Is Organic Farming a Viable Means in Reversing the Downward Trend of Small Game Populations?

Is Organic Farming a Viable Means in Reversing the Downward Trend of Small Game Populations?

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A Thesis in the Field of Sustainability

for the Degree of Master of Liberal Arts in Extension Studies

Harvard University

May 2018

Abstract

This thesis investigates whether organic farming has a positive effect on small game populations. Europe has experienced a strong decline in European brown hare, common pheasant, and grey partridge densities. Current scientific literature suggests that the simplification of agricultural systems is the main driver. However, to what degree conventional farming methods such as the application of synthetic pesticides, herbicides and fertilizers contribute to this decline is unknown. My research addresses this question about the impact of conventional farming practices on small game species and hypothesizes that over the last decade in Lower Austria, hunting yields increased as the organic farming increased. In addition, I evaluate if European brown hare, grey partridge and common pheasant densities have changed similarly. Evidence-based knowledge could help decision makers provide the right policies to benefit small game species important to the environment, economy, and culture of Europe.

I used a large dataset of conventional and organic agriculture and hunting for around 570 different municipalities in the state of Lower Austria. With the help of GIS technology, I increased comparability between municipalities to adjust for differences in habitat structure and geographic boundaries. Statistical tests then searched for correlations between hunting and farming patterns.

Simple linear regression analyses showed that organic farming is a weak but significant predictor of brown hare and common pheasant hunting yields. Results from

the Welch's t-test confirm the positive influence from this farming practice but a deviation of residuals from normal distribution warrants caution when interpreting this test's results. I conclude that the avoidance of using synthetic materials in agriculture indeed benefits small game. However, steadily decreasing adj. R^2 values over the years of the study suggest that benefits from organic farming are disappearing. Other land management trends seem to be more decisive factors. While organic farming is a tool that positively contributes to small game abundance, data suggest that this factor is too small as a viable means for reversing the downward trend in small game populations.

Acknowledgements

I would like to thank Alfred Gansterer from the Lower Austrian Hunting Association for granting me access to their hunting database and for the many conversations that helped to improve my understanding of the data and its accuracy.

Thanks also go to Günter Griesmayr (Agrarmarkt Austria) for granting access to the agriculture data and to Herwig Bauer (Agrarmarkt Austria) for tailoring the datasets to my needs.

I would like to thank Nicole Kocher for her creativity and enthusiasm that helped me tackle big data challenges that more than once showed the limits of Microsoft Excel.

I thank Mark Leighton for equipping me with the ecology knowledge and skills needed for this endeavor and for his guidance and keen insights.

Thanks shall also go to Diane Corbin for using her love for the English language to make it less painful for everyone who reads this work.

Finally, I want to thank Josef Zeitlberger. His lifelong dedication to understanding and managing small game is a true inspiration and certainly sparked my interest in learning more about these species.

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Chapter I.

Introduction

Over the last decades, Europe has experienced a strong decrease in grey partridge (*Perdix perdix*), common pheasant (*Phasianus colchicus*) and European brown hare (*Lepus europaeus*) populations (Smith & Johnston, 2008; EBCC, 2011; Ronnenberg, Strauß & Siebert, 2016). Changes in farmland management practices that coincide with population declines are believed to be the biggest drivers. Many studies suggest that the simplification of agricultural systems, characterized by bigger fields and lower plant diversity, has the strongest impact (Meeus, 1993). Others suggest that populations suffer from insect shortages caused by pesticides (Potts, 1986; Potts, 1997). Herbicide induced changes in vegetation are found to have an effect too (Sullivan, 1990), but not all studies have found a correlation between the application of pesticides and herbicides, and declining small game populations (Birkhofer, Ekroos, Corlett, & Smith, 2014).

In the years 2000 to 2014, the size of organically managed crop land tripled in Austria (Bio Austria, 2015), yet there are no studies investigating the impact of this region's land use change on small game populations. Hunting on farmland is an important industry in some regions, providing employment benefits in rural areas (MacDonald & Johnson, 2000), but game species are also important indicators of the health of other species and thus, biodiversity in general (Shoko, Masocha, & Dube, 2015). Some of those indicators may have direct economic benefits vis-à-vis recreational activities, such as bird watching (Stoate, 2001). As such, a better understanding of the impact of farming practices on small game populations bears examination.

Research Significance & Objectives

Because of the environmental and social significance of small game species for rural areas, and given the large drop in game abundance experienced over the last decades and the considerable expansion of organic farming, I assessed the impact of this farming practice on grey partridge, common pheasant and European brown hare populations. This was achieved by addressing the following objectives:

- To understand how small game population density and the share of organic farming have developed over recent years in the case study area
- To identify whether small game population sizes are correlated with organic farming
- To contribute to the knowledge of the impact of synthetic fertilizers, pesticides and herbicides on wild life
- To provide a basis for more informed policy decisions about land management

Background

Small game species are important elements of agricultural landscapes that are sensible to changes in farming practices (Delibes-Mateos, Farfán, Olivero, Márquez, & Vargas, 2009). Changes in the abundance of the European brown hare, the common pheasant and the grey partridge may have implications for entire ecosystems.

An Introduction to Small Game

The term "small game" refers to small animals and birds that are hunted or trapped (Oxford Reference, 2017), and whose adult life body weight does not exceed 5kg (Shoko et al., 2015). On the contrary, "big game" defines larger mammals, such as deer or bison (Oxford Reference, 2017). It seems, however, that there is not a universally accepted weight or size threshold in place for these two terms.

Small game species play a vital part in the transfer of energy and matter (Shoko et al., 2015) and exert substantial influence, especially on predator population cycles (Schmidt, Olsen, Bildsøe, Sluydts, & Leirs, 2005). As a result, their abundance is a major determinant of the functioning of ecosystem services (Shoko et al., 2015).

Hunting, both small and large game, is a major economic driver across Europe. In Austria, the yearly economic value of hunting is estimated around 360 million Euros. The composition of game species is dependent on geographic and climatic factors. The most important small game species in Lower Austria are the European brown hare, the European rabbit, the common pheasant and the grey partridge (NÖLJV, n.a.); however, rabbits were not considered in this study because rabbit hunting efforts vary strongly between hunting estates and the proposed study relies on comparability of hunting yields.

European brown hare (Lepus europaeus). The European brown hare is native in large parts of continental Europe. Its distribution stretches from Italy in the south to Finland in the north. It has naturally expanded east to Siberia and can be found in the Northern parts of the Middle East (Figure 1).

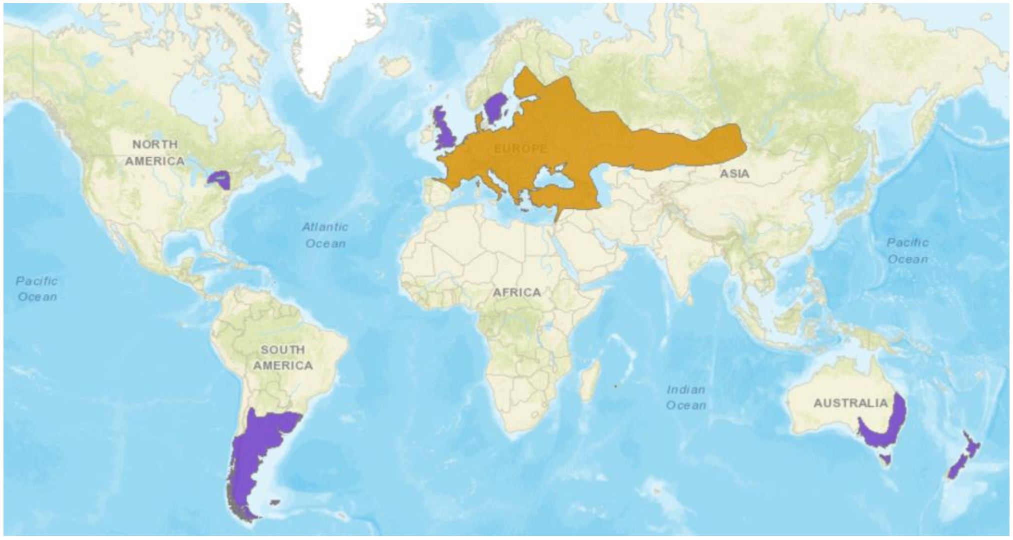

Figure 1. Distribution of the European brown hare (Yellow = native, Purple = introduced) (Smith & Johnston, 2008).

Although this species can persist in many habitat types, hare densities are highest in regions with an altitude of < 200m, snow cover duration of 40 – 60 days, mean annual precipitation of 450 – 700mm, and mean annual temperature of > 10 °C. The European brown hare is still abundant, but due to rapid population declines, some countries, including Austria, have placed it on their red list as “near threatened” (Umweltbundesamt, 2005; Smith & Johnston, 2008).

Short crops, weeds and wild grasses are the main food source (Tapper & Barnes, 1986; Smith & Johnston, 2008). Hares often feed at night while staying in natural shelters during the day provided by hedgerows and woodland (Tapper & Barnes, 1986). Hares average three litters per year of two to three leverets (Hansen, 1992; Smith & Johnston, 2008) with a gestation period of 41 – 42 days. Leveret production is determined by nutrition and weather patterns (Tapper, 1987 as cited by Edwards, Berny, & Fletcher, 2000). Females reach maturity between seven and eight months and males around six months. Average life expectancy is 1.04 years (Smith & Johnston, 2008). Hares are sedentary with home ranges between 10 and 100 ha (Broekuizen & Maaskamp, 1982; Tapper & Barnes, 1986; Kovacs & Buza, 1992; Reitz & Leonard, 1994 as cited by Edwards et al., 2000). The hare relies on available forage the whole year. This makes crop and landscape diversity crucial (Tapper & Barnes, 1986). Especially in winter, hares are dependent on available winter cereals (Chapius, 1990). In the absence of these, less nutrient rich grass found in pasture land is required (Barnes, Tapper, & Williams, 1983). The red fox (*Vulpes Vulpes)* is an important predator and predation is more intense in the absence of cover that can be used for shelter. (Pepin, 1989; Goszczynski & Wasilewski, 1992; Reynolds & Tapper, 1995 as cited by Edwards et al., 2000).

Grey partridge (Perdix perdix). The distribution of the grey partridge overlaps to a large degree with the brown hare. It is widespread throughout Europe, including Great Britain and expands to Central Asia and the Middle East. The grey partridge is predominantly found in temperate climates in steppe regions but even more in open arable land (BirdLife International, 2016).

The grey partridge has a preference for places with low ground cover close to shrubby patches, such as hedgerows (BirdLife International, 2016). In fact, the availability of hedgerows is a determining factor in breeding density which is highest along field boundaries (Blank, Southwood, & Cross 1967; Rans, 1986). Preferred foods are seeds of grains and weeds, cereals, clover, grass leaves and insects. Females typically lay two clutches of eggs per year. The first consists of 15-17 eggs followed by a second smaller clutch (BirdLife International, 2016). After hatching, hens lead chicks away from the nest where the chicks need to feed themselves. In the first two weeks, chicks predominantly feed on insects. In addition, partridge broods show a strong preference for staying in cereal fields. One study found 97 percent of the broods habitually reside in those fields. Their roost sites were found in those fields, too, consisting of shallow depressions in the soil below the crops (Green, 1984).

Across Europe, grey partridge abundance is estimated to have decreased by 82 percent over the last three decades (EBCC, 2011). In Great Britain, the grey partridge has been added to the red list of Birds of Conservation Concern 4 (BTO, 2015). Nonetheless, this species is still relatively abundant over an extremely large range. As a result, the grey partridge is considered "least concern" by the IUCN (BirdLife International, 2016).

Common pheasant (Phasianus colchicus). Unlike the European brown hare and the grey partridge, the pheasant is native to Asia. It has, however, been introduced to Europe where it has become more abundant than the native grey partridge, and to North America (Figure 2).

The common pheasant is a non-migratory, ground feeding bird that is mostly found in open plant communities, including both wild and agricultural landscapes (Tesky, 1995; NRCS, 1999). In winter, it stays mostly in woodland, shrubs and dense grasses where it finds shelter from wind and snow. The pheasants move out in spring, yet the close proximity of cover is always required. Male pheasants establish territories along woodland edges or hedgerows (Robertson, Woodburn, Neutel, & Bealey, 1993). Feeding occurs usually in the open at dusk and dawn (Hill & Robertson, 1988).

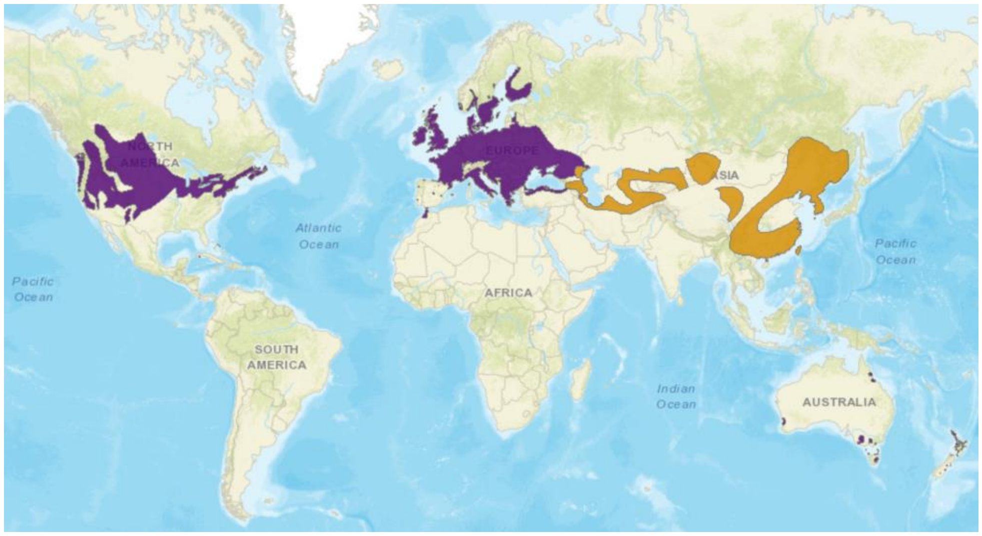

Figure 2. Distribution of the common pheasant (Yellow = native, Purple = introduced) (BirdLife International, 2016).

Main food sources are grains, seeds, shoots, berries and insects. While insects are an additional food source for adult pheasants, chicks rely entirely on this protein source for the first five weeks after hatching (NCRS, 1999).

For nesting, the common pheasant requires dense ground cover with overhead concealment. Preferred brooding areas show a lower degree of ground cover which allows chicks to move around and forage but provide some overhead concealment for protection against predators (NCRS, 1999). Nests are shallow depressions in the ground and the clutch sizes are from 9 to 14 eggs (BirdLife International, 2016). A hen hatches only one brood per year but is able to re-nest in case clutches are destroyed. First reproduction occurs in spring in the year after the hen itself is hatched (Tesky, 1995).

The common pheasant has shown a strong negative population trend across Central Europe (Ronnenberg et al., 2015). Nonetheless, it is overall very abundant over a wide area and is classified as “least concern” by the IUCN (BirdLife International, 2016).

The Link between Small Game Abundance and Farming

Biodiversity has been decreasing in large parts of the world. The main culprit is predominantly human induced changes to natural habitats and conservation efforts often focus on the preservation of those changed habitats. In Europe, the link between biodiversity and man-made habitat changes is different, especially in agricultural areas (Schmitt & Rákosy, 2007). The long lasting anthropogenic land use in Europe, characterized by small field sizes, high crop diversity and semi natural areas, has formed heterogeneous and species-rich environments that are important natural heritages that deserve conservation for natural and cultural reasons (Reif et al., 2005; Rusdea et al., 2005 as cited by Schmitt & Rákosy, 2007).

These environments provide crucial habitats for many species, including small game. Farmland is the primary habitat of the European hare (Smith, Vaughan, Jennings, & Harris, 2005). Hare density is higher in farming than in non-farming areas (Tapper & Parsons, 1983). Studies suggest a similar link for pheasants. Although pheasants predominantly breed in woodland edges rich in shrubby cover, feeding occurs in adjacent arable and grass land; however, breeding density has been found to be higher when close to arable land where pheasants find more growing shoots and seeds than on grassland (Robertson et al., 1993). This is also true for the grey partridge which thrives close to cereal fields that provide the vegetative composition and invertebrate fauna it needs as opposed to the more sparse conditions in grasslands (Sotherton, 1998).

Changes in Farming Practices and their Impact on Small Game Populations

The main goal of farming has historically been to feed local communities but nowadays it is even more important to feed non-local communities. Site productivity and economic yield have become major determinants in how farming is undertaken and both have led to an intensification of land use (Hodgson et al., 2005). This has changed the formerly heterogeneous and species rich traditional agricultural landscapes throughout most European countries. Average crop area per farm has generally increased and the highly beneficial edge and marginal areas have decreased at the expense of small game, among other animal types (Delibes-Mateos et al., 2009). These semi-natural habitats, including hedgerows, set-asides, herbaceous strips and grassy tracks, have often been removed entirely. During the same period, crop diversity has decreased, increasing habitat homogeneity (Zellweger-Fischer, Kéri, & Pasinelli, 2011). According to Duelli and Obrist (2002, p. 130), "In today's agricultural land-scape, natural and seminatural habitats are scarce, mostly small, and often they are isolated islands in a sea of cultural steppe".

The effects of using synthetic herbicides, pesticides and fertilizers. In addition to the change in composition of agricultural landscapes, management of arable land has changed, too. The use of synthetic herbicides, pesticides and fertilizers has especially changed considerably. Before 1950, only 15 percent of agricultural fields were sprayed with herbicides in the UK. This number increased to 70 percent in 1960 and 90 percent in 1965 (Potts, 1986). The effect of those chemicals on wildlife is mostly indirect rather than direct (Boatman, et al., 2004). Over the last few decades, the growing use of herbicides has decreased weed and grass diversity and abundance, negatively affecting the quantity of available food for hares (Brunce et al., 1994; as cited by Hackländer & Ruf, 2002). Hares selectively feed on plants that have a high energy content. In the absence of these plants and because of herbicides, hares would need to increase their food intake of less nutritious plants to make up for the lower energy source. Studies suggest, however, that hares are not able to fully make up for that loss and are thus faced with lower energy availability. A possible explanation is that increased food intake would require larger and heavier digestive organs. Those might be detrimental for this species which relies on high running speed to evade predation (Hackländer & Ruf, 2002).

The application rate of pesticides has developed similarly to herbicides but roughly 10 years later, and with a strong impact on grey partridge populations (Potts, 1986). A review of several in-depth studies suggests that the first drop in grey partridge abundance coincided with the increased use of pesticides, which reduced insect abundance and diversity. This decreased food availability for chicks caused a rise in chick mortality (Kujiper, Oosterveld, & Wymenga, 2009). At the same time, the quality of food decreased too. A diet consisting of a high variety of insect species was shown to increase chick survival compared to a low insect diversity diet (Browne, Aebischer, Moreby, & Teague, 2009). In contrast, adult partridges seem to be more affected by herbicides, which reduce the abundance of preferred weed species (Potts, 1986).

The impact of synthetic chemicals might be similar for the common pheasant, one of many different farmland birds indirectly affected by herbicides and pesticides (Boatman, et al., 2004). Older studies even suggested a direct negative effect from pesticides on this species. Crop seeds are an important part of a pheasant's diet. Seeds treated with pesticides have a detrimental effect on reproduction rates (Stromborg, 1979). Another study found that pheasants are able to detect pesticides on their food and that they reduce their intake if only treated food is available (Bennett & Prince, 1981); however, no newer literature has been found that has investigated the direct impact of modern pesticides on the common pheasant.

Not only have synthetic herbicides and pesticides changed the way in which agriculture is conducted but synthetic fertilizers have a dramatic effect, too. A survey even suggests that mineral fertilization is one of the most dominant drivers of agriculture change. The use of synthetic fertilizers mostly gained favor around 1945 across Europe. In Austria, nitrogen application reached its peak in 1960 and has decreased since then (Figure 3). The eventual drop in fertilization has occurred in most Western European

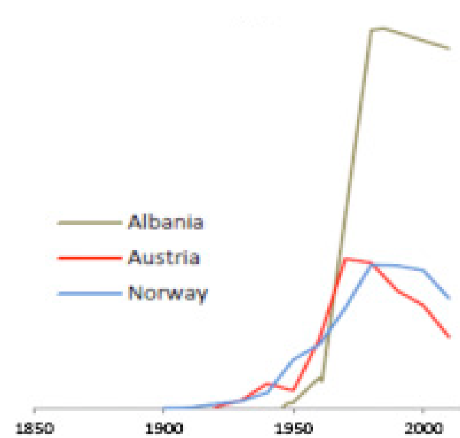

Figure 3. Changes in nitrogen fertilizer application per hectare of agriculture land over last 100 years (Jepsen, et al., 2015).

countries (Jepsen et al., 2015). A large body of research confirms that fertilization and the subsequent eutrophication of habitats have a negative effect on biodiversity (Gotelli & Ellison, 2002; Schmitt & Rákosy, 2007). A study of Central European Red List species even found that 65-80 percent of those are found in areas especially vulnerable to the effects of eutrophication (Lee, 1998; Skogen, Holsinger, & Gardon, 2011). It seems there is no literature available on the impact of synthetic fertilizer use on small game species in particular. Reduced biodiversity, however is likely to negatively impact those species, as well.

The Potential Benefits of Organic Farming

The major principle of organic farming is to avoid the use of synthetic herbicides, pesticides and fertilizers in growing crops (Kujiper et al., 2009). Instead, crop rotations, natural nitrogen fixation, recycling of farm manure, and biological weed and pest control are major components of organic farming which is also called "ecological farming" (EC, 2015; BMLFUW, 2017). Because of those factors, organic farming often leads to higher crop diversity, too (Bengtsson, Ahnström, & Weibull, 2005).

A meta-study that covered a large set of different regions suggests that organic farming may increase biodiversity by as much as 30 percent in farmland areas. Especially birds, insects and plants seem to profit from a change to this farming practice. Population abundance increased by up to 50 percent for birds, predatory insects, soil organisms and plants, but the analysis also revealed high variability among individual studies, suggesting that the impact of organic farming may differ among groups of organisms and landscapes. Wildlife in intensively managed farmlands seem to benefit most, while the impact is negligible in already heterogeneous landscapes consisting of farm and semi-natural land. Furthermore, non-predatory insects and pests failed to increase in abundance and 16 percent of the studies even detected a loss in biodiversity in organic farms compared to conventional farms. As a whole, organic farming seemed to be beneficial both for a species' richness and its diversity (Bengtsson et al., 2005). Another meta-study arrives at a different conclusion and sees non-predatory insects as winners and predatory insects as losers in organic farming systems. In addition, the study rejects the claim that organic farming is, in general, more beneficial for species diversity (Birkhofer et al., 2014).

No studies were found that focused on identifying the impact of organic farming on small game species in particular. Nonetheless, studies did observe the effects on birds in general (Beecher, Johnson, Brandle, Case, & Young, 2002). Results might give an indication relevant for the common pheasant and the grey partridge. The study sampled different bird species (excluding pheasants and partridges) in organic and non-organic farm areas and detected a 2.6x higher abundance in the former. Although the sample size was small (15 organic plus 15 non-organic sample sites), the authors concluded that better foraging opportunities due to the avoidance of pesticides and herbicides might be responsible for the higher bird abundance in organic fields.

Similarly, a study conducted in Argentina suggests a positive impact on small mammal abundance from organic farming in intensive farming areas but failed to detect an impact on a species' richness (Coda, Gomez, Steinmann, & Priotto, 2015). The European Brown Hare may respond similarly but no comparable studies on this species could be found.

Since 2000, the size of organically managed agricultural land has tripled in Austria (Bio Austria, 2015), yet I was not able to find studies analyzing the effect this may have had on wildlife in this region in particular.

Thesis Rationale

The impact of the transition from traditional, small scale farming landscapes to modern, conventional agriculture landscapes on certain small game species has been studied extensively across Europe. The body of research on the popular grey partridge is especially large. Many researchers took samples to detect statistically significant differences in species richness and abundance between different types of landscapes. Some of them also considered synthetic pesticides, herbicides and fertilizers as factors.

A small set of meta-studies analyzed research on the impact of organic farming on biodiversity in general but not necessarily on small game species. Their conclusions differ. While one meta-study suggests a general positive impact (Bengtsson et al., 2005), the other rejects such a claim (Birkhofer et al., 2014). Consequently, more research on this topic may help to create a more unified view on the effects organic farming may have on wildlife. In addition, and to the best of my knowledge, no individual study has analyzed this topic with a focus on Austria so far.

Past research has tracked the development of hunting yields including small game hunting yields (for example, Figure 4). Small game hunting yields are likely correlated with small game population density. This is because hunting of those relatively fast reproducing species is usually carried out on an equal effort basis, meaning that no quotas are put in place that would limit hunting yield. Since small game is seen to be a good bio-indicator sensible for land use change, studies focusing on those species yield results that go beyond the study group and have relevance in a broad ecological context (Delibes-Mateos et al., 2009).

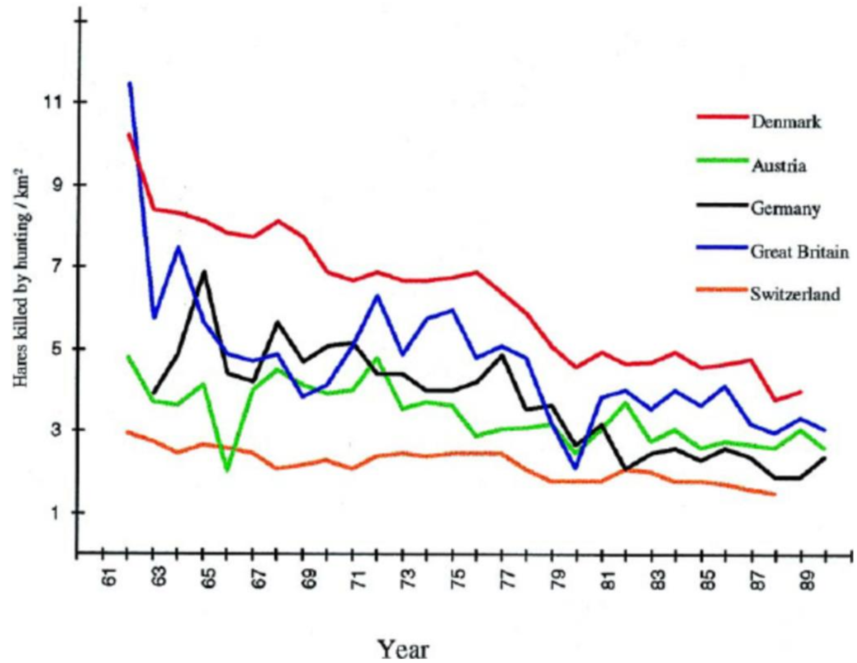

Figure 4. Changes in hunting yield of the European brown hare (hares shot per km^2). (Mary & Trouvilliez, 1995 as cited by Edwards et al., 2000).

The use of Geographuc Information Systems (GIS) has helped process temporal and spatial changes in small game abundance (for ex. Delibes-Mateos et al., 2009). Extending GIS to also gather data on the expansion of organic farming may add additional value and allow for an easier understanding of how this farming practice has evolved compared to small game in the case study area.

Since 2000, the size of organically managed agricultural land has tripled in Austria (Bio Austria, 2015), yet I was not able to find studies analyzing the effect this may have had on wildlife in this region in particular. Therefore, Austria provides a useful case study to see if the declines in small game with increased industrial agriculture (Figure 4) are reversed with an increase in organic agriculture.

Research Questions, Hypotheses and Specific Aims

My research will focus on the following questions and linked hypotheses:

Does organic farming increase hunting yields of the European brown hare, the grey partridge and the common pheasant? I hypothesize that organic farming does increase hunting yields of the European brown hare, the grey partridge and the common pheasant. Specifically, I propose that the density of small game species killed on hunting estates in municipalities in Lower Austria will increase with the proportion of agricultural land devoted to organic farming. In addition, I hypothesize that small game developed differently in areas that are characterized by strong growth in organic farming than in areas that show only modest growth or even a decline in organic farming.

Since all three species are hunted on an equal effort basis, it can be inferred that higher hunting yields are a result of higher game abundance. In addition, it could be inferred that conventional farming practices, such as applying synthetic herbicides, pesticides and fertilizers, negatively impact small game density.

Is there an association between European brown hare, grey partridge and common pheasant hunting densities? Hares, partridges and pheasants partially share the same habitat and hunting densities may be influenced by common underlying factors. Therefore, I predict that there is a correlation between all three small game species.

In addition, I intend to address these ancillary research questions: How widespread is small game hunting and farming in Lower Austria and how has organic farming developed over the last decade? I hypothesize that both farming and small game hunting is widespread and that farming areas dedicated to organic agriculture have increased. However, I expect hunting yields to be different between the respective small game species.

Specific Aims

Answering the research questions required a pre-defined order of achieved milestones, from gathering data and aligning different datasets, to performing regressions. These were to:

1. Identify a suitable case study area: Eligible areas were those characterized by a relatively high amount of conventional and organic griculture and widespread small game hunting efforts. Large parts of Lower Austria met both attributes.
2. Gather, improve and to prepare data: Hunting data were retrieved from the Lower Austrian Hunting Association, and data on farming from the Austrian Paying Agency for Agriculture and Rural Development. Plausibility checks helped detect potential irregularities, although close cooperation with both agencies minimized those and improved data accuracy. Finally, I calculated the key variables in the datasets and prepared the data spreadsheet for statistical analyses.
3. Align hunting with agriculture data: Hunting estates frequently cross political municipality and county borders while agricultural data does not. Geographic Information Systems were used to make datasets comparable.
4. Gain an understanding on the nature and development of farming and small game hunting across the study area: An analysis of the datasets reveal differences in nature and the past development of farming and hunting. With the help of GIS, key data were visualized to ease understanding of and to add geographic components to the data.

5. Detect possible correlations between the different small game species: European brown hare, grey partridge and common pheasant partially share the same habitat and hunting yield may be influenced by the same factors. Simple linear regression can test that.

6. Identify correlations between small game abundance and organic farming development: Again, simple linear regression analyses can detect a potential link between organic farming extent and small game hunting yield.

7. Analyze whether small game hunting yields show a different trajectory in municipalities that experienced high growth in organic farming than in municipalities with low growth or declining numbers. T-tests examined if these were different.

Chapter II

Methods

I used ArcGIS® software by Esri (Esri, 2017) to visualize differences in the nature of agriculture and small game hunting across Lower Austria. In order to identify possible links between the respective small game species, and between small game and organic farming, regression analyses using R were undertaken. Finally, t-tests were performed in R to study whether small game developed differently in areas that showed high organic farming growth than in areas with low organic farming growth or decline.

I applied separate workflows to collect and to prepare data. One was focused on historic hunting yield data and involved adjustments to 1) increased comparability between hunting estates reflecting differences in habitat structures and 2) establish comparability with agricultural data which uses different geographic boundaries. ArcGIS was used for those adjustments. The other work flow dealt with agricultural data. Both datasets were then joined in a common field to allow for the regression analyses. All maps throughout this section were created using ArcGIS® software by Esri.

Hunting Data Preparation

Hunting data, including hunting yield per hunting estate for the years 2005 through 2016, were retrieved in Excel format from Niederösterreichischer Landesjagdverband (http://www.noeljv.at), which translates to Lower Austrian Hunting Association. This is a public body and interest group for hunters. Membership is mandatory for every person in possession of a hunting license and game estate managers are obliged to report hunting yields (Noeljv, n.d.). Geographic data on hunting estates was retrieved from UNIDATA Geodesign GmbH in the form of a polygon-based shapefile.

Fenced hunting estates have been deleted from the dataset because game abundance is artificially distorted. Basic plausibility checks revealed data entries that required double checks by Noeljv. Variance calculations using Pivot Tables hinted at a small number of possibly incorrect hunting yield entries that were manually adjusted. Data also showed some irregularities in terms of estate sizes that had to be adjusted. I used ArcGIS to calculate surface area (in hectare) of each estate contained in the shapefile, copied the numbers to the Excel workbook, associated with the estate hunting data.

Aligning Hunting Estates with Municipalities

Since agricultural data is on a municipality level, the estate-based hunting yield had to be projected to the same level, which required several steps. First, I used ArcGIS to identify to which municipality each hunting estate belongs. Community-owned estates are largely found within one municipality but proprietary hunting estates frequently span across two or more municipalities. For those estates it was necessary to quantify the share of each estate that falls within each municipality.

I downloaded a map of the study area provided by Lower Austria's state department of Hydrology and Geoinformation. The map is a polygon-based shapefile containing geographic information on municipality boundaries derived from the Austrian Federal Office of Metrology and Surveying (BEV). In ArcGIS, I projected the map using the coordinate system Continental Europe Albers Equal. I computed the geometric intersection between this map and the hunting estate map using Esri's Intersect feature. Finally, I used the Dissolve feature to aggregate all the intersections between a hunting estate and its municipalities. The output field contained the surface area of each hunting estate per municipality. The data was then converted to Excel. This step was only possible for hunting estates that were in existence before the hunting estate map existed. The hunting data Excel file, however, also contains hunting yields of estates that had since ceased to exist. Since I could not assign a municipality to those estates, I deleted their data entries.

The hunting estate and municipality maps were not perfectly identical. Almost all hunting estates, including the estates truly being located within one municipality only, overlap to a small degree when the two maps are overlaid. To adjust for this distortion and to make the processing of the large dataset easier and more practical, I rounded the numbers using the following approach: if more than 95 percent of the hunting estate fell within a municipality, I assumed 100 percent was in this municipality. Conversely, if equal or less than five percent of the hunting estate falls within a municipality, it is assumed that zero percent is in this municipality.

I used the share of hunting estate falling within each municipality to adjust the hunting yields and to weigh them in accordance with their location: *HUNTING YIELD PER ESTATE IN MUNICIPALITY = HUNTING YIELD PER ESTATE * SHARE OF HUNTING ESTATE FOUND IN MUNICIPALITY*. I used Pivot tables to aggregate hunting yield per estate in municipality to compute total hunting yield per municipality.

The Pivot table also highlighted years with missing data entries. If a game species was not successfully hunted in a certain year, it was not reported. I, therefore, assigned 0 values to missing data entries since every field needed a value for further computations.

Adjustments for Habitat Differences

Habitat composition differs among hunting estates, as do game densities and hunting yields. The European brown hare, grey partridge and common pheasant need access to open land, especially arable land (Tapper & Parsons, 1983; Robertson, et. al., 1993; Sotherton, 1998; Smith, et al., 2005). The prevalence of open land changes, however, across Lower Austria. The same is true for urban areas. Human settlements are supposedly negatively correlated with small game abundance. In addition, hunting is banned in and in close proximity to residential areas and public places (NÖ Jagdgesetz, 1974). As such, I adjusted hunting yields for both forest coverage and urban areas. I acknowledge that other habitat factors, such as the size of agricultural fields, crop diversity and the prevalence of edge and marginal areas like hedgerows, also influence small game density, yet it was technically not possible to take all the factors into account.

I downloaded a publically available map showing forest coverage across study areas published by the state of Lower Austria. The map is a polygon-based shapefile. I changed the symbology of the map to 1 = forest, 0 = no forest and projected the map using the coordinate system ETRS1989 Austria Lambert. Again, I used the Intersect and the Dissolve feature of ArcGIS to compute the area of forest coverage per municipality (Figure 5). The output data was converted to Excel and added to the hunting yield data.

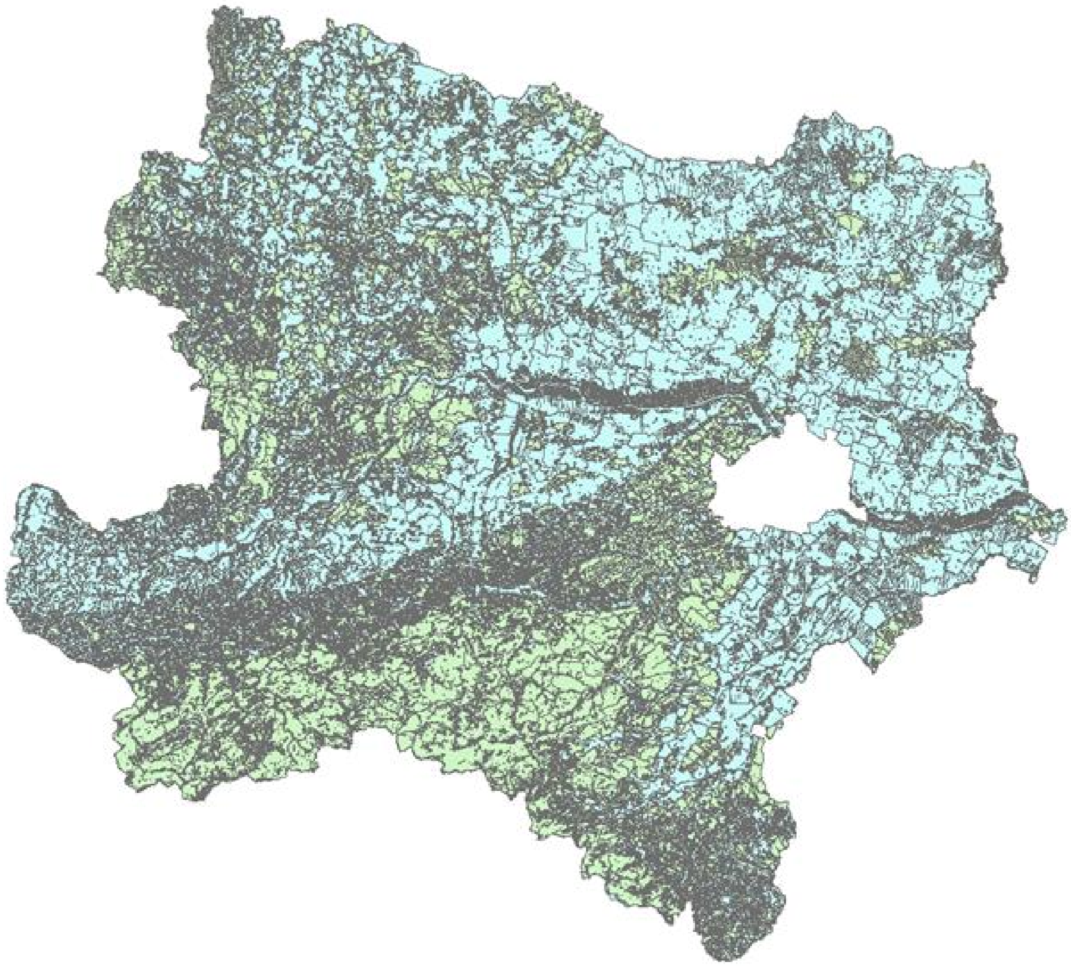

Figure 5. Forest distribution in Lower Austria. Green is forest coverage; turquoise is no forest coverage; open is metropolitan area of Vienna. Data Source: Amt der NÖ Landesregierung, 2017.

In order to adjust hunting yield for urban areas, I downloaded the European Nightlight image from NOAA/NCEI's Earth Observation Group's Visible Infrared Imaging Radiometer Suite. This is an image based on raster data (Figure 6).

Figure 6. Nightlight image of Europe (NCEI, 2017).

I used the Clip feature of ArcGIS to zoom into the study area. I then used the Reclassify feature to distinguish between urban and non-urban areas. This was necessary because most places are illuminated to a certain degree even in the absence of human settlements. The closer a location is to light-emitting sources, the more it reflects their light. I used a trial and error method to find a threshold which produces meaningful results. The lower the threshold, the more areas are classified as human settlement areas (Figure 7). If the threshold is set too low, entire hunting estates close to towns and cities are classified as human settlement areas. If the threshold is too high, settlement areas on up to small towns cannot be detected. From a scale of 0 to 241, I opted for a 10.0 threshold, meaning that illumination values ranging from 0 to 10 are classified as nature (ie. no human settlements) and from 10.00001 to 241 as human settlement area (Figure 7, right). Using this threshold, small villages could still not be detected but big villages and small towns tended to be identified.

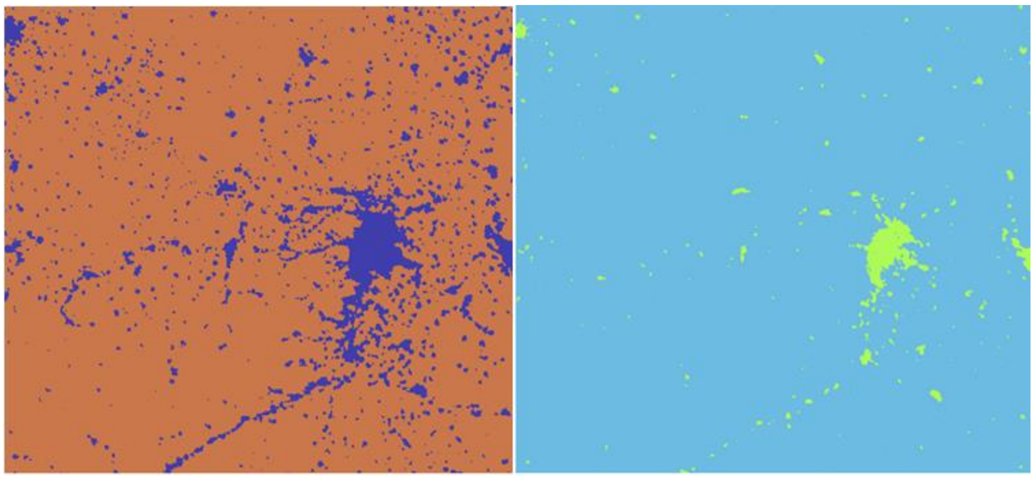

Figure 7: Nightlight map of Lower Austria and Vienna. Left (Illumination threshold 2.0). Right (Illumination threshold 10.0). Data Source: NCEI, 2017.

The raster-based image was converted to a map based on polygons and projected using the coordinate system ETRS1989 Austria Lambert. I used the Intersect and the Dissolve feature of ArcGIS jointly with the municipality map to compute the area of human settlements per municipality. The output data was converted to Excel and added to the hunting yield data.

I used both the nightlight and the forest coverage figures to compute hunting yield densities that were adjusted for habitat differences applying the following formula: ADJUSTED HUNTING YIELD DENSITY = *HUNTING YIELD IN MUNICIPALITY : (MUNICIPALITY AREA – FOREST COVERAGE AREA – ILLUMINATED AREA).* I used this formula for each small game species, for each year between 2007 and 2016, and for municipalities across Lower Austria.

Agriculture Data Preparation

Agriculture data, including total and organic farming development across Lower Austria for the period 2007 and 2016, were retrieved in Excel format from Agrarmarkt Austria (AMA), which is the Austrian paying agency for agriculture and rural development.

I merged all years into one sheet and calculated conventional farming area as: CONVENTIONAL FARMING = TOTAL FARMING – ORGANIC FARMING. Then I used the municipality map of Lower Austria and computed with the help of ArcGIS the area of each municipality. I converted the figures to Excel format and added them to the farming data. I conducted plausibility checks and compared the organic farming area with the total farming area and total farming area with total municipality area. Irregularities were found when organic farming exceeded total farming and total farming exceeded the total municipality area in some municipalities. Double checks with AMA improved the dataset but it turned out that some distortions are inevitable for the years 2015 through 2017. This is because the reporting procedure was changed in 2015. While each agricultural field was tagged to the correct municipality until 2014, the fields were tagged to the farmer's main residence starting in 2015. Although the vast majority of agricultural fields are believed to coincide with the farmer's main residence, some areas certainly cross municipalities (H. Bauer, personal communication, September 27, 2017).

I computed organic farming density by applying the following formula: ORGANIC FARMING DENSITY = ORGANIC FARMING AREA / TOTAL MUNICIPALITY AREA. This calculation was carried out for all municipalities between 2007 and 2016. I used the total municipality area instead of the total farming area to calculate density. The latter has steadily decreased over the study period due to public works and other constructions (Österreichische Hagelversicherung, 2013). If the total farming area was used instead, an unchanged amount of organic farming would be shown as an increase in organic farming density, thereby potentially overstating organic farming development and ignoring the loss of general game habitat.

Statistical Analyses

Linear regressions and t-tests were undertaken in R using the dplyr package (R Core Team, 2017; Wickham, Francois, Henry & Müller, 2017).

Simple Linear Regressions

I converted the Excel sheets containing the independent variable organic farming density and dependent variables small game hunting densities into csv files. I loaded them into R where the analyses took place. I carried out simple linear regressions and analyzed diagnostic plots to see whether the data is suitable for this kind of analyses. First results showed a significant if weak correlation between organic farming and brown hare and common pheasant hunting density throughout most of the years while organic farming and grey partridge density did not (Table 1).

Table 1. Correlation of untransformed variables of organic farming and hunting yield.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Brown Hare	0.017**	0.014**	0.035***	0.034***	0.014**	0.013**	0.013**	0.005	0.013**	0.013**
Common Pheasant	0.007*	0.010*	0.012**	0.021***	0.007	0.0200***	0.006	0.004	0.012**	0.007*
Grey Partridge	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.006

Multiple R-squared values for simple linear regressions between untransformed organic farming density and hunting yield density for the different small game species. Stars correspond to the following significance levels: * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

Diagnostic tests, however, resulted in strongly curved normal Q-Q graphs, indicating that residuals were not normally distributed and the assumption of a linear model not met. Consequently, I tested different transformations to find the most suitable ones for the variables. Using log10 transformations made the variables more normally distributed but a combination of arcsin transformation for organic farming density, which is a proportion, and log10 transformation for hunting yield density, which is a ratio, yielded the best results (Figure 8).

Hunting density values of 0 (no small game hunted) are an obstacle to a meaningful analysis. Game densities below a certain threshold make best effort hunting unfeasible from a practical point of view. This is especially true for game densities close to 0. If hunting is not undertaken, however, there is no chance of detecting a possible impact from organic farming. As a result, I excluded all municipalities where no small game was hunted in each respective year.

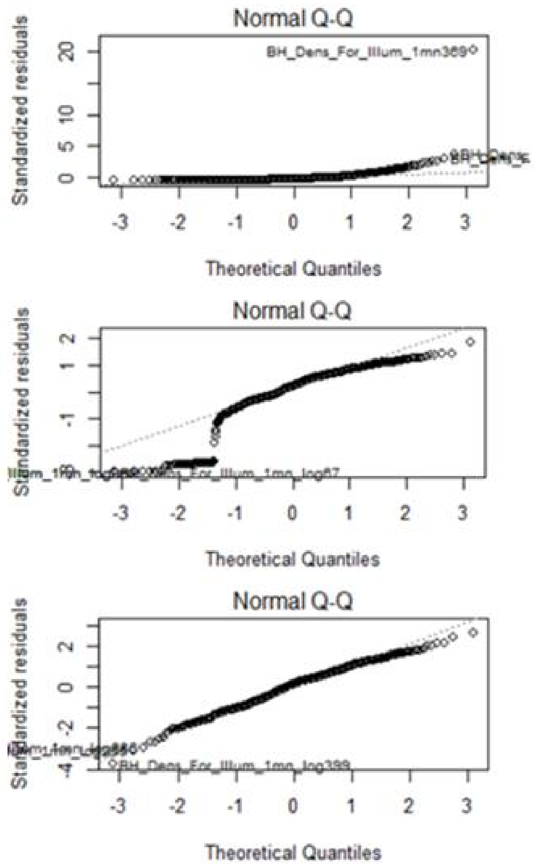

Figure 8. Distribution of variables using different transformations. Top graph shows distribution of untransformed variables. The middle graph illustrates log10 transformed variables. The bottom graph shows the independent variable arcsin transformed and the dependent variable log10 transformed.

T-Tests

T-tests were used to compare the sample mean of small game hunting density development in municipalities characterized by high growth in organic farming with the mean of the same in low growth and declining organic farming municipalities. I first calculated the difference in organic farming areas between 2007 and 2016 for each municipality. I then used Pivot Tables to group together municipalities that showed the strongest growth figures during the study period. The same calculation was done for municipalities that showed the least amount of growth or even a decline in organic farming. Finally, I calculated the change in hunting yield density for each municipality of both groups (high organic farming growth municipalities and low organic farming growth municipalities) and for each species. The results were converted to csv files and imported to R.

Diagnostic tests were used to determine if assumptions for a t-test were met and which kind of t-test was most suitable for the underlying data. Results for the untransformed data showed a fairly horizontal Q-Q plot indicating a non-normal distribution of residuals. Using the change to log10 transformed hunting yield density between 2007 and 2016 as a variable rather than an untransformed change in hunting yield density improved the distribution (Figure 9).

In order to confirm that the data transformations were indeed successful and that assumptions for applying a t-test were satisfied, I further analyzed the data using the Shapiro-Wilk normality test. This test is based on the hypothesis that the data in question is normally distributed. In order to decide which type of t-test would be appropriate, I carried out an f-test with the aim to find out whether both populations (small game development in high and small game development in low organic growth municipalities) have an equal variance. While student's t-test assumes equal variance, the Welch's t-test was designed to analyze means of populations exhibiting different variances. The f-test yielded p-values below the significance threshold of 0.05 for the common pheasant and the brown hare, rejecting the hypothesis that their variances are equal and proposing the

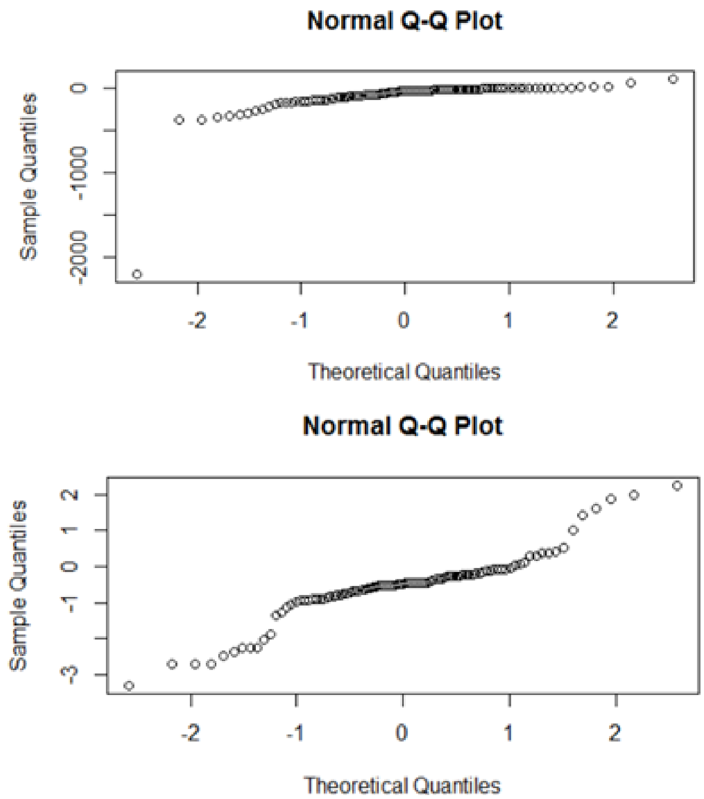

Figure 9. Distribution of variables using different transformations. The top graph shows the distribution of change in common pheasant yield density in high organic growth municipalities between 2007 – 2016. The bottom graph illustrates distribution of change in log10 transformed common pheasant yield density in high organic growth municipalities between 2007 – 2016.

Welch's t-test for the final analyses. Grey partridge developments in high and low growth organic farming municipalities seem to have equal variances, however (Table 2).

Table 2. Changes in log10 transformed small game development between 2007 and 2016 in high organic farming growth municipalities with low organic farming growth municipalities.

	F	den. DF	P-value	Confidence Intervals		Ratio of variance
Common Pheasant	0.586	110	0.007	0.399	0.865	0.586
Brown Hare	0.669	140	0.018	0.480	0.933	0.669
Grey Partridge	0.833	76	0.420*	0.533	1.300	0.833

* correspond to significance levels > 0.05.

Chapter III

Results

Small game hunting is widespread in the state of Lower Austria. An exception to this is in the alpine regions to the south. Hunting yield densities (median value for 12 years of 2005-2016, inclusive) vary considerably while highest yields are generated in the north, northeastern regions bordering Czech Republic and Slovakia, and in the east bordering the state of Burgenland (Figure 10).

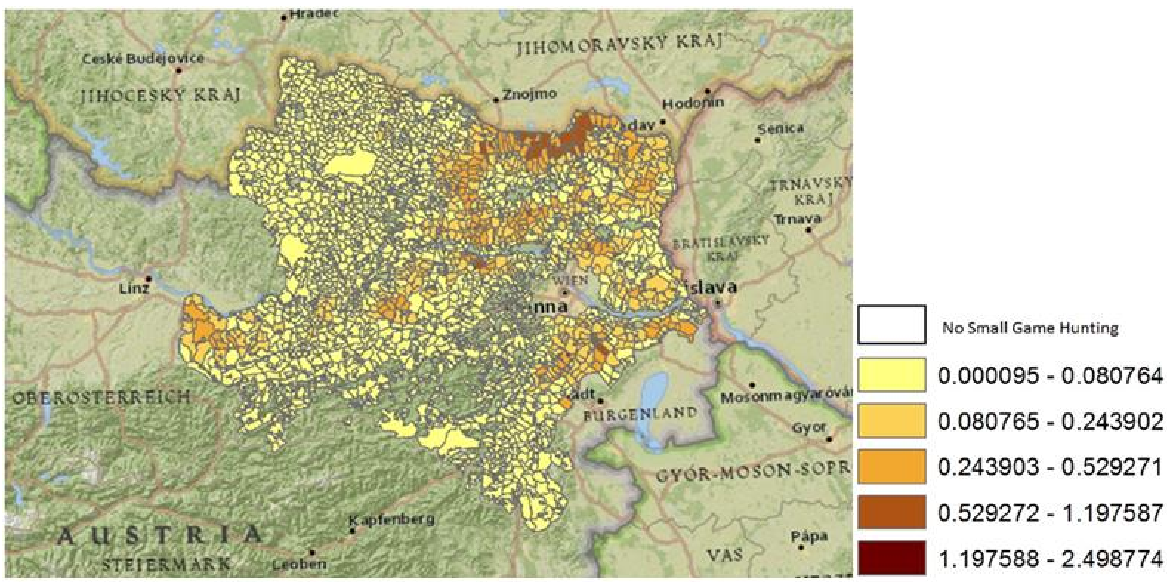

Figure 10. Median small game hunting density in Lower Austria between 2005 and 2016. Numbers represent the median of aggregated annual brown hare, common pheasant and grey partridge kills per hectare in each municipality. Data Source: Noeljv, 2017.

Hunting of Small Game Species in Lower Austria

The European brown hare is the most commonly hunted small game species in Lower Austria followed by the common pheasant (Figure 11). Hunting yields of the brown hare also exceed yields of the common pheasant in the majority of estates. Nonetheless, the common pheasant shows the highest maximum hunting density among the three species. Up to a median of 2.34 pheasants per hectare were killed per season during this 2005-2016 period (Figure 11). Yields exceeding 1 pheasant per hectare are almost exclusively generated in proprietary hunting estates and not in community-run estates.

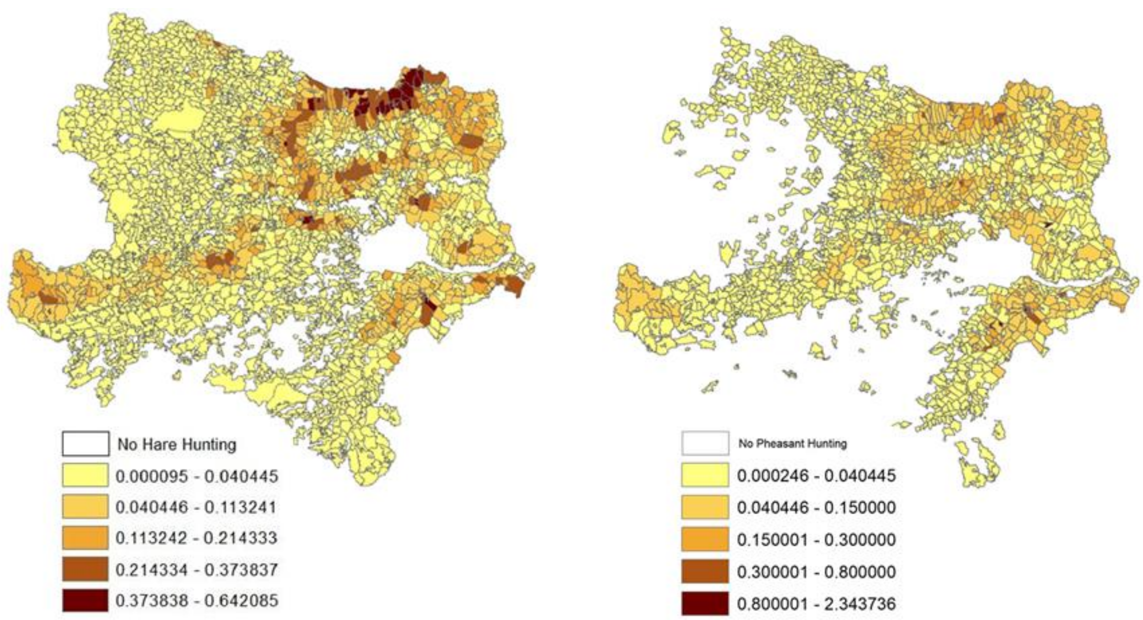

Figure 11. Median brown hare hunting density (left) and common pheasant hunting density (right) in Lower Austria between 2005 and 2016. Data Source: Noeljv, 2017.

Hunting of the grey partridge is least widespread and hunting yield densities are the lowest among the three small game species (Figure 12).

In addition to spatial differences, temporal differences in hunting yields are visible (Figure 13). Hare and pheasant yields have decreased since 2005 but a considerable yield spike took place in 2007. Hare and pheasant kills showed similar patterns indicating common underlying impact factors (Figure 13).

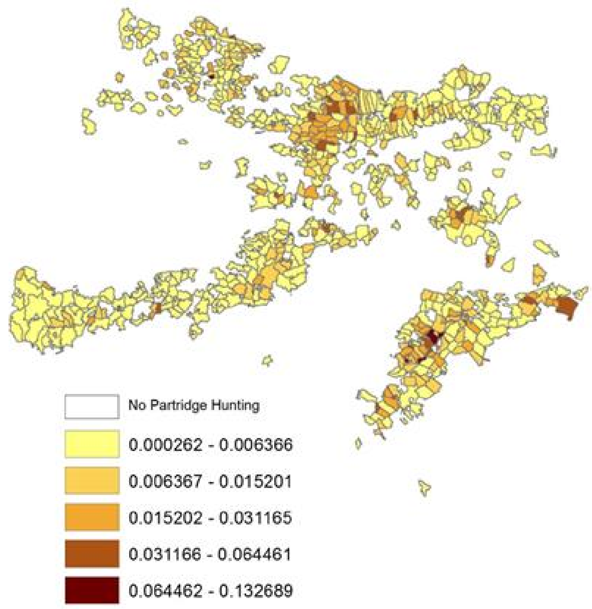

Figure 12. Median grey partridge hunting density in Lower Austria between 2005 and 2016. Data Source: Noeljv, 2017.

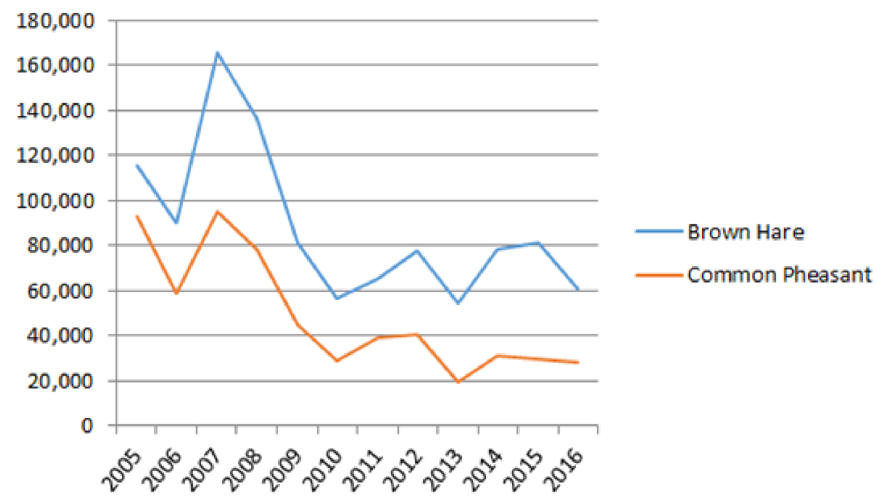

Figure 13. Brown hare and common pheasant hunting yields in Lower Austria. Y-axis (absolute number of kills); X-axis (study period). Data Source: Noeljv, 2017.

Grey partridge hunting yields dropped the most among the three small game species. While almost 7,000 individuals were killed in 2005, only 960 were killed in 2016 (Figure 14).

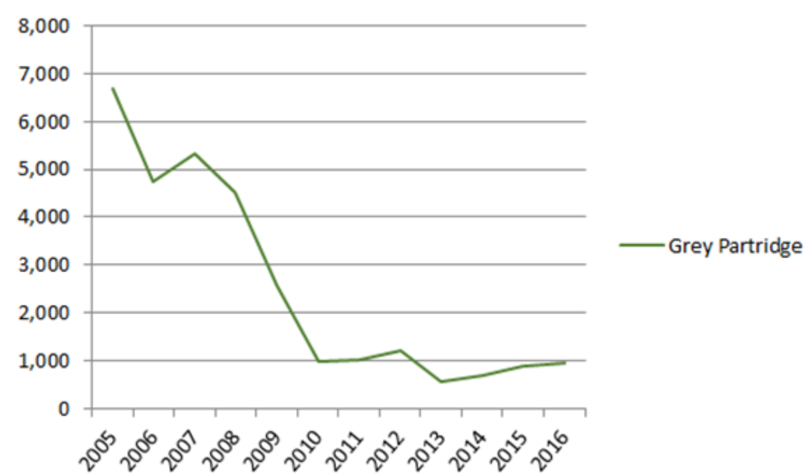

Figure 14. Grey partridge hunting yields in Lower Austria. Y-axis is absolute number of kills. Data Source: Noeljv, 2017.

Organic Agriculture Density across Lower Austria

Agriculture density varied across the study area, too. Especially in municipalities located north/north east of Lower Austria, agricultural fields represented up to 92 percent of the municipalities' total areas (Figure 15). By comparing Figure 15 to Figures 10 and 11, one can see that small game hunting density tended to be highest in areas which are characterized by high farming density.

Organic farming as a share of total farming tended to be highest in municipalities which show low total farming densities. This is especially true for the mountainous south/southwest region of Lower Austria (Figure 16).

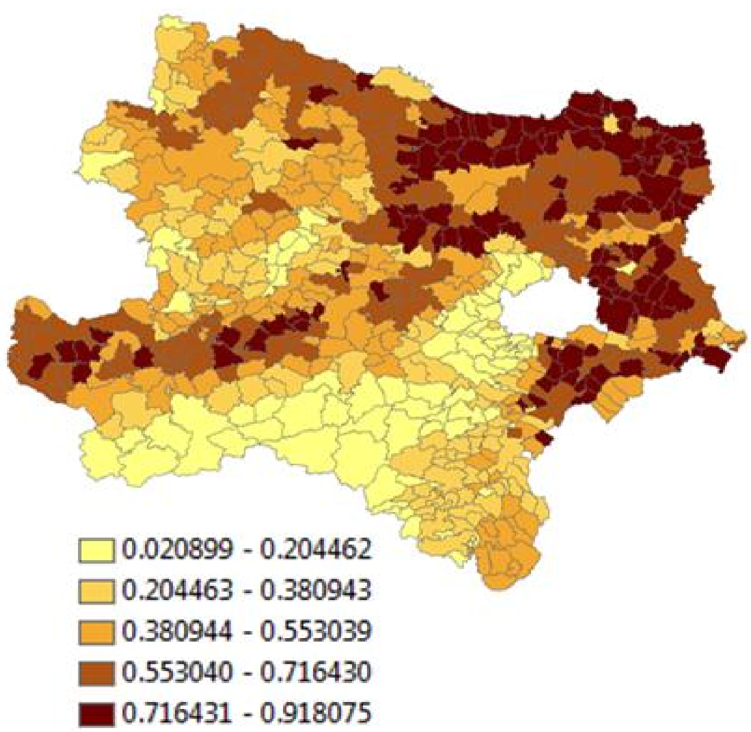

Figure 15. Median farming density. (Calculated as Median Farming Area 2007 – 2016 per Municipality / Municipality Area). Data Source: AMA, 2017; Amt der NÖ Landesregierung, 2017.

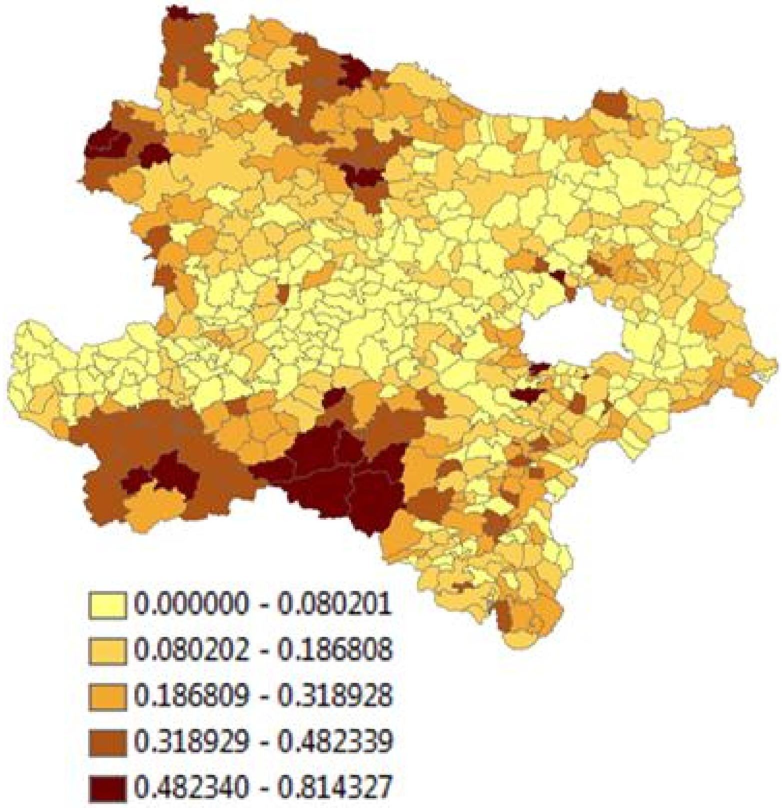

Figure 16. Median organic farming density. (Calculated as Median Organic Farming Area 2007 – 2016 per Municipality / Median Total Farming Area 2007 – 2016 per Municipality). Data Source: AMA, 2017; Amt der NÖ Landesregierung, 2017.

The area dedicated to organic farming in Lower Austria increased by 45.7 percent between 2007 and 2016, equal to a compounded annual growth rate (CAGR) of 3.8 percent. The expansion of organic farming was highly diverse across municipalities, however. While some municipalities showed CAGR of > 50 percent, in others organic farming ceased to exist (Figure 17).

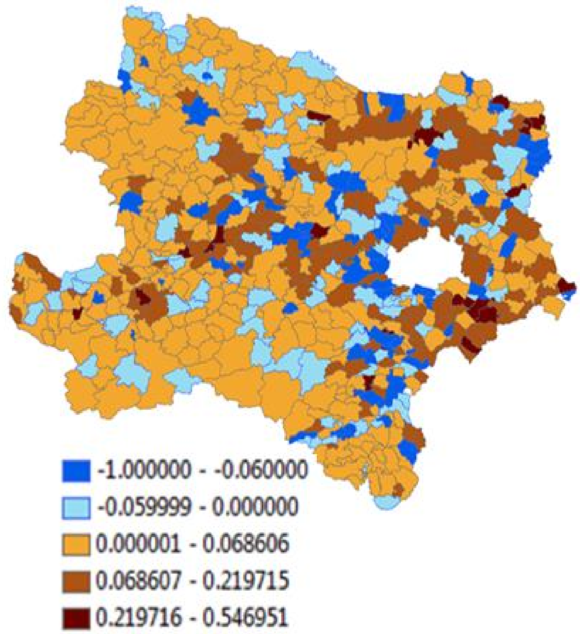

Figure 17. Organic farming increase 2007 – 2016 as compounded annual growth rate per municipality. Data Source: AMA, 2017; Amt der NÖ Landesregierung, 2017.

Interspecific Correlations in Hunting Density

As expected, hunting densities for brown hare, common pheasant and grey partridge were all positively and significantly correlated with each other, showing varying degrees of strengths between them and across years (Table 3). Hare and pheasant showed the strongest correlations followed by pheasant and partridge hunting densities (Table 3).

Table 3. Interspecific correlation of transformed variables

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Hare ~ Pheasant	0.624***	0.625***	0.554***	0.400***	0.481***	0.531***	0.409***	0.545***	0.575***	0.497***
Pheasant ~ Partridge	0.219***	0.200***	0.164***	0.175***	0.128***	0.226***	0.140***	0.173***	0.183***	0.085**
Hare ~ Partridge	0.138***	0.181***	0.099***	0.072**	0.052*	0.080**	0.097**	0.114***	0.072**	0.054*

Adj. R-squared values for simple linear regressions between log10 transformed small game hunting yields per km². Stars correspond to the following significance levels: * = p < 0.05; ** = p < 0.01; *** = p < 0.001.

In 2016, the adj. R^2 was around 0.5 for brown hare and common pheasant, 0.2 for common pheasant and grey partridge and 0.05 for brown hare and grey partridge. Since municipalities are excluded that did not exhibit hunting of the respective small game species, sample size varied considerably. While hunting of brown hare and common pheasant took place in 361 municipalities in 2016, only 90 municipalities exhibited common pheasant and grey partridge yields (Table 4).

Table 4. Linear regression results of interspecific correlations.

Pheasant ~ Partridge 2016	Estimate	Std. Error	t value	Pr(>|t|)
pheasant	0.63183	0.0894	7.067	3.56E-10
partridge	0.29734	0.09744	3.051	3.01E-03
Observations	Residual Std. Error	Mult. R^2	Adj. R^2	
90	0.5798	0.09569	0.08541	

Hare ~ Pheasant 2016	Estimate	Std. Error	t value	Pr(>|t|)
hare	0.469	0.02116	22.16	<2e-16
partridge	0.5352	0.02837	18.87	<2e-16
Observations	Residual Std. Error	Mult. R^2	Adj. R^2	
361	0.3905	0.4979	0.4965	

Hare ~ Partridge 2016	Estimate	Std. Error	t value	Pr(>|t|)
hare	0.92331	0.07487	12.332	<2e-16
partridge	0.20124	0.08109	2.481	0.0149
Observations	Residual Std. Error	Mult. R^2	Adj. R^2	
92	0.4857	0.06404	0.05364	

Variables are log10 transformations of hunting yield per km^2.

Diagnostic tests of the regression results suggest that the linear model is appropriate (Figure 18). The residuals vs. fitted graphs of the three species across all years illustrate a fairly straight, horizontal red line indicating an even spread of residuals and a linear relationship. The Normal Q-Q plots show that the log10 transformed variables closely follow a normal distribution which is depicted by the 45° degree line.

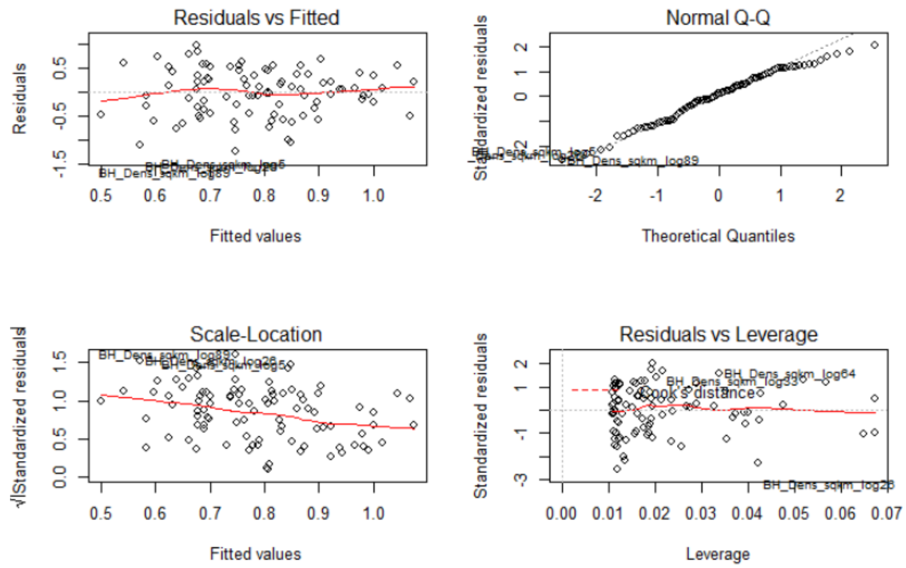

Figure 18. Diagnostic residual plots for simple linear regression between log10 transformed brown hare and grey partridge hunting yield per km² in 2016.

Correlations between Organic Farming and Small Game Hunting

Brown hare hunting density is positively and significantly associated with organic farming density throughout the study period (Table 5). Common pheasant yields correlated in eight out of ten years with organic farming while grey partridge yields correlated only once (Table 5).

Table 5. Organic farming and hunting yield correlations of transformed variables.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Organic Farming ~ Common Pheasant	0.057***	0.041***	0.044***	0.024**	0.029***	0.019**	0.001	0.002	0.008*	0.012*
Organic Farming ~ Brown Hare	0.107***	0.113***	0.081***	0.059***	0.079***	0.048***	0.057***	0.049***	0.049***	0.035***
Organic Farming ~ Grey Partridge	0.011	0.002	0.035**	-0.004	-0.008	-0.003	-0.011	-0.011	-0.005	0.001

Adj. R-squared values for simple linear regressions between arcsin transformed organic farming densities and log10 transformed small game hunting densities per km². Stars correspond to the following significance levels: * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

Adjusted R^2 values decreased between 2007 and 2016. The strongest association between organic farming and small game species is for brown hares (adj. R^2 between

0.11 – 0.04) followed by common pheasant (adj. R^2 between 0.06 – 0.01). Grey partridge hunting yields show both positive and negative but mostly insignificant correlations with organic farming. Please note, however, the substantially lower number of observations for this species. Again, diagnostic tests suggest that the assumptions for regressions were met for log-transformed hunting yield vs. arcsin transformed organic farming density (Figures 19-21).

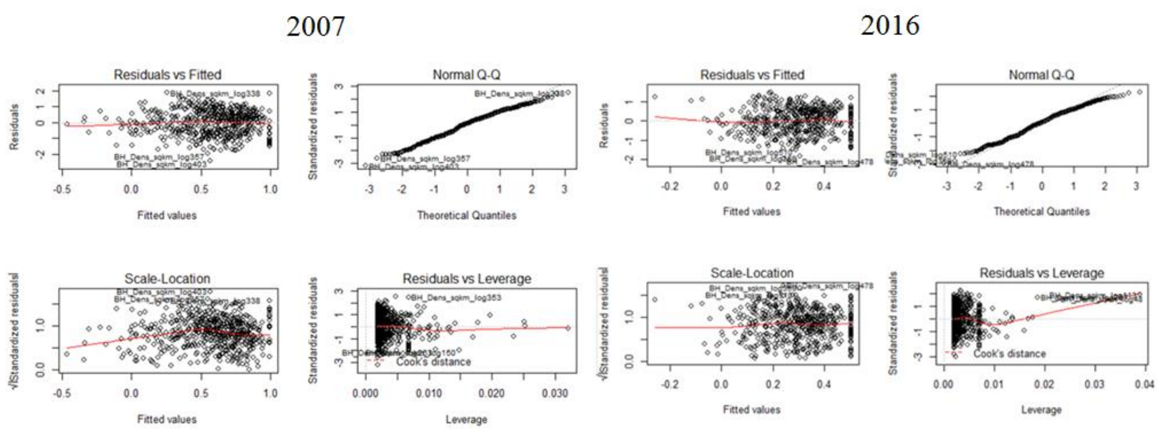

Figure 19. Diagnostic residual plots for simple linear regression of acrsin transformed organic farming density and log10 transformed brown hare hunting yield per km².

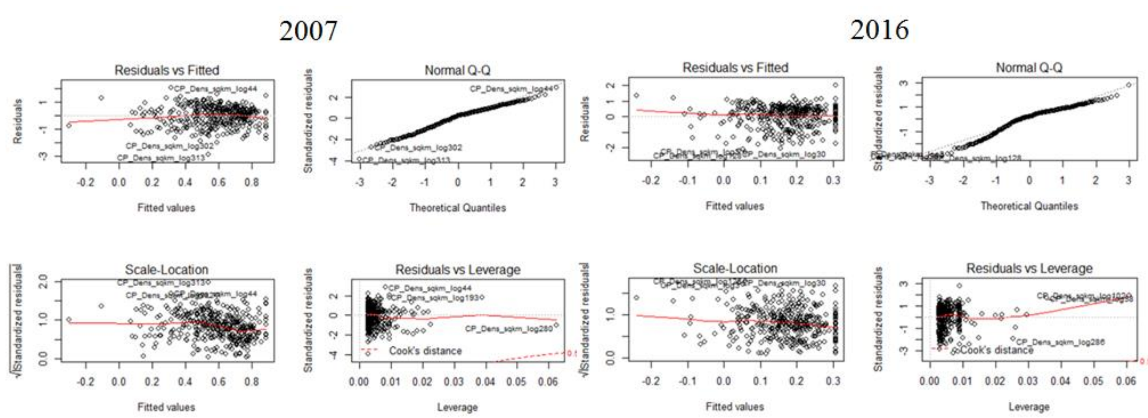

Figure 20. Diagnostic residual plots for simple linear regression of arcsin transformed organic farming density and log10 transformed common pheasant hunting yield per km².

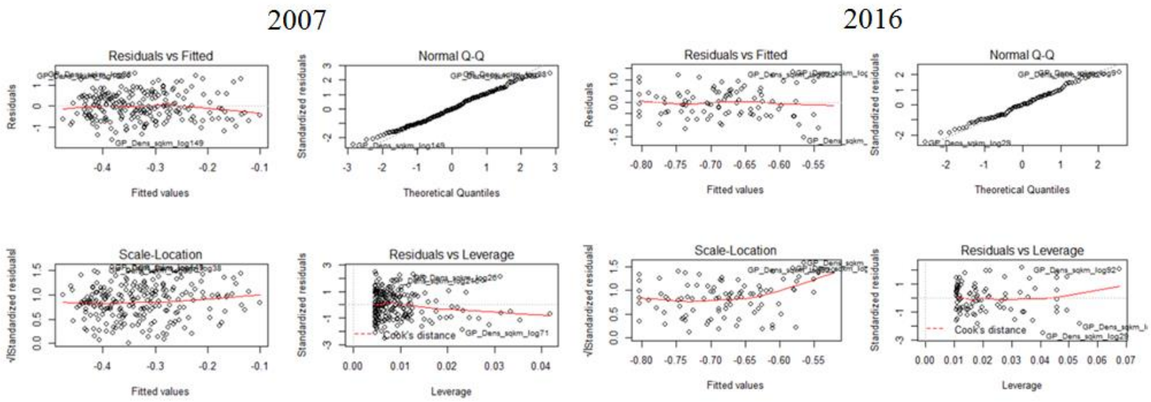

Figure 21. Diagnostic residual plots for simple linear regression of arcsin transformed organic farming density and log10 transformed grey partridge hunting yield per km².

Means Comparison of High and Low Organic Farming Growth Municipalities

Results of the Welch's t-test suggested that common pheasant and brown hare hunting yields developed differently in municipalities exhibiting the strongest growth in organic farming compared to municipalities characterized by the weakest growth and decline in organic farming (Table 6). P-values of > 0.05 for the grey partridge indicate, however, that means are not different for this small game species (Table 6). Again, sample size was smallest for grey partridge.

Table 6. Hunting yields in municipalities with strong vs. weak increases in organic agriculture.

	T	DF	P-value	Confidence Intervals		Mean of x	Mean of y
Common Pheasant	2.473	203.46	0.014*	0.075	0.662	-0.536	-0.904
Brown Hare	2.317	269.42	0.021*	0.050	0.613	-0.296	-0.627
Grey Partridge	-0.657	153.37	0.512	-0.621	0.311	-1.755	-1.600

Welch's t-test results comparing the variance of changes in log10 transformed small game development between 2007 and 2016 in high organic farming growth municipalities with low organic farming growth municipalities. * correspond to significance levels < 0.05.

Diagnostic tests show that the residuals along the regression line only loosely follow a linear model (Figure 22).

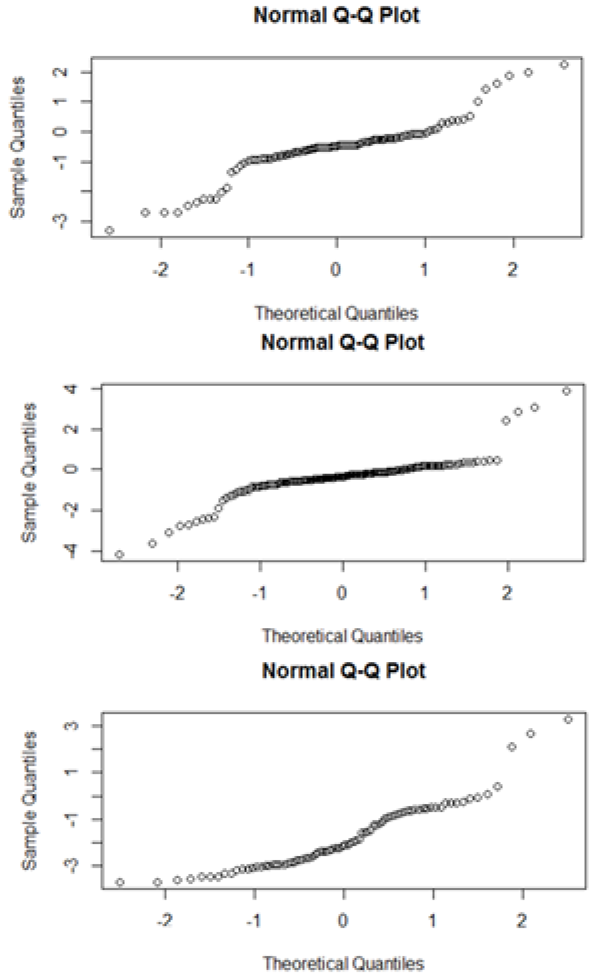

Figure 22. Normal Q-Q plots for Welch's t-test of change in log10 transformed hunting yield density between 2006 and 2017. Top graph (common pheasant). Middle graph (brown hare). Bottom graph (grey partridge).

Further, the Shapiro-Wilk normally test produced p-values consistently below the significance threshold of 0.05, meaning that the hypothesis of normal distribution was rejected (Table 7). Therefore, this comparison should be interpreted cautiously.

Table 7. Results of the Shapiro-Wilk normality test

	Bottom OF		**Top OF**	
	W	p-value	W	p-value
Common Pheasant	0.858	6.2E-09	0.898	1.3E-06
Brown Hare	0.844	6.4E-11	0.814	4.2E-12
Grey Partridge	0.879	2.7E-06	0.907	2.0E-05

Shapiro-Wilk normality test results of changes in log10 transformed small game development between 2007 – 2016 in both municipality groups (Bottom OF = municipalities experiencing lowest growth in organic farming; Top OF = municipalities experiencing strongest growth in organic farming).

Chapter IV

Discussion

GIS and simple linear regression proved to be suitable tools to test my hypotheses, which were largely confirmed, although correlations were weak. Some aspects of the hypotheses were disproved. Results from t-tests seem to confirm those findings but a failure to meet all t-test model assumptions warrants caution in interpretation. The results, both confirmatory and non-confirmatory, convey interesting patterns and invite a lively discussion and further studies.

Spatial Variation in Small Game Hunting and Organic Farming

With the help of GIS, I intended to answer the research question of how widespread small game hunting is in the study area. I hypothesized that it is widespread across lower Austria which was confirmed by maps drawn in ArcGIS (Figure 10, 11, 12). Small game has been hunted in the vast majority of municipalities; however, yields vary significantly from region to region. Mountainous regions in the south to southwest that are part of the Alps show the lowest densities followed by regions characterized by large forest coverage that are particularly common in the north, northwest of the state. Areas showing a low level of elevation, low forest coverage, and an abundance of open land are found especially in the north, northeast, and eastern parts of Lower Austria. In those areas, hunting yields have been highest over the last ten years. This confirms findings of studies carried out in other regions that small game species thrive in such habitats.

All three species show a large overlap in distribution. The European brown hare is the most, and grey partridge the least, widely distributed species among this peer group. More than 90 percent of municipalities in Lower Austria show brown hare hunting. Hunting estates in 2/3 of municipalities reported common pheasant kills while only 1/5 did so for grey partridge. All three species have in common the fact that the number of municipalities where hunting takes place has decreased but at different rates. While in 93.5 percent of municipalities brown hare hunting took place in 2007, in 2016 it was down to 90 percent. The reduction is similar to the one observed for common pheasants (68 to 64 percent). The distribution of grey partridge hunting dropped however by more than 60 percent from 38 percent to 16 percent of municipalities.

While brown hare hunting generated higher yields than common pheasant and grey partridge hunting in most estates, common pheasant hunts exhibited the highest maximum yields of up to 2.34 pheasants per hectare; however, such high hunting yields seems to be a result of artificial restocking. While less frequently undertaken in community-run hunting estates where the majority of land owners would need to consent to such practice (NÖ Jagdgesetz, 1974), restocking is decided solely by the owners of proprietary hunting estates and benefits, often financial, may provide incentives in doing so. This assumption is supported by the underlying data where proprietary hunting estates indeed exhibit the highest pheasant densities while few community-run estates kill more than 1.0 pheasants per hectare.

The trajectory of hunting distribution over the period 2005-2016 is in line with the decrease in hunting yield for all three species during the study period. Yet, grey partridge yields dropped by much more than its peers. In 2016, less than 1000 grey partridge kills were reported and the majority of hunting estates had median yields (2005 to 2016) of less than 0.006 grey partridges per hectare. The results suggest that small game hunting is widespread only for the European brown hare and the common pheasant but not for the grey partridge. The hypothesis that small game hunting is widespread in Lower Austria is only therefore partially confirmed.

GIS analysis confirmed the hypothesis that farming is widespread in the state of Lower Austria. Agriculture is similar to small game hunting, occurring where there is relatively little forest coverage, and most prominent in low elevation regions. The link between farming density and small game hunting yield becomes visible when Figure 15 is compared to Figures 10, 11, 12. This confirms findings from other studies that open arable land is the preferred habitat for many small game species (Tapper & Parsons, 1983; Green, 1984; Robertson et al., 1993; Sotherton, 1998; Smith et al., 2005).

GIS maps also confirmed that the area dedicated to organic farming has increased substantially in the majority of municipalities from 2007 to 2016 and that organic farming is widely distributed. Since small game hunting yields have decreased during the same period however, organic farming does not seem to be positively correlated by looking at GIS maps alone.

Interpretation of Statistical Analyses

The results of simple linear regression suggest that hunting yields for the European brown hare, common pheasant and grey partridge are all spatially associated with each other, confirming the stated hypothesis that their densities weakly covary. Interestingly, the link is strongest between the brown hare and common pheasant (Table

3). This was unexpected, since common pheasant and grey partridge are part of the same order and are thus supposed to share more ecological similarity (Haverschmidt, 2016).

A possible explanation is that the higher adj. R^2 values for hare and pheasant regressions may indirectly stem from the substantially wider distribution of those species and higher hunting densities. Only those municipalities have been considered where both species of the respective simple linear regression were hunted. Brown hare and common pheasant show a much wider distribution and were hunted in 361 municipalities whereas in 2016, only 90 municipalities were active in grey partridge hunting, leading to a much smaller sample size for regressions that include grey partridge as a variable. Although adj. R^2 should already account for the statistical impact of varying numbers of observations, a bigger sample size may help balance out uncertainties associated with the data (see section research limitation and caveats). In addition, very low hunting densities lead to irregular hunting efforts. The majority of municipalities exhibit grey partridge hunting densities < 0.006 per hectare, meaning that in many municipalities only a very small number of partridges were killed. In 2016, in 50 out of 90 municipalities where grey partridges were hunted, fewer than five individuals were killed. With such small hunting densities it is doubtful whether the same hunting efforts are undertaken as for the more abundant brown hare and common pheasant. The possibility that low grey partridge hunting yields and distribution are decisive impact factors is supported by the fact that the association between common pheasant and grey partridge is indeed stronger than between brown hare and grey partridge.

Results of the simple linear regressions between organic farming densities and small game hunting densities partially confirm the hypothesis that organic farming is increasing small game hunting yields. It was partial because a link was only identified for the European brown hare and the common pheasant, but not for the grey partridge. A possible explanation is again not necessarily the absence of an association but narrower hunting distribution and smaller hunting densities of the grey partridge. The brown hare exhibits the strongest among the three small game species but it is still weakly associated with organic farming. Why brown hares show higher adj. R^2 values is not clear. While it is a possible that hares indeed benefit more than the other species from organic farming, higher overall hunting densities and a wider hunting distribution may lead to higher adj. R^2 values, as well. Yet, the weaker association of the common pheasant with organic farming may also be a result of the artificial restocking endeavors that likely distort the data. Compared to pheasants, grey partridge breeding is more difficult because male individuals show a higher degree of territorial aggressiveness, and male and females need to be kept in pairs. Successfully breeding brown hare is seen to be even more difficult. Restocking of those two species is thus less economically feasible and less common (E. Klansek, personal communication, January 16, 2018).

Adj. R^2 values steadily decreased over the study period. One explanation is that organic farming has been changing. Also this form of farm management pursues efficiency and profitability that leads to bigger fields, less crop diversity and a decline of non-profitable semi-natural habitats such as hedgerows. Such trends may eat up benefits from the absence of synthetic herbicides, pesticides and fertilizers. Another possible explanation is the steady drop in game abundance and distribution, which weakens the predictive power of the linear regression analyses.

It must be stressed that R^2 values are generally low. These positive but weak associations suggest that factors other than the application of synthetic pesticides, herbicides and fertilizers are more decisive in promoting high densities of the study species. This conforms to previous studies that traced the drop in small game abundance primarily back to the above-mentioned deterioration of beneficial small game habitat (Zellweger-Fischer et al., 2011; Meeus, 1993).

T-tests confirm findings from the regression analyses and suggest that the median brown hare and common pheasant hunting densities differ between high organic farming growth municipalities, and low organic farming growth and decline municipalities. Yet, the underlying data of this analysis did not show a sufficient degree of normal distribution that would satisfy the assumption of a t-test. As such, precaution has to be taken in interpreting the significance levels < 0.05 because of the risk of facing a Type I error and falsely rejecting the hypothesis, as it may be true.

Conclusions

Analyses of spatial data confirmed that small game hunting is widespread across Lower Austria, especially of the European brown hare and the common pheasant. Agriculture is similarly widespread.

Statistical tests detected an association among the three small game species subject to this study. Correlations, albeit weak, were found between organic farming and European brown hare and common pheasant hunting yields suggesting that organic farming indeed positively contributes to small game abundance. The weak associations also indicate however that this factor is too small as a viable means for reversing the downward trend in small game populations.

Research Limitations and Caveats

There are several caveats and limitations to these results and conclusions. Results can only be as good as the data provided. There are a number of potential factors that may have negatively influenced data accuracy.

- Hunting estate managers submit hunting yields on an annual basis, yet, there is no formal, mandatory procedure informing the hunting estate managers on how best to collect the data. In addition, data is neither audited nor checked for inconsistencies, as such, there is no guarantee that all numbers mirror real hunting yields.
- There are differences in hunting estate management between hunting estates but also in the same hunting estate over time. While small game hunting principally occurs on a best effort basis, some estates may hunt more intensively than others or hunt more intensively in one year than another. The same is true for other management tools, such as the feeding of game and predator control.
- Common pheasant hunting is often subject to artificial restocking while usually brown hare hunting is not. Very high pheasant hunting density numbers (especially > 1 per hectare) make such a practice very likely but even from relatively low density numbers it cannot be inferred that modest restocking had not been undertaken.

- Hunting yield is not GPS tracked, meaning that it is not known where exactly small game was killed within a hunting estate. This is especially troublesome when it comes to proprietary hunting estates. Since proprietary hunting estates frequently cross municipality boarders, it was necessary to split these up and to assign hunting yields to different municipalities in accordance with the area of the hunting estate found in each municipality. Yet, small game hunting yield is usually not evenly generated across the estate but is rather concentrated. Without GPS data, however, an even distribution had to be assumed.
- Agricultural fields are not GPS tracked. Organic fields close to municipality borders may benefit small game eventually hunted in adjacent estates in neighboring municipalities.

It has to be noted that larger sample sizes may help mitigate the above-mentioned effects. This is assumed because the higher the number of observations, the more likely it is that such effects get balanced out. This might be the cause of the lower adj. R^2 numbers observed for regressions including the relatively less hunted common pheasant and grey partridge, and the high p values for regressions between grey partridge hunting and organic farming.

In addition to data accuracy I would like to highlight the following caveats:

- The co-efficient of determination between small game hunting density and organic farming density is low. The predictive ability of the results is thus low.

- The study was focused on the state of Lower Austria. Results should only be extrapolated to regions that are characterized by similar small game habitats and agriculture.

Further Research

A weakness of this study is the accuracy of the data stemming inter alia from the lack of geographic data. While it is unlikely that the exact location of small game kills will be known in the foreseeable future, geographic data on the location of organic farmland already exists. AMA recently changed the capturing system of agriculture information and coordinates were tagged to farmland. While this measure was not undertaken retrospectively, in a few years enough data should be available to rerun meaningful linear regressions between small game hunting density and the more accurate organic farming density numbers.

Once the exact locations of the fields are known, it might also make sense to take different crop types into consideration and run multiple linear regression analyses to find the most suitable combination of conventionally and organically managed crop types for small game hunting.

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