response variable, and as the aim of the thesis was to investigate the effect of size, distance and time these three variables were included as main fixed effects. A null model was tested in an ANOVA to investigate if the model would change if other variables were used (McKillup, 2005). To reduce the model to only include MI size and distance, and to remove factors improving the model, AIC-values were examined and compared to find the model with the best predictive power (Quinn & Keogh, 2002; Winqvist, 2011). The Tukey test compares the means between the indicators large midfield islets (LMI), medium-sized islets (MMI) and fields with no midfield islets (NMI), and states if the differences are significant or not (Quinn & Keogh, 2002).

This study uses a standard statistical significant level according to Fisher (1954) which means that it is appropriate to conclude that the difference is statistically significant if the actual outcome is less than 5% (which is the same as 1/20 or 0.05). Simply the p-value is a measure of the degree of uncertainty in our alternative hypothesis. If the p-value is 0.02, it is 2% chance that our alternative hypothesis is incorrect and therefore 98 % chance that the hypothesis is correct. In other words a P-value below 0.05 is a strong indication of a true difference and may therefore verify the actual hypothesis (Fischer, 1954; McKillup, 2005; Winqvist, 2011). P-values near 0.05 have also been considered in the Result and Discussion. All analyses were conducted using version 2.15.2 of The R Project for Statistical Computing 2012 (R, 2012).
RESULTS

Aphid removal was significantly different between fields with midfield islets (MI) and fields with no midfields islets (NMI) (P <0.01). More aphids were removed in fields with MI compared to NMI, see table 1 and figure 3. Furthermore there was a significant effect of distance on aphid removal as less aphids were consumed further away from the edge (P<0.001), see table 1 and figure 3. However, the model in table 1 do not separate the different distances in the logarithmic scale. I found no significant effect of time on aphid predation (P>0.5), see table 1. Neither did I find a significant interaction of size and distance.

Table 1. The results of the size of midfield islets (MI), the distance and timing was analyzed using a mixed model. Significant values are illustrated with the symbol shapes as a star (*) where three stars indicate P<0.001, two stars P <0.01, one star P<0.1. No stars mean no significance. The model does not take into account the different distances used between fields with no MI and fields with MI.

<table>
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<th></th>
<th>DF</th>
<th>Value</th>
<th>Std. Error</th>
<th>T-value</th>
<th>P-value</th>
<th>Significance</th>
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<td>0.0538</td>
<td>-3.7083</td>
<td>0.0076</td>
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<tr>
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<td>0.0000</td>
<td>3.5599</td>
<td>0.0004</td>
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<tr>
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<td>0.0525</td>
<td>-0.4779</td>
<td>0.6329</td>
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</table>

The Tukey’s test states a significant difference in the predation rate between LMI and NMI (P <0.001), as well as between LMI and MMI (P<0.01), see table 2. However, no significant difference between MMI and NMI were detected (P >0.05).

Table 2. The result in the Tukey’s test includes differences in aphid removal between fields with large (LMI), medium-sized (MMI) or no midfield islets (NMI). Significant values are illustrated with the symbol shaped as a star (*). Three stars indicate P<0.001, two stars P <0.01, one star P<0.1. No stars mean no significance.

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>Std. Error</th>
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<td>0.1021</td>
<td>2.787</td>
<td>0.0148</td>
<td>*</td>
</tr>
<tr>
<td>NMI - LMI == 0</td>
<td>0.3993</td>
<td>0.1021</td>
<td>3.909</td>
<td>&lt;0.001</td>
<td>***</td>
</tr>
<tr>
<td>NMI - MMI == 0</td>
<td>0.1146</td>
<td>0.1022</td>
<td>1.121</td>
<td>0.5009</td>
<td></td>
</tr>
</tbody>
</table>

There was an effect of MI size and distance on aphid removal, see figure 3. The vertical axis shows if two, one or no aphids was consumed, and the horizontal axis show the distances in the transects. However, in the fields without MI the glued aphids were placed approximately every 2,50 meter, but the graph present the NMI in a logarithmic scale because the same
parameters have to be used in the model. The lines show the mean value from the two experiments (June and July) and merge the data from the three locations with LMI, three MMI and three fields with NMI. For all locations in the size classes (MMI and LMI) aphid removal was highest closest to the edge and decreased with increasing distance. As mentioned, the aphid removal was higher in the sites with MI, but the graph in figure 3 indicates that the aphids were affected up to a distance of 40 cm from the MMI and up to a distance of 160 cm for LMI, and affected relatively similarly over the whole distance in the fields with NMI. Therefore I can conclude that distance matters, although there are no statistical significance on the more detailed levels on the effects of distance from MI.

**Figure 3.** The graph illustrates the result of the midfield islet (MI) experiment with distance from the MI on the x axis and the mean number of aphids consumed on the y axis. For details on color coding of MI classes, see legend on the top in right corner of the graph.

Finally, the collection of natural enemies from the pitfall traps did not result in enough data to draw any conclusions regarding the ground living predators as too few replicates were used.

**DISCUSSION**

The study design enabled me to separate the effects of aphid consumed around large (LMI) and medium sized midfield islets (MMI), and in the fields (NMI) across four farms on Selaön.
west of Stockholm, Sweden. As proposed in hypothesis a, a higher effectiveness of aphid consumed around MI was found. Although the pitfall traps did not provide enough data regarding the predator abundance, the aphid consumed in the different sites gives a basis to say that it is higher abundance of natural enemies around LMI. As proposed in hypothesis b, LMI will be more effective than smaller MI meaning there are less pest insects (aphids) in the crop field. The positive correlation between MI size and aphids consumed mainly include the LMI; islets larger than 1000 m². Surprisingly there was no significant difference between MMI and NMI. It could be that MMI do not have enough predators, or that competition between aphid predators are high close to smaller midfield islets compared to larger midfield islets.

Contrary to hypothesis c, LMI did not provide a more effective reduction of pest insects over a longer distance from edge. There are still differences in how efficient the predators are in relation to its distance to prey, but the differences are marginal, see figure 3. The aphids consumed at the longer distances from transects are largely the same for all sites. One explanation can be that the predators using the MI as a habitat, do not strive for food longer that the need to. The high activity close to the MI may indicate that there were enough preys at a close distance, which could explain the small difference between the MI size. Furthermore, according to my result no correlation between aphid consumed and time appeared which is in contrast to previous studies (Östman, et al., 2001; Östman, 2002). This means that timing may not always be compatible with the aphid removal. My result suggests that the predators are equally effective to remove aphids at both time steps. One possible explanation could be that the aphid lice population was low early in season, as well as the natural enemies, but later when the Rhopalosiphum padi (R.padi) population increased the predators increased evenly to yielding significant difference.

However, there are four factors that may weaken these conclusions, which are interesting to investigate in further studies. Firstly, the vegetation type on the MI may affect the predator abundance. A detailed vegetation classification was not within the scope of this study, but the vegetation type seems to be the same on all islets when all the MI were covered with abundant vegetation of deciduous trees, except for the LMI in the flax which had sparser vegetation compared to the other MI (see appendix 5). Secondly, the surrounded habitats of the fields used in the experiment can also be important to consider, as natural enemies and aphids may use these habitats (Östman, 2012 personal communication). However, all the sites with MI had a crop cover above 50 % within a 500 meter buffer. It was the fields with NMI that had a
comparative low crop cover and more water or forest nearby, see table 3 in appendix 3. All the samples with aphids were placed at least 100 m from the field edge, and as the graph in the results (figure 3) are not shaped as a “U” it indicates that the transects are not affected of natural enemies from the surrounding landscapes. Thirdly, the crops in the fields with LMI differed from MMI and NMI, such as flax and broad beans are spring crops, but could harbor other species of natural enemies. During the experiment natural aphids occurred in the fields, which improve the validity of the study (Esaiasson, et al., 2002). All the fields except the one with flax, had aphids naturally occurring in the crop (R.padi in grain and oat, and pea aphids in the broad beans). On other hand, the predators may choose their habitat not on the basis of which crops that surrounds the MI. Moreover the statistical implementation has removed factors improving the model/result (Quinn & Keough 2002), and the effect of different crop types should therefore be rather small. However, if the crop was more developed in a field compared to another, more natural preys to the natural enemies’ may have been available at any of the sites, which would make the glued aphids more or less attractive. On other hand, according to the prognosis (Jordbruksverket, 2012b) the winged aphids appeared in the crop fields at the same time in the area where the experiment was done, and should therefore not affect the result. Finally, another sample design might have gained another result, but it was necessary to use a logarithmic scale to investigate the abundance of predators linked to distance around MI and to avoid that the transects would come too close to the fields’ edge. The logarithmic scale was not used in fields with NMI, but the aphids were similarly consumed over the entire transect. Hence, the divergence in set-up design between LMI, MMI and NMI did not affect the result.

Due to time and financing limitations nine replicates of MI size and fields where used, although more replicates would have been even more preferable to draw general conclusions. Nevertheless, the mechanisms and systems underlying biodiversity and biological pest control are general and therefore relevant for other regions (Östman, 2002). Altogether my result stresses the importance of non-crop habitats in crop fields to stimulate existing ecosystem services in terms of natural pest control, in addition to previous studies (Wilby & Thomas, 2002; Gurr, et al., 2003). Non-crop habitats enhance the abundance and diversity of natural enemy species in the agricultural landscape (Thies & Tscharntke, 1999; Wilby & Thomas, 2002; Bianchi, et al., 2006). However, in contrary, other authors mean that depending on the vegetation composition it seems as non-crop habitats not only act as reservoirs for natural enemies, but also for pest insects that invade crops (van Emden, 1965; Roschewitz, et al.,
If the MI contains the winter host *Prunus padus*, they may stimulate the pest. On the other hand winged *R. padi* can migrate from their hibernation quarters located far from the arable fields, or be brought long distances with winds (Wiktelius, 1992). Still, heterogenic landscapes with many non-crop habitats allow effective early season field colonization by natural enemies, and consider an important prerequisite for successful pest control when pest populations have little time to establish and increase unrestrictedly (Östman, et al., 2001; Östman, 2002; Bianchi, et al., 2006).

The suppression of pest populations in crops by natural enemies does not only provide environmental benefits when less chemical pesticides are used, it also gives economic benefits because it may reduce yield loss (Naylor & Ehrlich, 1997; Östman, et al., 2001; Bianchi, et al., 2006). According to Lewis et al (1997) and Östman (2002) the basic problem is lack of knowledge about the biological control agents, and that the production based management causes farmers to use inorganic substances to be on the safe side, in order to enhance the yield. Moreover, the approvals using the insecticide Primor, which not affect the natural enemies in same extent as many other substances, have been banned (Arvidsson, 2012 personal communication; Jordbruksverket, 2012). In addition, some aphids dwell below the soil surface or in compact crop, which make them hard to eliminate with the insecticides. Furthermore, the *R. padi* populations often naturally collapse when the crop matures (Wiktelius, 1992). These factors indicate to use as little pesticides as possible. However, it is important to make the “biological processes” sustainable for the farmer. The already existing agri-environmental schemes is one step, the call for food produced in an environmentally sound manner is another. Local management and landscape complexity need to be considered when developing future agri-environmental schemes, where midfield islets can play an important role as providing an existing ecosystem service. These factors will help us to get closer to some of the National Environmental Goals.

**CONCLUSION**

This thesis demonstrates a high activity in pest control around midfield islets (MI). Increased MI size correspond to a more effective reduction of cereal aphids (*Rhopalosiphum padi*) in crop field than smaller islets. However, increased MI size did not lead to a significantly efficient pest control over longer distances, and the diversity and density of natural enemy populations seems to decline with increasing distance from non-crop habitats (MI). Moreover, in contrast to previous studies this thesis shows that the predators had a significant impact of
the aphid removal around MI, irrespective of the time during season. This thesis improves the understanding of effects of agricultural intensity on biodiversity and biological control of cereal aphids. Higher landscape diversity with existing non-crop habitats such as MI are apparently a subject to early predation of pest insects in season, and provide important life-support functions for natural enemies to \textit{R. padi}. As MI seem to enhance the abundance of natural enemy species controlling pest insect populations in the agricultural landscape, they are an important ecosystem service providing economic and environmental benefits in the agricultural production.

**FUTURE CHALLENGES**

In order to increase the possibility to make general conclusions regarding the role of MI in natural pest control, additional studies are needed to highlight effects of landscape composition and the interaction of crop production, natural enemies and pest insects/herbivores. Future research could for instance highlight how to stimulate natural enemy populations where the vegetation on the midfield islets may play an important role. Another interesting perspective is to investigate which predators the MI harbor over a distance from edge, and a suggestion to set-up design for such an experiment is to collect natural enemies with pitfall traps in a transect from the edge of MI into the crop fields. Another unresolved issue is what role the size of a MI plays for effective pest-reduction. It would also be useful to combine different methods to get a better overall picture of biological pest-control use, for instance use quantitative methods together with qualitative as interviews with farmers to investigate sustainable and productive management schemes. For instance, would it be a possibility to restore MI in crop fields to develop natural pest control?
ACKNOWLEDGMENTS

This is an independent Master Degree Project, 30 ECTS credits, carried out at The Department of Physical Geography and Quaternary Geology at Stockholm University. The project started in June 2012 with an experiment financed by a scholarship from Svenska Sällskapet för Geografi och Antropologi (SSAG), and was finished in Stockholm in December 2012.

Thanks to my supervisors Sara Cousins and Matti Ermold who have made this Master Degree Project possible and also have provided useful guidance and encouragement. Furthermore, I would like to thank all farmers involved that permitted me to use their fields for the study. I also want to thank Robert Glinwood and colleagues, in department of Ecology in Swedish University of Agricultural Sciences, providing me with the aphids (*Rhopalosiphum padi*) and explaining me the way using them in the experiment. I thank SSAG (Svenska Sällskapet för Antropologi och Geografi) for the funding through the scholarship that supports research in the fields Anthropology and Geography.


Available at: [http://www.naturvardsverket.se/Documents/allmrad/ar_95_4.pdf](http://www.naturvardsverket.se/Documents/allmrad/ar_95_4.pdf)  


Available at: [http://www.r-project.org/](http://www.r-project.org/)  
[Accessed 7 10 2012].


Available at: [http://www.smhi.se/klimatdata/meteorologi/temperatur/normal-arsmedeltemperatur-1.3973](http://www.smhi.se/klimatdata/meteorologi/temperatur/normal-arsmedeltemperatur-1.3973)  

Available at: [http://www.smhi.se/klimatdata/meteorologi/nederbord/normal-arsnederbord-1.7956](http://www.smhi.se/klimatdata/meteorologi/nederbord/normal-arsnederbord-1.7956)  


APPENDIX

Appendix 1:

Bird cherry-oat aphid (Rhopalosiphum padi)

The bird cherry-oat aphid (*Rhopalosiphum padi*) overwinters as an egg in woody habitats, more specific the Bird Cherry Tree (*Prunus padus* L.) function as winter host of the *R.padi* (Östman, 2002; Bianchi, et al., 2006). The *R.padi* population develops in two stages, an establishment phase and an exponential growth phase (Östman, et al., 2001; Östman, 2002). The life cycle of the *R.padi* in Sweden is illustrated in figure 4. The eggs hatch in May and winged *R.padi* develop after some non-winged parthenogenesis generations, which is a form of asexual reproduction where embryos grow and develop without fertilization (A, B and C in figure 4) (Wiktelius, 1992; Östman, 2002). The winged aphids migrate to cereal fields and other grasslands (D) and once again begin to produce non-winged aphids parthenogenetically (Es and Eg). The aphids choose the cereal which is least developed and most tender, meaning that the sow period is important for the farmer (Arvidsson, 2012 personal communication). When the aphids establish in cereal fields in late spring – early summer a large part of the aphids population is active on or near the soil surface, later in season the aphids move and are active on the whole plant (Wiktelius, et al., 1990). The *R.padi* populations collapse when the crop matures and the decline of the population is partially due to that winged aphids develop (F), and winged aphids move to natural grassland where they develop in autumn (G) (Wiktelius, 1992; Östman, 2002). The males also develop (H) and the sexual reproduction occurs on *Prunus padus* where eggs are laid for hibernation (I and A). The *R.padi* has a high reproductive capacity, thus in cold weather the reproduction is slower and faster during warm periods. A normal warm early-summer the aphids may increase 20 times per week (Wiktelius, 1992).

![Figure 4. The lifecycle of the bird cherry-oat aphid (*R.padi*). Figure adapted from Wiktelius et al. (1992).](image-url)
Early in Spring prognoses are done to estimate the expecting amount of aphids in crop fields by counting eggs on *Prunus padus* (Wiktelius, 1992; Jordbruksverket, 2012b). In years with abundant amount of eggs, a single *Prunus padus* are able to produce several million winged *R.padi*, which all are potential colonizers of cereal. In mid-June relative safe predictions can be set regarding the pests’ infestation size and timing of individual fields (Wiktelius, 1992; Arvidsson, 2012 personal communication; Jordbruksverket, 2012b). The weed control (herbicide) should be used after that the winged aphids have migrated to the crop fields. It is in general the pesticide Primor that is used (Jordbruksverket, 2012) which does not affect the natural enemies in same extent as many other substances (Arvidsson, 2012 personal communication). The approval of Primor has however ended but the pesticide was still used during the season 2012 (Jordbruksverket, 2012). Otherwise it is the pesticides Mavrik or other pyrethroids that are used. These substances damage natural enemies more, which may lead to that the aphids increase again later on. The aphids below the soil surface or aphids on the plant close to the ground in compact crop are hard to eliminate with the insecticides, and can also result in that the aphids reproduce in the fields. It also happens that the farmers use unnecessary insecticides too late (Arvidsson, 2012 personal communication), and that the *R.padi* populations naturally collapse when the crop matures (Wiktelius, 1992).

![Figure 5. Aphid lice (*R.padi*) in spring cereals. Photo: Sabine Sigfridsson 2012](image1)

![Figure 6. A close-up view of an aphid lice *R.padi*. Photo: (Ipmdss, 2013)](image2)
Appendix 2:

Natural enemies
The natural enemies to the *Rhopalosiphum padi* often have their hibernation quarters in adjoining non-crop habitats. Even though the aphids’ birthplaces may be far from the fields, winged aphids migrate into the arable fields in May-June (Ekbom, 1996; Östman, 2002). The different natural enemy species differ in dispersal ability from several kilometres to a couple of hundred meters, which impacts species composition and pest control effectiveness at a landscape scale (Bianchi, et al., 2006). Moreover the natural enemies have to find and consume the aphids early in the season to be able to suppress the pest, which indicates the importance of non-crop habitats in conjunction to crop-fields, resulting in an effective pest-control (Ekbom, 2004; Östman, 2004).

The natural enemies to the bird cherry-oat aphid are some spiders (*Aranea*), for instance the wolf spider from the genus and family *Pardosa: Lycosidae* which is usually present during the aphid’s establishment phase (Ekbom, 2004; Winqvist, 2011). The generalist rove beetle (*Coleoptera: Staphylinidae*) also consume a large amounts of aphids, as well as Carabids (*Coleoptera: Carabidae*) where *Bembidion lampros, Bembidion quadrimaculatum* and *Pterostichus cupreus* are the most common species in spring fields (Åkerberg, 1988; Ekbom, 1996). The lady bird (*Caloptera: Coccinellidae*), its larvae and some parasitic wasps are specialized on aphids and reduce aphid population growth later in season (*Hymenoptera*) (Snyder & Ives, 2003; Ekbom, 2004; Winqvist, 2011). As the aphids are active near the soil surface in late spring and early summer (Wiktelius, et al., 1990), ground living predators may be effective biological agents in natural pest control and decrease the use of pesticides (Ekbom, 1996; Östman, 2002; Öberg, 2007; Winqvist, 2011).
Appendix 3:

Information about the study sites on Selaön

Table 3. The location of the experimental sites and the category and area of the midfield islets (MI) as large (LMI), medium sized (MMI) or fields without MI (NMI). The table shows the type of crop in field, the surrounded habitats within a 500 meter buffer (%) and if pesticides were used. Only herbicides were used and listed below. The data of the surrounded landscapes is processed in GIS (Geographic Information System), based on the terrains map including information about land cover and land use (Geodata, 2012; Lantmäteriet, 2012), (CORINE. Land Cover. Resolution: 25x25 m). The coordinates collected from the experiment period was used to identify the surrounded habitats within a 500 meter buffer around the MI with different sizes, or a created rectangle of same size (1771 m²) in the fields. The data is then recalculated from m² to %.

<table>
<thead>
<tr>
<th>Location</th>
<th>Category</th>
<th>Area (m²)</th>
<th>Crop</th>
<th>Surrounded habitats within a 500 meter buffer (%)</th>
<th>Pesticides (date applied)</th>
</tr>
</thead>
</table>
| Klahammar | LMI | 9403 | Flax | Forest cover 40,3%  
Open land cover 4,4%  
Crop cover 55,2%  
Water cover 0% | Gratil, MCPA,  
Ally 50 ST  
(27 May) |
| Runsö | LMI | 3252 | Grain | Forest cover 28,9%  
Open land cover 1,1%  
Crop cover 70%  
Water cover 0% | Ariane S  
(7 June) |
| Vreta | LMI | 4387 | Broad bean | Forest cover 43,1%  
Open land cover 3,7%  
Crop cover 53,2%  
Water cover 0% | None |
| Eneby | MMI | 384 | Grain | Forest cover 26,7%  
Open land cover 7,6%  
Crop cover 65,7%  
Water cover 0% | Ariane S  
(7 June) |
| Klahammar | MMI | 875 | Grain | Forest cover 15,5%  
Open land cover 4,4%  
Crop cover 80,1%  
Water cover 0% | Ariane S  
(7 June) |
| Runsö | MMI | 999 | Grain | Forest cover 28,6%  
Open land cover 7,3%  
Crop cover 64,1%  
Water cover 0% | Ariane S  
(7 June) |
| Sjöbacka | NMI | 0 | Oat | Forest cover 71,6%  
Open land cover 6,3%  
Crop cover 18,6%  
Water cover 3,6% | Ariane S  
(24 March) |
| Vreta | NMI | 0 | Grain | Forest cover 18,4%  
Open land cover 7,7%  
Crop cover 73,4%  
Water cover 0,5% | Ariane S  
(13 June) |
| Vreta | NMI | 0 | Oat | Forest cover 12,4%  
Open land cover 34,5%  
Crop cover 24,4%  
Water cover 28,7% | Ariane S  
(13 June) |
Appendix 4:

Illustrations of the field work

Figure 7. The two living *R. padi* were placed on small pieces of self-adhesive labels anchored with a map-pin. Photo: Sabine Sigfridsson 2012.

Figure 8. The labels were placed on a piece of Styrofoam when transported to the study site. Photo: Sabine Sigfridsson 2012.

Figure 9. The glued aphids were placed faced-down into the soil on the ground. Photo: Sabine Sigfridsson 2012.

Figure 10. The pitfall trap is a plastic cup buried in the ground containing water and detergent. The trap was covered with a tile placed on a couple of stones. Photo: Sabine Sigfridsson 2012.
Figure 11. Sticks was used to show the farmers and myself were the transects were placed. 
Photo: Sabine Sigfridsson 2012.
Appendix 5:

Pictures of the midfield islets in the study site of Selaön

*Large midfield islets*

![Figure 12. Klahammar – Flax in May. Photo: Sabine Sigfridsson 2012.](image1)

![Figure 13. Runsö - Grain in June. Photo: Sabine Sigfridsson 2012.](image2)
Figure 14. Vreta - Broad beans in July. Photo: Sabine Sigfridsson 2012.

Medium sized midfield islets

Figure 15. Eneby - Grain in May. Photo: Sabine Sigfridsson 2012.
Figure 16. Klahammar – Grain in May. Photo: Sabine Sigfridsson 2012.

Figure 17. Runso - Grain in June. Photo: Sabine Sigfridsson 2012.
Fields with no midfield islets

Figure 18. Sjöbacka - Oat in June. Photo: Sabine Sigfridsson 2012.

Figure 19. Vreta - Grain in July. Photo: Sabine Sigfridsson 2012.
Figure 20. Vreta – Oat in May. Photo: Sabine Sigfridsson 2012.
## Appendix 6:

### Raw data

**Table 4. Raw data of the mixed model.**

<table>
<thead>
<tr>
<th>Fixed effects: Lice ~ Size + Distance + Time</th>
<th>DF</th>
<th>Value</th>
<th>Std.Error</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>521</td>
<td>1.8171996</td>
<td>0.07626001</td>
<td>23.828997</td>
<td>0.0000</td>
</tr>
<tr>
<td>Size</td>
<td>7</td>
<td>-0.1996827</td>
<td>0.05384806</td>
<td>-3.708261</td>
<td>0.0076</td>
</tr>
<tr>
<td>Distance</td>
<td>521</td>
<td>0.0001196</td>
<td>0.00003360</td>
<td>3.559856</td>
<td>0.0004</td>
</tr>
<tr>
<td>Time</td>
<td>521</td>
<td>-0.0251025</td>
<td>0.05252780</td>
<td>-0.477890</td>
<td>0.6329</td>
</tr>
</tbody>
</table>

Fit: lme.formula(fixed = Lice ~ Size + Distance + Time, data = Lice, random = ~1 | Site, method = "ML", na.action = na.omit)

**Table 5. Raw data of the Tukey’s test.**

| Linear Hypotheses: | Estimate | Std. Error | z value | Pr(>|z|) |
|--------------------|----------|------------|---------|----------|
| Medium - Large == 0| 0.2847   | 0.1021     | 2.787   | 0.0148 * |
| No - Large == 0    | 0.3993   | 0.1021     | 3.909   | < 0.001 *** |
| No - Medium == 0   | 0.1145   | 0.1022     | 1.121   | 0.5009   |

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Assorted p values reported -- single-step method)