Preventing wild boar *Sus scrofa* damage – considerations for wild boar management in highly fragmented agroecosystems

Inauguraldissertation
zur
Erlangung der Würde eines Doktors der Philosophie
vorgelegt der
Philosophisch-Naturwissenschaftlichen Fakultät
der Universität Basel

von

Adrian Schlageter
aus Basel BS

Basel, 2015

Genehmigt von der Philosophisch-Naturwissenschaftlichen Fakultät

auf Antrag von

Prof. Dr. Marcel Tanner

Prof. Dr. Daniel Haag-Wackernagel

PD. Dr. Peter Odermatt

Basel, den 18.6.2013

Prof. Dr. Jörg Schibler, Dekan

Acknowledgements

Of the many people who contributed in one way or another to this project, I would especially like to thank the following:

This project was supported financially by the *Volkswirtschafts- und Sanitätsdirektion* of the Canton Basel-Land, the Federal Office for the Environment (FOEN), and the *Freiwillige Akademische Gesellschaft (FAG)*. Dr. Ignaz Bloch and Daniel Zopfi, head and deputy of the department *Veterinär-, Jagd- und Fischereiwesen* supported the project with their knowledge, data and time, and brought me into contact with game wardens, hunters, and farmers at our study sites. Also I would like to thank Gabriel Zimmermann, who provided assistance in the field. Christoph Zentner, Martin Küng, and Hans Wampfler game wardens of Sissach, Rothenfluh, and Hofstetten provided valuable information on the local conditions, activity ranges, and trails of the wild boars in the study area. I thank Peter Zimmermann and Manfred Bloch for detailed and interesting insights into hunting practice. Many thanks go to the numerous farmers and landowners who readily let me perform my experiments on their land. Fränzi Korner-Nievergelt calculated the statistical models for the papers. Pius Korner provided valuable additional input for analysis of the data.
Amongst many people who supported me at the Department Biomedicine, University of Basel, special thanks go to Andreas Ochsenbein, who gave technical support and valuable input for the field experiments, and provided a helping hand whenever it was needed. For helpful comments on early drafts of the manuscripts and this thesis I thank Ila Geigenfeind, Chris Müller, and Birte Stock.

Prof. Dr. Daniel Haag-Wackernagel, Department Biomedicine, University of Basel, conceived the initial idea for the project and provided supervision and support throughout the project, as well as invaluable help, ideas, advice and patience.

Finally, I would like to thank all my unmentioned friends and my family for company, encouragement, and shoulders. I thank my parents, for their support, for their patience and their love!

Thank you!

Summary

Schlageter A (2013). Preventing wild boar *Sus scrofa* damage – considerations for wild boar management in highly fragmented agroecosystems. Doctoral dissertation.

Context

During the last three decades wild boar populations have grown rapidly and the range of the species has increased steadily, covering almost the whole European continent today. The huge spread of the wild boar and the high population densities pose major problems, particularly to agriculture. Wild boars cause considerable damage to fields and grassland, but also pose a potentially high threat to livestock, as carrier of the pathogen of the classical swine fever, which may be transmitted to domestic pigs and can cause huge losses. To prevent economic problems by high wild boar populations, an effective wild boar management has to be established. Besides the regulation of the populations by means of hunting, vulnerable crop fields have to be protected adequately. Crop protection is usually achieved by the use of electric fences. Alternatively, various methods are available that claim effective deterrence of wild boars, however, most of which lacking scientific proof of effectiveness.

Objectives

This thesis, based on a field study conducted in the Canton Basel-Land, northwestern Switzerland, presents research results on the effectiveness of three different deterrent systems: solar-powered blinkers, an odour repellent, and a gustatory repellent. The aims of the study were: (1) to investigate three means to deter wild boars from agricultural land representative for other deterrents based on optic, olfactory, or gustatory effects; (2) to provide relevant and evidence-based data, which contribute to the policy and practice of wild boar management and damage prevention in the Canton Basel-Land, also applicable to other regions. I discussed the results in a broader context, also considering the role of hunting in damage prevention.

Results

Solar blinkers and the odour repellent, which were investigated at baited luring sites, reduced the probability of wild boar visits by 8.1% and by 0.4% respectively. Both deterrents were not effective in preventing wild boars from accessing the lure food. Additionally, we did not find any initial deterrence effect. The gustatory repellent, which was investigated in experimental fields, did not have a significant effect on the frequency of damage events. Although we observed a slight trend towards a damage reduction, the results show, that the repellent was

not able to prevent damage. We further could not detect any area avoidance by the wild boars as a response to the repellent.

Conclusions

The present study revealed, that none of the deterrents investigated was able to prevent wild boars from entering the experimental sites. Hence the deterrents in question are no effective means for field protection. Moreover, I suggest that any other deterrent basing on startling response, neophobia, fear-evocation, or conditioned avoidance would not be effective in preventing wild boars from entering agricultural land. To date, the only recommendable means for damage prevention is the electric fence, which should be taken into account by the responsible authorities. Based on the findings of the present study, farmers must be discouraged from the use of other deterrents than electric fences to protect their fields. Additionally, damage compensation should be subject to the condition of fencing of the fields.

Besides the protection of vulnerable crops the reduction of wild boar populations by means of hunting is crucial for damage prevention. Hunting rates have to be increased and hunting effort should focus on females of all age classes, but especially on juvenile females, which have shown to be highly reproductive and substantially contribute to population growth. For this purpose, selective hunting techniques like hide hunting and stalk hunting should be prioritised and promoted.

The highly reproductive wild boar possesses the ability to recover from population losses in a very short time. Hence, both effective hunting management and field protection will remain the most important tools for damage control. Further research is required to investigate and compare different wild boar management systems including also damage prevention under an economic perspective. Stakeholders like farmers, hunters, and authorities must be involved.

The omnivore wild boar is enabled to adapt to various environments. Wild boar populations are expected to increase further and to spread into areas not yet populated. In Switzerland, the spread into the central parts of the country will also be supported by additional wildlife crossings that are in construction or in process of planning which will pose a challenge for wildlife management in these regions.

Keywords: wild boar, *Sus scrofa*, damage prevention, crop protection, electric fence, optic deterrent, odour repellent, gustatory repellent, hunting, wildlife management

Zusammenfassung

Schlageter A (2013). Schadensverhütung beim Wildschwein *Sus scrofa* – Überlegungen zur Schwarzwildbewirtschaftung in stark fragmentierten Agroökosystemen. Doktorarbeit.

Ausgangslage

Die Wildschweinpopulationen sind in den vergangenen drei Jahrzehnten in Europa stark angewachsen. Heute kommt das Wildschwein in vielen Gebieten in beträchtlicher Anzahl vor und hat - mit Ausnahme der alpinen Regionen - eine nahezu flächendeckende Verbreitung. Die grosse Ausbreitung des Wildschweins und die hohen Populationsdichten stellen insbesondere die Landwirtschaft vor Probleme. Wildschweine verursachen erhebliche Schäden in landwirtschaftlichen Kulturen und Grünflächen und stellen als potentielle Krankheitsüberträger zudem eine Gefahr für Nutztierbestände dar. Frei lebende Wildschweine gelten als Reservoir für die Klassische Schweinepest, einer viralen Tierseuche, welche enormen wirtschaftlichen Schaden in Nutzschweinbeständen verursachen kann. Zur Vorbeugung dieser wirtschaftlichen Probleme bedarf es eines effektiven Managements der Wildschweinbestände. Nebst der Reduktion der Populationen durch jagdlichen Eingriff sind präventive Schutzmassnahmen für die Vermeidung von Feldschäden unerlässlich. Feldkulturen müssen angemessen geschützt werden, was üblicherweise mittels Elektrozäunen geschieht. Alternativ zu Elektrozaunsystemen sind derzeit diverse Abwehrmittel verfügbar, um Wildschweine von den Feldern fern zu halten. Zur Wirksamkeit der meisten dieser Methoden ist bislang wenig bekannt und es fehlen wissenschaftliche Untersuchungen.

Ziele

Die vorliegende Doktorarbeit basiert auf einer Feldstudie welche im Kanton Basel-Landschaft, Nordwestschweiz durchgeführt wurde und präsentiert Forschungsresultate zur Wirksamkeit von drei unterschiedlichen Abwehrsystemen: Solarblinker, geruchliche Abwehr und geschmackliche Vergrämung. Die Studie hatte zum Ziel: (1) drei repräsentative Abwehrmittel welche auf optischen, olfaktorischen und gustativen Effekten basieren stellvertretend für diverse weitere, auf dem Markt erhältliche Abwehrmittel auf ihre Wirksamkeit zu untersuchen und somit (2) relevante und evidenzbasierte Daten zu liefern, welche einer verbesserten Schadensprävention auf Gesetzlicher- sowie auf Praxisebene dienen sollen. Die Resultate werden zudem im breiteren Kontext der Rolle der Jagd bei der Schadensprävention diskutiert.

Resultate

Die Wirksamkeit der Solarblinker und des geruchlichen Abwehrmittels wurden an eigens dafür angelegten Lockfütterungen untersucht. Solarbinker konnten die Besuchswahrscheinlichkeit von Wildschweinen um 8.1% senken, geruchliche Abwehr um 0.4%. Beide Abwehrsysteme konnten somit die Wildschweine nicht davon abhalten, sich Zugang zum angebotenen Futter zu verschaffen. Zudem konnte kein kurzzeitiger, anfänglicher Abwehreffekt nachgewiesen werden. Auch das auf geschmacklicher Vergrämung basierende Abwehrmittel, welches direkt in landwirtschaftlichen Kulturen bzw. in experimentellen Feldern untersucht wurde, hatte keinen signifikanten Effekt auf die Häufigkeit von Schadensereignissen durch Wildschweine. Obschon wir einen schwachen Trend zur Schadensreduktion beobachten konnten, konnte mittels geschmacklicher Abwehr Wildschweinschaden nicht verhindert werden. Weiter konnten wir keine temporäre Meidung der behandelten Flächen nachweisen.

Schlussfolgerungen

Die vorliegende Studie hat gezeigt, dass keines der untersuchten Abwehrsysteme Wildschweine davon abhalten konnte, die experimentellen Flächen zu besuchen bzw. Frass- und Wühlschaden anzurichten und stellen somit keine geeigneten Mittel zum Schutz und zur Verhütung von Schäden auf landwirtschaftlichen Flächen dar. Die Resultate meiner Studien legen nahe, dass Abwehrsysteme, die auf Schreckreaktionen, Neophobie, der Provokation von Angst oder konditioniertem Meidungsverhalten basieren grundsätzlich nicht dazu geeignet sind, landwirtschaftliche Flächen vor Wildschweinschäden zu schützen. Momentan existieren einzig für die Wirksamkeit von Elektrozäunen wissenschaftliche Belege sowie auch positive Erfahrungen aus der landwirtschaftlichen Praxis. Aufgrund der Erkenntnisse der vorliegenden Studie muss den Landwirten zwingend von der Verwendung von alternativen Abwehrsystemen, welche auf den erwähnten Effekten basieren, abgeraten werden. Dies sollte entsprechend in die Gesetzgebung bezüglich der Schadensprävention und der Schadensvergütung einfliessen. Die Vergütung von Wildschweinschäden an landwirtschaftlichen Kulturen muss an die Bedingung des Schutzes mittels Elektrozaun geknüpft sein.

Nebst dem Schutz gefährdeter landwirtschaftlicher Kulturen ist eine effiziente jagdliche Regulierung der Wildschweinbestände für die Schadensprävention unablässig. Der jagdliche Eingriff sollte sich noch stärker auf weibliche und juvenile Tiere konzentrieren, da insbesondere die Anteilsmässig grosse Jugendklasse ein grosses Reproduktionspotential

aufweist. Dabei müssen selektive Jagdmethoden wie die Ansitzjagd und die Pirsch priorisiert und gefördert werden.
Da das sich hoch reproduktive und anpassungsfähige Wildschwein schnell von starken regulativen Eingriffen in die Population erholt, wird sowohl der Jagd wie auch dem wirkungsvollen Schutz der Felder weiterhin eine zentrale Rolle in der Schadensprävention zukommen. Weitere Forschung ist nötig, um verschiedene Jagd- und Wildschadensmanagement-Systeme zu untersuchen und einer ökonomischen Betrachtung zu unterziehen. Interessensgruppen wie die Landwirte, die Jäger sowie die zuständigen Behörden müssen dabei mit einbezogen werden.

Wildschweine sind aufgrund ihrer Omnivorie befähigt, sich an unterschiedliche Lebensräume anzupassen. Es ist davon auszugehen, dass die Population in der Schweiz weiter wächst und sich in noch nicht oder kaum besiedelte Gebiete ausbreitet, so etwa ins Schweizer Mittelland und in die Zentralschweiz. Künstliche Barrieren wie Autobahnen und Bahnstrecken werden mit dem laufenden Bau von Wildübergängen zunehmend durchlässiger und bisher fragmentierte Habitate werden mit einander vernetzt. Die zu erwartende Ausbreitung und der Anstieg der Wildschwein-Bestände in weiten Teilen des Mittellandes bis hin zur Zentralschweiz, wird diese Regionen vor ähnliche Probleme stellen, wie sie in weiten Teilen der Nord- und Westschweiz sowie dem Tessin bereits bestehen. Eine besondere Herausforderung wird insbesondere das jagdliche Management in Patentkantonen darstellen.

Schlüsselwörter: Wildschwein, Sus scrofa, Schadensprävention, Wildschaden, Elektrozaun, Solarblinker, geruchliche Abwehr, geschmackliche Vergrämung, Jagd, Landwirtschaft

Table of content

CHAPTER 1: INTRODUCTION ... 1

1.1 Wild boar ... 1

1.1.1 Taxonomy ... 1

1.1.2 Distribution ... 2

1.1.3 Natural habitats ... 3

1.1.4 Diet ... 3

1.1.5 Ranging behaviour ... 4

1.1.6 Social behaviour ... 7

1.1.7 Reproduction ... 9

1.2 Wild boar populations ... 11

1.2.1 Population dynamics ... 11

1.2.2 Population increase ... 12

1.2.3 Conflicts with human interests ... 13

1.3 Damage in agriculture ... 15

1.4 Wild boar management ... 17

1.4.1 Hunting ... 17

1.4.1.1 Hunting techniques ... 18

a.) Hide hunting ... 18

b.) Battue ... 18

c.) Stalk hunting ... 19

1.4.1.2 Hunting period ... 19

1.4.2 Supplemental feeding ... 21

1.4.3 Field protection ... 23

1.4.3.1 Electric fences ... 23

1.4.3.2 Other deterrents ... 24

a.) Visual deterrents ... 24

b.) Acoustic deterrents ... 24

c.) Chemical repellents ... 25

1.5 Aims and scope of the thesis ... 27

CHAPTER 2: METHODS ... 29

2.1 Study area ... 29

2.2 Design and approach **30**

CHAPTER 3: RESULTS **33**

3.1 Paper section **33**

I. Solar blinkers 35

II. Odor repellent 45

III. Gustatory repellent 55

CHAPTER 4: DISCUSSION **67**

4.1 Wild boar biology **67**

4.2 Wild boar management considerations **67**

4.3 Damage prevention **69**

4.4 Conclusions **71**

REFERENCES **73**

Supplementary information **95**

List of papers (Chapter 3)

The present thesis is based on the following papers, which will be referred to in the text by their corresponding Roman numerals.

I. Schlageter A, Haag-Wackernagel D (2011). Effectiveness of solar blinkers as a means of crop protection from wild boar damage. *Crop Protection* 30: 1216–1222.

II. Schlageter A, Haag-Wackernagel D (2012). Evaluation of an odor repellent for protecting crops from wild boar damage. *Journal of Pest Science* 88: 209–215.

III. Schlageter A, Haag-Wackernagel D (2012). A Gustatory Repellent for Protection of Agricultural Land from Wild Boar Damage: An Investigation on Effectiveness. *Journal of Agricultural Science* 4(5): 61–68.

Chapter 1: Introduction

This thesis concerns the damage prevention and the management of the wild boar in an anthropogenic influenced environment. In this chapter I first review the literature on the biology and behaviour of the wild boar. I then summarise information about population dynamics and growth. In the subsequent sections I address the problems associated with wild boars, I describe the management of the species and I provide relevant background information about hunting practices, hunting statistics and damage prevention in the Canton Basel-Land, Switzerland.

1.1 Wild boar

1.1.1 Taxonomy

The Eurasian wild boar *Sus scrofa* is the only wildlife representative of the family *Suidae* in Europe. The *Suidae* developed about 30 million years ago in the late Oligocene on continental Asia and descendants of the earliest forms reached Europe soon after in the early Miocene. Together with the Peccaries, or New World Pigs (*Tayassuidae*), suids build the suborder *Suiformes*, which are the only non-ruminants in the order *Artiodactyla* (Oliver 1993). *Suiformes* are generally regarded as the most primitive recent members of artiodactyls. Domestication of the wild boar took place independently in Asia and Erope about 9000 years ago (Hemmer 1990, Giuffra *et al.* 2000, Kijas & Andersson 2001, Minagawa *et al.* 2005). Wild boars and their domestic descendants are still able to interbreed (Randi 2005). Hybrids between domestic pigs and wild boars occur in free-ranging populations as well as in captive livestock. Farming of wild boar and/or hybrids becomes increasingly popular (Wilson 2005). Domestic pigs are amongst the most important of all domestic livestock, while wild boars are one of the most popular game species over much of Europe (Oliver 1993).

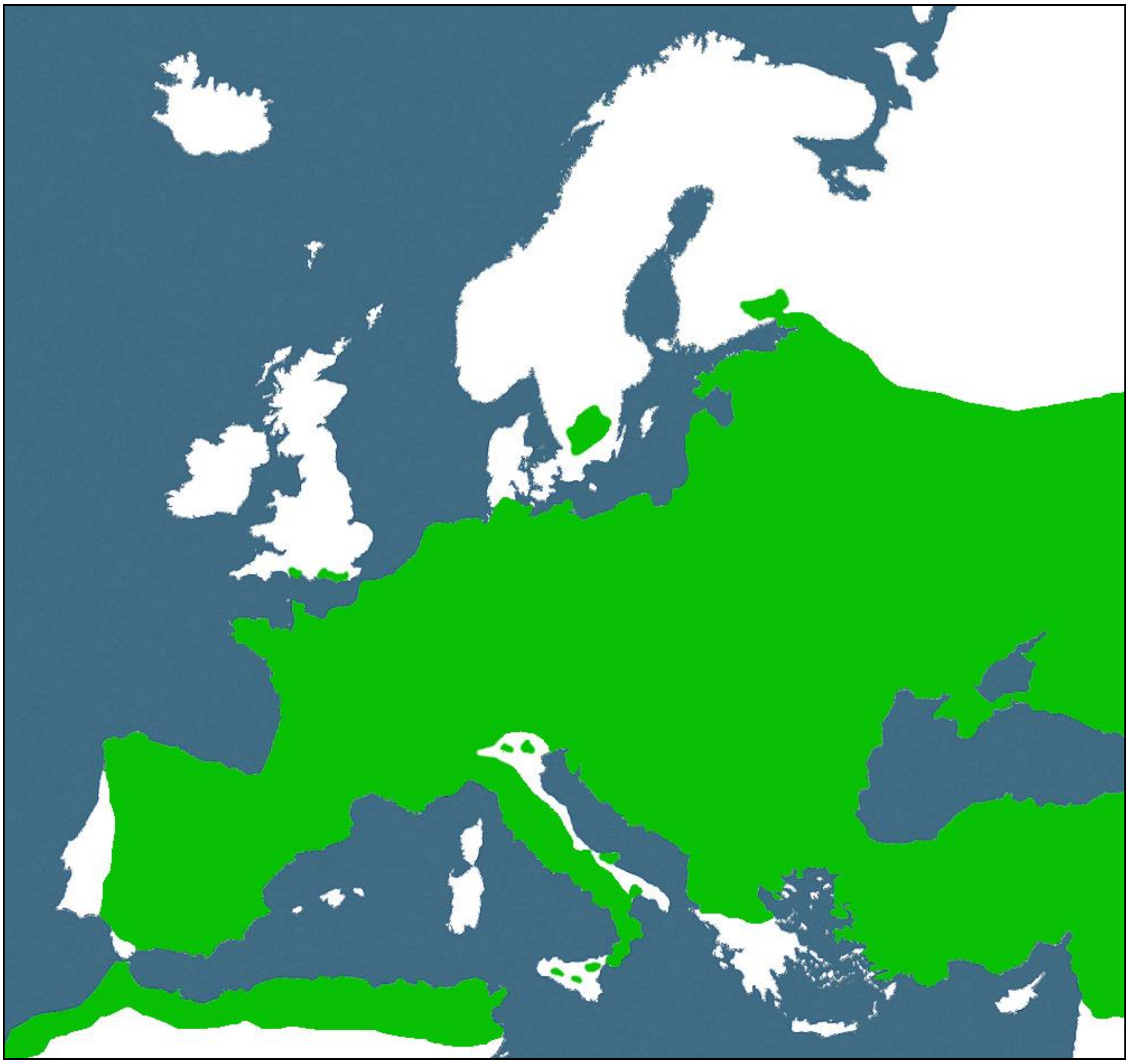

Fig. 1. Distribution of the wild boar in Europe including isolated populations derived from escaped captive animals in southern England and southern Sweden.

1.1.2 Distribution

The Wild boar has an almost area-wide spread all over Continental Europe (Fig. 1). The omnivorous and opportunistic nature of the species allows wild boars to adapt to harsh climatic conditions. The key-limiting factor for wild boar colonisation seems to be the availability of food. Continuous high snow cover and frozen ground as well as extreme drought prevent wild boars from rooting the ground in search for food (Erkinaro *et al.* 1982, Briedermann 1986, Acevedo *et al.* 2006).

Except for the deserts, the alpine regions and the northern, cold temperate zone, wild boars reach a natural distribution ranging from Western Europe to Southeast Asia and Northern

Africa. The natural distribution of wild boars varied along with climatic changes and associated fluctuations in food availability in the past. The northern and western range of wild boars repeatedly pulsed during the Pleistocene glacial periods. In the last centuries, distribution of the wild boar mainly changed due to anthropogenic impact. The wild boar was driven to extinction in Netherlands, Denmark, Southern Scandinavia, Britain, parts of Central Europe including Switzerland. During the 20th century, the species had naturally recolonised, or was reintroduced to most of its previous habitats (e.g. Niethammer 1963, Erkinaro *et al.* 1982, Briedermann 1990, Wilson 1999, Yalden 1999). Today, escaped or released wild boars, feral pigs, and their hybrids can be found in Britain (Goulding 2001, Wilson 2005), North America (e.g. Bratton 1975, Conover & Conover 1987, Taylor *et al.* 1998), Chile and Argentina (Jaksic *et al.* 2002), Australia (e.g. Hone 1990, Pavlov *et al.* 1992, Cowled *et al.* 2009), New Zealand (Campbell & Rudge 1984), and Hawaii (Nogueira-Filho *et al.* 2009).

1.1.3 Natural habitats

The large distribution of wild boar populations highlights the species' high adaptability to various types of habitats. The main reason for this is the species' wide range of diet, which is unique amongst ungulates, but also the species' ability to shift its rhythm of activity according to the climatic conditions and to the occurrence of predators. In Europe, wild boars generally live in deciduous forests and mixed forests, but also in marshes (Dardaillon 1986, Abaigar *et al.* 1994). In the absence of mast spending trees like oak (*Quercus robur*) and beech (*Fagus sylvatica*) in the coniferous forest of boreal regions, wild boars preferably live close to humans (Markov *et al.* 2004). Actually, the vast intensification of agriculture all over Europe has led to much of an improvement in the food conditions for wild boars. The cultivation of crops, in particular of maize and wheat allows for bigger populations in many regions where the natural vegetation only provides limited food resources. Furthermore, supplementary feeding has been proven to substantially enhance habitats, thus supporting higher populations for different regions in central Europe (Eisfeld & Hahn 1998, Cellina 2008).

1.1.4 Diet

The plasticity of wild boars concerning the environmental factor food is almost infinite. The species' huge potential of exploiting nearly any food is reflected in its vast geographic range (Genov 1981). The euryphageous and omnivorous wild boar is capable of adapting to seasonal changes in food availability very quickly, concentrating on the resource which enables the highest energy intake in the shortest time. As a result, in mast years stomach contents may almost exclusively be made up by one single component as for example beechnuts or acorns. Although wild boars exhibit an opportunistic foraging strategy, they nevertheless have quite pronounced preferences if more than one food item is available (Genov 1984, Vassant 1994). In spite of its omnivorous nature, the wild boar's diet consists mainly of vegetal matter, which makes 70–98% of its food intake (e.g. Massei *et al.* 1996, Eisfeld & Hahn 1998, Schley & Roper 2003, Hohmann & Huckschlag 2004). These references show that natural food varies with location and season but foods found to be important in several studies include acorns, beechnuts, olives, grasses, roots, fruit, earthworms and insects. In dependence of the habitat and the seasonal availability, wild boars also feed on leaves, shoots, mushrooms, lichens, molluscs, vertebrates of all classes and all of their developmental stages, as well as carrion.

Wild boars often exploit food resources of human origin when they can access. As cultivation areas expanded drastically in the past decades, agricultural crops have become an important food resource for wild boars in many European regions. For instance wild boars feed on maize and wheat (e.g. Eisfeld & Hahn 1998, Cellina 2008, Herrero *et al.* 2006), potatoes (e.g. Genov 1984) and wine grapes (e.g Fournier-Chambrillon *et al.* 1995, Calenge *et al.* 2004). Furthermore, wild boars are intentionally provided with supplemental food by humans. Supplemental feeding is practiced in many European countries, mainly to bait wild boars for easier shooting, but also to avoid damage to crops (see 1.4.2).

1.1.5 Ranging behaviour

In regions lacking anthropogenic influence, wild boars predominantly exhibit the circadian activity patterns that are typical for diurnal or crepuscular animals. Several ecological factors such as seasonal changes in length of days, temperature, food supply, snow cover, extreme drought, the presence or absence of predators and their activity patterns affect the primary diurnal nature of wild boars, leading them to adapt their own circadian rhythm (Meynhardt 1990). In areas where wild boars are hunted, they completely shift to nocturnal activity, resting in dense vegetation such as shrubs or standing crops (e.g. maize) during the day and only leaving cover for foraging in open woodland or on agricultural land after dusk (Boitani *et al.* 1994, Hahn & Eisfeld 1998).

Wild boars have been reported to lack a pronounced philopatry in the past. Brandt (1974) described wild boars as widely streaking animals, regularly changing their home ranges according to their seasonal needs. Contrary to this view, which was already controversial back then, there is a broad agreement on the wild boar's philopatric nature today. On condition that there is enough food throughout the year, shelter from weather and safety from predators, the wild boar is very faithful to a habitat. A normal home range of a wild boar family group provides the essential components for the species wellbeing, such as foraging grounds, resting places, wallows (Fig. 2) and rubbing trees (Fig. 3), which are connected by traces.

Fig. 2. Wallows are a fundamental component of a wild boar habitat. Since wild boars are not able to sweat, wallows play an important role in regulation of body temperature, especially in summer.

Home ranges of different family groups may overlap but the resting grounds in the core area are defended against other wild boars of other family groups or solitary males. Territorial marking predominantly occurs through odour e.g. at resting grounds, special dropping-spots, and at rubbing trees near wallows where wild boars also leave optic marks (Mauget 1979, Keuling *et al.* 2009, Sodeikat & Pohlmeyer 2004). Spacial use of the home ranges varies with the seasons depending on the requirements of the family group. Wild boars choose resting grounds according to the weather and the season, or the food availability (Janeau & Spitz 1984). Provided that the temperatures and the weather allow for it, wild boars preferably choose resting places in the vicinity of their foraging grounds. Agricultural crops make up a substantial proportion of the food intake of wild boars in many regions of Europe and the species regularly uses high standing crops such as maize and rapeseed as temporary resting places and shelter during the day, especially in late summer and fall (Keuling 2008).

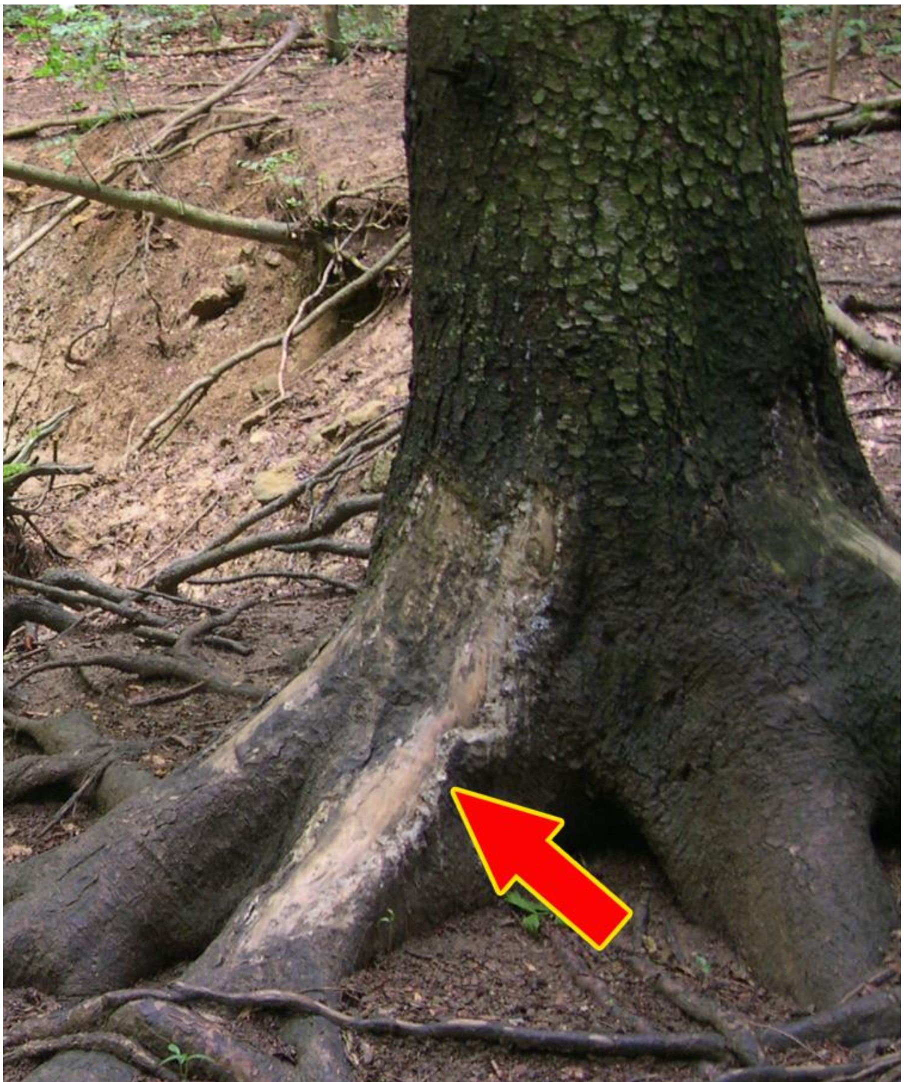

Fig. 3. Rubbing tree with its typical marks (red arrow). Rubbing trees are often situated nearby wallows.

The sizes of yearly home ranges have been reported to vary between 3 km^2 (Singer *et al.* 1981, Eisfeld & Hahn 1998) to 150 km^2 (Janeau & Spitz 1984) and depend on several factors, which themselves vary in effect according to the seasons. Hahn & Kech (1995) have indicated eight factors influencing the size of a wild boar home range: 1) abundance and distribution of food resources, 2) age class, 3) sex, 4) social status (family groups, subadult groups, solitary animals), 5) group size, 6) habitat changes by agriculture and/or forestry, 7) disturbances such as hunting and other human activities, 8) presence and abundance of predators.
In general, disturbance by humans or natural enemies and widely distributed food resources necessitate larger home ranges. In densely wooded areas with abundant food, however, wild boars are typically very faithful to a habitat. This may also be true for agricultural areas and urban habitats. Dinter (1991) described average home ranges of 170 ha for an urban population in the city of Berlin. Solitary males and subadults have larger seasonal home ranges than females and family groups (Boitani *et al.* 1994, Keuling 2008). The influence of hunting on the home range sizes was investigated by several studies (Maillard 1995, Baubet *et al.* 1998, Sodeikat and Pohlmeyer 2003, Scillitani *et al.* 2010) according to which displacements of family groups by drive hunts are usually short lived since the animals return to their familiar areas at the end of hunting season. Sodeikat and Pohlmeyer (2002), for instance, investigated the effect of 14 drive hunts on the movements of 10 wild boar family groups and found only little effects for parts of the examined animals. While most family groups remained within their home ranges, some family groups left their core area after the drive hunt and moved up to 6 km away. But mostly after four weeks, at the latest six weeks after the hunt, the groups returned back into the centre of their home ranges.
In a study in Northern Germany, Keuling *et al.* (2008) analysed the influence of hunting on the habitat use of wild boars. The authors did not find significant differences comparing home ranges before and after drive hunts or individual hunting.

1.1.6 Social behaviour

Wild boars are amongst the most social ungulates, exhibiting a wide range of intraspecific behavioral patterns and pronounced social hierarchies. One to five adult wild boar females, usually related to each other, form matriarchal units with their piglets and/or subadult yearlings (Teillaud 1986, Dardaillon 1988). The hierarchal order within the group is defined by age, body strength, social status (leading sows > sows without offspring), and sex (females > males). The dominant leading female determines the circadian activity rhythm of the group

and decides where and when to rest and to feed.
Keuling *et al.* (2009) have defined seven different forms of social units that occur in free-ranging wild boars: 1) basic family groups (BFG) formed by a sow and their piglets, 2) two adult female wild boars with their piglets (2 x BFG), 3) extended family groups (EFG) which additionally contain one or several subadults, 4) multi family groups (MFG) with more than three adult females plus subadults and piglets, 5) groups of subadults, 6) groups of piglets, and 7) solitary wild boars. These groups are relatively stable in composition, although several authors described the social units of wild boars to underlie dynamical changes over the seasons as a consequence of constant restructuring and temporary or permanent splitting of groups (Dardallion 1988, Boitani *et al.* 1994, Nakatani & Ono 1995, Fernández-Llario *et al.* 2003, Rosell *et al.* 2004).
Permanent splitting of wild boar groups occurs in consequence of enhanced intraspecific concurrence for resources in cases of food shortage or population growth, unfavourable group structure such as several equally dominant females within a group, or hunting by humans (Meynhardt 1978, Müller 1998). Keuling *et al.* (2009) have reported temporary splitting of groups, and reunion of sub-groups, during nocturnal activity periods to happen regularly in their study area in Northern Germany.
The average group size is 4–6 individuals, which however also includes solitary living wild boars and varies strongly throughout the year dependent on dynamic natality and mortality rates. Briedermann (1972) has described relative frequencies of different group sizes and their seasonal variation, which gives a more informative insight in wild boar group dynamics. In his study area in the former German Democratic Republic (GDR), solitary wild boars made an average proportion of less than 5% of the whole population. A majority of the population (in average 40%) was made up by wild boars living in groups of 6–10 individuals. Another 25% of the population lived in groups of 2–5 wild boars. These proportions, however, change over the seasons. After weaning in June and July, when losses through hunting were still small, 45% of the population lived in groups of more than 10 animals. By contrast, after the rutting season in January and February only 15% lived in groups of more than 10 individuals. Keuling *et al.* (2009) reported smaller groups of one or two sows including their piglets in their study area in Southeast Mecklenburg. The authors concluded group size to be a function of the carrying capacity of a certain habitat and the hunting pressure or the predator density respectively.
Group composition is a function of life cycle and seasonal changes. Reproductive females separate from the group shortly before giving birth. About one or two weeks after having built

a farrowing nest and having given birth to an average of 5 piglets, the sow usually rejoins her initial group (Martys 1982, Teillaud 1986). The piglets, which are striped, are weaned at about 3-4 months, when they lose the stripes and develop a reddish fur, which changes to dark brown at about 12 months (Briedermann 1986).

Most births take place around March – April but reproduction can occur all year round. Sub-adults remain in their natal home range until the age of 8 to 24 months (Cousse *et al.* 1994) and especially juvenile males sometimes regroup in low-bonded units (Cugnasse *et al.* 1987). Adult males are mostly solitary and only join groups of females during the rutting season (Dardaillon 1984). The onset of the rutting season is characterized by enhanced activity and restlessness of female wild boars and by changes of group structure. Females show a pronounced rutting behaviour such as hyperaesthesia, swelling of the vagina with mucous secretion, and leaving salivary marks on trees. At the same time, male boars begin to actively search for females, showing several characteristic behavioural traits like optical and olfactory marking of trees, display behaviour, and fighting.

Rutting of wild boar extends over a period of several months, but is most pronounced in November and December. Most fertilizations occur in winter (November – February), however, wild boar can reproduce all year round which is particularly the case in yearlings and subadults (Stubbe & Stubbe 1977). The onset of rutting depends on food abundance, weather conditions, and age structure within the population. Under good food conditions like in mast years, rutting season begins earlier, peaking in November. Briedermann (1971) reported differences between the age classes, showing that adult females get fertilized earlier than subadults and yearlings.

1.1.7 Reproduction

Unlike most other large mammals that have mainly k-selected reproductive characteristics such as small litters, slow growth, and late onset of puberty, wild boars show far more characteristics of r-selection (Geisser 2000). With sexual maturity reached within the first year under good food conditions, a mean litter size of 5 piglets, and adult sows usually reproducing every year, wild boars have the highest reproductive potential amongst ungulates. Today there is a general consensus that the onset of puberty is both dependent on the age and on the nutritional condition, thus, the body weight of female wild boars. Most of our current knowledge of wild boar reproduction in central Europe is still based on the outstanding long-term studies of Briedermann (1990) and Stubbe & Stubbe (1977) conducted during the 1970s.

Sexual maturity of females has been reported to occur at an age of 7–9 months and a body weight of 25–35 kg. These values have since been revised downwards by more recent studies, which have taken into account that food supply has become more abundant in many regions of Europe (Getthöfer 2005, Getthöfer & Sodeikat 2007). According to these authors, female piglets most likely reach sexual maturity at the age of 5 months and with a body weight around 20 kg. Steinfeldt (2004) even reported female piglets to become sexually mature at body weights between 13.5 kg and 19 kg.
The proportion of reproductive females in a population varies, dependent on the age class. According to the literature, 35–80% of piglets (< 1 year), 65–95% of subadults (1–2 years), and 80–95% of adult sows (> 2 years) contribute to reproduction (e.g. Briedermann 1971, Stubbe & Stubbe 1977, Meynhardt 1978, Getthöfer 2005). Reproductive rate in wild boar is dependent on the availability of energy-rich food and varies in particular with the quantities of acorn mast produced (e.g. Briedermann 1971, Groot Bruinderink *et al.* 1994).
Henry (1968) determined the average gestation period to last 115 days, with a spread from 108 to 120 days, which is in quite accurate correspondence with domestic pigs.

1.2 Wild boar populations

1.2.1 Population dynamics

Wild boars exhibit the highest reproductive rate amongst all ungulates, which enables the species to achieve dense populations in a very short time (e.g. Briedermann 1971). Several studies have investigated and addressed the main factors influencing wild boar densities, which are winter snow cover, availability of acorn and beech mast, and annual temperature, in the context of global climate change (e.g. Melis *et al.* 2006). As reproduction of wild boar is positively correlated with the nutritional status, long and cold winters, which lead to restricted access to particularly subterranean food, negatively influence the reproductive rate. Additionally, low temperatures and humid conditions in springtime increase piglet mortality. Many terrestrial ecosystems are characterized by pulsed resources i.e. temporary availability of an extremely high food basis. Probably the most common resource pulse in these ecosystems is mast seeding, the intermittent, synchronous production of large amounts off crops by plant populations. Pulsed food resources have been shown to have a major impact on herbivore population densities, which is also true for wild boar. However, the species' potential to compensate yearly or seasonal losses within a short time makes it less vulnerable to changes in food abundance. Furthermore, as an omnivorous animal the wild boar is able to adapt to changes in food availability by temporary shifting its dietary habits, for instance towards bigger proportions of subterranean food (Hahn & Eisfeld 1998). Shortage of the primary food resource therefore rarely leads to a population decline. Substantial losses normally occur when mast failure is followed by a long and cold winter (Cabon 1959, Koslo 1975, Okarma *et al.* 1995).

Cellina (2008) found reproductive performance to be negatively influenced by drought in Luxembourg. The influence of drought is also shown by studies carried out in Spain (Fernández-Llario & Carranza 2000, Fernández-Llario & Mateos-Quesada 2005a) and by the tendency towards smaller litter sizes in Mediterranean areas. In this context, global warming could limit further increases in wild boar population density if it causes summers to become hotter and drier, though it is also likely to favour higher winter survival and may enable wild boars to maintain high reproductive potential year-round.

Density-dependent intra-specific competition for resources may have a massive impact in case of food shortage, particularly where dispersal area is limited. However, Choquenot (1998) showed that food abundance is mainly dependent on extrinsic factors such as climate

and weather conditions for free ranging feral pigs in Australia. He considered the influence of feral pig population density on food abundance to be negligible.
High densities favour social stress by increasing aggressive interactions, but also enhance the spread and increase of diseases and parasites. Pathogens may have massive regulative impact on population densities of wild boar, although temporary and spatially limited (Briedermann 1990, Artois *et al.* 2002). Intrinsic density-dependent regulation in mammals has been discussed controversially. Social stress has been shown to negatively affect reproductive traits of some mammals, particularly small ones such as rodents and shrews (e.g. Terman 1965, Holst 1972, Blanchard *et al.* 2001). Wolff (1997) presented a conceptual model to predict whether the population density of a mammal species is more likely to be determined by intrinsic or extrinsic factors. He concluded that most ungulates are not susceptible to density-related reproductive suppression, which is also supported by earlier studies (e.g. Ozoga & Verme 1982). Up to date there is no evidence for fertility reduction as a result of social stress in wild boar whatsoever.

1.2.2 Population increase

Numerous studies have provided extensive evidence for a drastic increase of wild boar populations in Europe over the last several decades (Erkinaro *et al.* 1982, Aumaitre *et. al* 1984, Bouldoire 1984, Tellería & Sáez-Royuela 1985, Sáez-Royuela & Tellería 1986, Boitani *et al.* 1995, Csányi 1995, Fruzinski 1995, Moretti 1995, Feichtner 1998, Geisser 1998, Hahn & Eisfeld 1998, Krüger 1998, Schley *et al.* 1998, Fonseca *et al.* 2002, Lemel *et al.* 2003, Geisser & Reyer 2005). Several reasons for this population increase have been discussed in literature. There is a common consent that multiple factors have favoured this trend, the most important of which are probably favourable climatic conditions and increased availability of natural food resources, which have a strong influence on both reproduction and mortality. The rise of average annual temperature as well as the accumulation of mast years has been well documented for the past decades (e.g. Matschke 1964, Aumaître *et al.* 1982, Okarma *et al.* 1995, Massei *et al.* 1996, Uzal & Nores 2002).
Increasing availability of foods of human origin such as agricultural crops has also contributed to the increase in population size (Matschke 1964, Aumaître *et al.* 1984, Kabudi *et al.* 1987, Groot Bruinderink *et al.* 1994, Hahn & Eisfeld 1998, Geisser & Reyer 2005). Furthermore, supplemental food has favoured increasing wild boar populations in many European regions (Erkinaro *et al.* 1982, Ruiz-Fons *et al.* 2006, Cellina 2008). Several studies

have stressed the locally drastic impacts of artificial feeding on wild boar reproduction (Groot Bruinderink *et al.* 1994, Hahn & Eisfeld 1998).
The decrease or absence of natural predators in many European regions is probably of less importance since wild boars are intensively hunted (Tellería & Sáez-Royuela 1985, Okarma *et al.* 1995).

1.2.3 Conflicts with human interests

Problems associated with the increase in population size have been well documented and include: damage to agricultural crops and grassland (e.g. Mackin 1970, Andrzejewski & Jezierski 1978, Singer *et al.* 1984, Kristiansson 1985, Brooks *et al.* 1989, Groot Bruinderink & Hazebroek 1996, Schley 2000, Calenge *et al.* 2004, Geisser & Reyer 2004, Sulkowski *et al.* 2004, Krier 2005), damage to woodland through consumption of acorns and seedlings (Focardi *et al.* 2000, Hahn & Eisfeld 2002, Gomez *et al.* 2003), and disturbance of plant communities by rooting (Howe *et al.* 1981).
Additionally, wild boars are suspected of transmitting disease to domestic livestock (e.g. Dexter 2003, Caley & Hone 2004, Brauer *et al.* 2006, Gortázar *et al.* 2007). Especially classical swine fever cause enormous economic damages in pig farming, whereas wild boar populations often provided a reservoir (Kern *et al.* 1999, Acevedo *et al.* 2007, Kramer-Schadt *et al.* 2007). Consequently, farmers and animal health authorities claim for a stringent reduction of wild boar populations (Kaden 1999, Bieber & Ruf 2005).
Other issues, not yet extensively studied, are increasing numbers of car accidents caused by wild boars (Strein *et al.* 2006), and damage in or close to urban areas, for example in private gardens, public parks, cemeteries, sports grounds or golf courses (Cahill & Llimona 2002, Fischer *et al.* 2002, Möllers 2003).
On the other hand, the presence of wild boars may be ecologically beneficial in terms of providing prey for protected predators such as wolves *Canis lupus* (Mattioli *et al.* 1995), lynx *Lynx lynx*, or golden eagles *Aquila chrysaetos* (Roemer *et al.* 2001); consumption of pest insects (Klemm 1951, Genov 1981b); or dispersing seeds and facilitating their germination (Heinken *et al.* 2006). For example, presence of wild boar has been reported to enhance vegetation diversity in heathland through rooting behaviour (Simon & Goebel 1999).
Reviewing the impact of wild boar on plant and animal communities, Massei & Genov (2002) conclude that wild boars probably have a positive impact on animal and plant communities until they reach a population density that is beyond the capacity of a naturally equilibrated

ecosystem. At that point negative impacts are likely to outweigh the positive effects that wild boar can potentially have on both natural environments and on cultivated landscapes.

Fig. 4. Farmers call for help. The message was posted in summer 2007 besides the motorway A2 near Arisdorf, canton Basel-Land, Switzerland. It says: “Help, wild boar is a pest”.

1.3 Damage in agriculture

Wild boars have adapted well to agricultural changes in Europe. In many countries, their numbers have increased dramatically during the past three decades (e.g. Genov 1981, Erkinaro *et al.* 1982, Tellería & Sáez-Royuela 1985, Feichtner 1998, Klein *et al.* 2007). The relationship between damage and population density has been reported in several studies (e.g. Bouldoire & Havet 1981, Goryńska 1981, Labudzki & Wlazelko 1991, Spitz & Lek 1999, Schley *et al.* 2008). Following the spread and increase of wild boar populations, damage in agriculture has risen drastically in many counties all over Europe and compensation payments amount to millions of Euros every year (e.g. Geisser 2000, Linderoth & Elliger 2002, Calenge *et al.* 2004, Schley *et al.* 2008).

Wild boars cause damage in grassland by rooting and digging when searching for subterranean food (Fig. 5). Damage to grassland varies strongly with region and season but can account for more than 50% of all damage. (e.g. Geisser 2000, Klein *et al.* 2007). Damage to crops occurs not simply through consumption but also through trampling of the plants (Fig. 6). Kristiansson (1985) estimated that only 5–10% of crop destruction by wild boar was a consequence of actual consumption, the rest being due to trampling. Wherever maize is grown, it is almost always the most damaged annual crop, followed by wheat and other cereals (Vassant 1997, Geisser 2000, Calenge 2004, Schley *et al.* 2008). Briedermann (1976) suggested, that consumption of fresh maize as an important diet component is not even displaced by mast, usually considered the staple food of wild boar (Schley & Roper 2003).

In Switzerland, wild boar populations started to grow in the early 80s, simultaneously followed by increasing damage. Today, wild boars are present at considerably high densities especially in the northern and western parts of Switzerland, as well as in the cisalpine Canton Ticino. More detailed information on damage caused by wild boars in the Canton Basel-Land is provided in section 4.2.

Fig. 5. Wild boar damage to a meadow in Blauen, canton Basel-Land, Switzerland. Wild boars dig the ground in search for subterranean food such as insect larvae, earthworms, and roots. The repair of the sod is time-consuming. In Switzerland, 50% of damage compensation payments are spent for the repair of grassland.

Fig. 6. Wild boar damage to a maize field in Blauen, canton Basel-Land, Switzerland. Most of the damage is caused by trampling of the plants. Once entered a field, wild boars often stay for several days since the high standing crops offer both, food and shelter.

1.4 Wild boar management

Many economic and ecological factors give reasons for wild boar management, as this species is an important component of the indigenous European fauna and an economically important game species. Managing wild boar populations is conducted to produce meat of high quality (Wilke *et al.* 2000, Dobrowolska & Melosik 2008), but also to regulate populations to control damages (Andrzejewski & Jezierski 1978, Boutin 1990, Geisser & Reyer 2004, Putman & Staines 2004), diseases and zoonoses (Kaden 1999, Caley & Hone 2004, Acevedo *et al.* 2007, Gortázar *et al.* 2007), and vehicle collisions (Doerr *et al.* 2001).

This section addresses wild boar management under the perspective of damage prevention. I summarize general aspects of the different management approaches focusing on effectiveness and potential problems of the method. I also provide relevant background information on the common practice and the legal situation in Switzerland, particularly in the Canton Basel-Land.

Three methods dominate among the attempts to reduce wild boar damage that are recommended in many scientific and popular articles (Briedermann 1990, Breton 1994, Mazzoni della Stella *et al.* 1995, Vassant 1997, Geisser 1998). First, wild boars are hunted intensively to keep population densities on a sustainable level. Second, hunters offer supplemental food in the forest to keep the wild boars off the farmland. Third, farmers put up fences and other deterrent systems to prevent wild boars from entering the fields.

1.4.1 Hunting

The regulation of wild boar populations by means of hunting represents the most effective way of preventing damage to agricultural land. Several studies proved that hunting reduced wild boar damage (e.g. Briedermann 1971, Geisser & Reyer 2004). However, regulation needs to take the species' biology and ecology into account. Therefore, one fundamental aim of hunting is to achieve healthy populations in terms of both social structure and individual constitution. In the following sections I summarise the advantages and disadvantages of the most usual hunting techniques used in Switzerland. I then give a brief overview of the legal situation of hunting in Switzerland and particularly in the canton Basel-Land. Additionally, I provide detailed insights into the status and the development of hunting bags of the Canton Basel-Land, based on data obtained by the cantonal game authority (*Amt für Veterinär-, Jagd- und Fischereiwesen*).

1.4.1.1 Hunting techniques

a.) Hide hunting

In hide hunting the hunter sits at a lookout, which most often consists of a raised hide, and waits for wild boars or other game to pass. Raised hides are strategically placed at frequented game trails, wallowing places or at the border between forest and open land. Hunting from raised hides is carried out mainly during dusk or dawn. Baiting with dry maize, other food or a saltlick is commonly used to attract wild boars to the site in the Canton Basel-Land. Numbers of baiting sites and quantities of bait are legally fixed at one baiting site per 100 ha and 1 kg per site and day. The bait may only consist of locally cultivated crops and fruit such as maize, which is most commonly used, or apples. Hunters are not allowed to bait for other reasons than for hunting purposes (Cantonal Act on hunting practice, Basel-Land, Article 17). In Switzerland, hide hunting contributes to the major part of the hunting bag. In the Canton Basel-Land, 78% of hunted wild boars were shot from raised hides during the past two decades. The main advantages of this hunting strategy are the relatively low planning effort and the high selectivity. On the other hand, the method is spatially inflexible and relatively time consuming as hunters spend an average 30 h to shoot a wild boar (*Amt für Veterinär-, Jagd- und Fischereiwesen, Basel-Landschaft*, D. Zopfi, pers. comm.).

b.) Battue

In battue hunting usually one or several neighbouring hunting communities organise themselves to hunt together. In many cases additional hunters and beaters, with their dogs, are invited. Battues are conducted to cover big parts of a hunting area within one day. Usually one hunting area is divided into smaller areas that are tracked one after the other. The hunters are posted around the tracked area with their rifles. The beaters walk through the area in a line, trying with the help of the dogs to find wild boars and other game animals and to make them move towards the hunters. The animals can be shot when moving, usually from a relatively short distance (30–50m).

Advantages of this hunting technique include the spatial flexibility and the possibility of temporally applying a considerably high hunting pressure over a bigger area, which can result in high numbers of shot wild boars within a relatively short time. Battues contribute to the annual hunting bags in regional different amounts, which can reach up to 90% (Herrero *et al.* 1995, Maillard & Fournier 1995). In Switzerland as well as in many other central and east

European countries, the impact of battues is much lower. In the Canton Basel-Land, an average 13% of the annual hunting bag was made up by wild boars shot on battues during the past two decades.

Besides the high planning effort and the short timeframe (see 1.3.1.2), the main disadvantage of battues is the reduced selectivity compared to hide hunting as hunters normally must decide very quickly which animal to shoot or not.

c.) Stalk hunting

In a stalk hunt the hunter walks quietly through the hunting area, trying to track wild boar by following signs of their presence. Stalk hunting is the most dominant way of hunting in the alpine Regions of Switzerland and predominantly focuses on deer and chamois. In the northern parts of Switzerland as well as in most non-alpine European regions stalk hunting plays a minor part. Stalk hunting of wild boars has no long tradition in the Canton Basel-Land, but is rapidly gaining in importance (see also 4.2. and Fig. 2). Because of the nocturnal activity of wild boars, stalk hunting is in most cases performed during the night. The effectiveness of this way of hunting is therefore dependent on clear nights, moonlight and snow cover. Although this hunting technique requires a lot of experience, is physically demanding and time-consuming for the individual hunter, it can contribute to the annual hunting bags in considerably high amounts.

1.4.1.2 Hunting period

In Switzerland, general issues of hunting are regulated by federal law and by federal act. As Swiss Cantons have a high degree of sovereignty, hunting is regulated in more detail by cantonal ordinance. The information on hunting period and close season I provide here refers to the federal law on hunting and the revised federal act on hunting (Federal Department of the Environment, Transport, Energy and Communications DETEC) as well as to the cantonal ordinance on hunting of Basel-Land (*Amt für Veterinär-, Jagd- und Fischereiwesen*).

Federal law defined close season for wild boar between 1st of February and 30th of June, which was shortened to the period from 1st of March to 30th of June by federal act in 2012. Furthermore, wild boars under 2 years of age can be hunted throughout the year outside the forest. In the case of high population densities, Cantons may, conditional on federal approval, temporally order further shortening of the close season. Additionally, the basic prohibition of night hunting was disestablished for wild boars in 2007.

Battues are allowed between 1st of October and 15th of December. However, since 2011 wild boars may be hunted on so called drive hunts from 1st of July to 30th of September in crop fields and from 16th of December to 31st of January in the forest. Drive hunts are a special form of battues, defined by less disturbance of the game, as beaters walk quietly through the area and the utilisation of dogs is principally not permitted.

The legal adjustments, particularly the shortening of close season mentioned above are to be understood as a reaction to increasing wild boar populations in the past decades.

Fig. 7. Hide hunting spot: Raised hide in the background (green arrow). In the foreground, a perforated barrel filled up with maize is fixed with a rope (red arrow). By pushing and rolling it, the wild boars make the maize kernels drop out. The wild boars are kept busy and stay for a longer time by this means.

1.4.2 Supplemental feeding

Supplemental feeding consists of providing additional food for wild animals. Supplemental feeding of wild boar is legal and widely used for different purposes in many European countries, e.g. Belgium (Kabudi *et al.* 1987), France (Vassant & Boisaubert 1984, Vassant *et al.* 1987b, Jullien *et al.* 1988, Kaberghs 2004), Germany (Eisfeld & Hahn 1998, Hohmann & Huckschlag 2004), Hungary (Náhlik & Sándor 2003), Luxembourg (Cellina 2008), the Netherlands (Groot Bruinderink *et al.* 1994), Poland (Sulkowski *et al.* 2004), Spain (Fernández-Llario & Mateos-Quesada 1998, Vicente *et al.* 2005b), Sweden (Lemel *et al.* 2003) and Switzerland (Geisser & Reyer 2005).

The way in which wild boars are fed supplemental food depends on the purpose of the feeding, the two most common of which are dissuasion and baiting. In order to prevent damage from wild boar to cultivated land, supplemental food is provided during the critical phase of crop ripening when crop damage is expected (Andrzejewski & Jezierski 1978, Briedermann 1986, Vassant *et al.* 1987a, Jullien *et al.* 1988, Calenge *et al.* 2004). This technique has two different aims. Firstly, by eating supplemental food the animals should satiate their appetite and therefore avoid feeding on crops; secondly, if supplemental food is provided in woodlands, the animals should stay in this habitat and not stray onto cultivated land.

The effectiveness of dissuasive feeding in terms of damage reduction is highly controversial and seems to depend on several aspects. While some studies provide evidence for the success of the method in reducing wild boar damage to agricultural crops (Vassant & Breton 1986, Meynhardt 1991, Vassant *et al.* 1992, Vassant 1994a, Vassant 1994b, Calenge *et al.* 2004), others showed no effect (e.g. Geisser & Reyer 2004), or even concluded that dissuasive feeding enhances wild boar damage (Hahn & Eisfeld 1998, Cellina 2008). The latter revealed considerable amounts of artificial food in the stomachs of shot wild boars of 40% and 50% respectively. Additional food enhances survival under poor environmental conditions and accelerates the onset of reproduction, which both can lead to population growth (Andrzejewski & Jezierski 1978, Briedermann 1990, Bieber & Ruf 2005, but see also 1.1.7 and 1.2.2).

Today there is a growing consent on the conditions under which dissuasive feeding is expected to reduce agricultural damage. In those studies that reported successful damage reduction by means of dissuasive feeding, food was supplied inside the forest at a distance of at least 1 km from the edge of the forest, the food supplied was spread out over large areas and was only provided during the critical period.

These criteria are hard to be met in Switzerland with its highly fragmented landscape and patchy forest distribution. This is also true for the Canton Basel-Land where dissuasive feeding is prohibited by law and supplemental feeding is exclusively practiced to bait wild boars for easier shooting (see above section on hide hunting: 1.4.1.1.a.).

1.5 Field protection

1.5.1 Electric fences

As described in sections 1.2.1 and 1.2.2 wild boar populations can quickly recover from massive losses. Mild winters, warm springs, and abundant crops of common acorn and beech during recent years provided ideal conditions for the wild boars to thrive over the past years (Geisser & Reyer 2005). Hence, protection of the fields is an essential means of damage prevention. Farmers preferably protect vulnerable fields with electrical fences, which have been proven to be effective in preventing wild boars from entering crop fields (Boisaubert *et al.* 1983, Vassant & Boisaubert 1984, Santilli & Mazzoni della Stella 2006).
In Switzerland, protection policy is not uniformly regulated. Most cantons provide financial support for the costs of fencing. In the Canton Basel-Land, reimbursement for fencing costs repeatedly exceeded compensation payments for wild boar damage in the past years and was therefore disestablished in 2008 (Revised act on hunting, *Amt für Veterinär-, Jagd- und Fischereiwesen).* For some cultures such as vineyard cultivations and newly planted fruit-growings, however, fencing is required by law and therefore reimbursed.
Compensation for wildlife damage to agricultural crops is also legally attached to appropriate cultivation and protection. Damage occurring in clover sowings on former maize fields, a method of cultivation, which is often performed for the purpose of crop rotation, is only compensated if old corncrobs have been removed prior to sowing. In the case of crop fields such as maize or wheat, repeated damage to the same field is reimbursed on condition of adequate protection and proper maintenance. Damage in unprotected fields is reimbursed only the first time. In such a case, authorities may order the installation of an electric fence. If the farmer does not protect the field or if the fence is inadequately installed and/or maintained, reimbursement for the second damage is only 50% and any following damage is no longer reimbursed.
The wildlife damage compensation fund, which is managed by the cantonal authority (*Amt für Veterinär-, Jagd- und Fischereiwesen*), is directly fed from the hunting licenses and the lease fees for hunting grounds.

1.5.2 Other deterrents

The number of non-lethal tools available for pest control and damage prevention has augmented in the past decades, as popular demands for such tools increased and continue to increase. Deterrents are particularly receiving widespread attention, although for many products almost no data exists to support claims of effectiveness (Mason 1998, Gilsdorf *et al.* 2002). Deterrents can be chemical, visual, acoustic, or some combination of these characteristics. Chemical deterrents are based on sensory irritation (Norman *et al.* 1992), semiochemical mimicry such as predator urines (Belant *et al.* 1998), or gastrointestinal malaise (El Hani *et al.* 1995). Visual and acoustic deterrents base on startle responses, neophobia, or avoidance of sign stimuli (e.g. eyespots).

a.) Visual deterrents

Visual deterrents are mostly designed to affect birds (Mason 1997). Visual stimuli used to frighten problem animals include lights, moving/reflective objects, and threatening images (Koehler *et al.* 1990). Strobe lights (Linhart *et al.* 1992, Green *et al.* 1994) and floodlights are often used to deter animals from an area. Moving and/or reflective objects include flags, wind propellers, plastic jugs, aluminum reflectors (Scott & Townsend 1985) and reflective tape (Bruggers *et al.* 1986, Dolbeer *et al.* 1986; Conover & Dolbeer 1989). Threatening objects may consist of scarecrows (Scott & Townsend 1985, Stickley & King 1995) or predator models such as hawk-kites (Conover 1984), hawk or owl decoys, scary-eyes or eyespots (Belant *et al.* 1998), and rubber or inflatable models of snakes.

b.) Acoustic deterrents

Because animals often have very acute and sensitive hearing, acoustic frightening devices may deter animals from an area. Loud noises, including explosions from gas exploders, sirens, and recorded animal sounds (bioacoustics), are commonly used as acoustic deterrents. Animals tend to initially avoid areas with loud and/or unfamiliar sounds (Koehler *et al.* 1990). Bioacoustics are animal communication signals, often in the form of alarm or distress calls. Most studies using bioacoustics have been conducted on birds (Frings 1964, Thompson *et al.* 1968a, Thompson *et al.* b, Mott & Timbrook 1988, Aguilera *et al.* 1991). Knowledge of the potential use of mammalian communication signals is limited (Frings 1964, Koehler *et al.* 1990).

c.) Chemical repellents

Vertebrate chemical repellents fall into three different classes, according to the way they operate: those that cause pain, those that cause fear, and those that cause sickness (Mason 1998).

Pain-causing sensory irritants are nearly always more effective deterrents than fear-provoking semiochemicals or substances that cause sicknes. Avoidance is immediate, no learning is required to sustain the aversion, and adaptation is minimal (Mason 1997). Sensory irritants are most effective when they are applied directly on the crops. However, there is no evidence for area-repellency by irritants.

Fear-causing semiochemicals such as predator urines or sulfur odours (e.g. odours that result from protein degradation) have proved to be effective against many herbivore species, including deer and rabbits (Conover 1984, Scott & Townsend 1985, Milunas *et al.* 1994). Unlike sensory irritants, there is some evidence that semiochemicals may cause animals to leave areas. A disadvantage to the use of fear provoking substances as repellents is habituation.

The deterrence effect of chemical repellents that cause sickness is based on learned (or conditioned) avoidance. Learned avoidance can occur after a single aversive experience. Conditioned taste aversions have been tested as a strategy to reduce of bird depredation on grain or fruits (Avery 1992, Stone *et al.* 1974), coyote predation on sheep (Conover & Kessler 1994), racoon predation on eggs (Nicolaus 1987), and in many other contexts (Conover 1998).

In Switzerland, the use of deterrents other than electric fences is not widespread. Visual and acoustical deterrents are used either to prevent deer accidents (e.g. reflectors, blinkers) or to frighten away birds in vineyards and orchards (e.g. reflecting objects, scarecrows, electric horns, and gas canons). Chemical repellents relying on fear-evocation are also predominantly used for reducing animal-vehicle crashes.

1.6 Aims and scope of the thesis

As highlighted in section 1.4.3.1, electrical fences are an effective means of damage prevention. However, they require regular surveillance to assure maintenance of both fences and batteries, which is costly in terms of time. Additionally, electrical fences are expensive and the government does not provide financial support. Farmers and authorities are therefore highly interested in efficient alternatives to the expensive and labour-intensive electrical fences. Various optic-, odour-, and gustatory deterrents are available today that claim to be effective in deterring wild boars. At present, there is little or no data to support claims of efficacy for the majority of commercially available deterrent systems. Information on successful deterrence of wild boars mainly derives from the manufacturers of the deterrent systems themselves. Methods based on acoustic and gustatory deterrence have not yielded satisfactory long-term results (Vassant & Boisaubert 1984, Vassant 1994a). These methods include radios, PIR-activated horns, gas cannons, and chemical treatment of corn seeds with several repellents. These findings raise the question, if there are any effective alternative deterrents to electric fences.

The aims of my study were: (1) to provide relevant data on the effectiveness and the sustainability of three representative deterrent systems. For this purpose, I investigated an optical deterrent, an odour repellent, and a gustatory repellent in field experiments with free-ranging wild boars; (2) to provide an evidence-based contribution to the policy and the practice of wild boar management and damage prevention.

Hypothesis: Deterrent systems based on startling responses, fear provocation, or negative experience and learned area avoidance are effective means for the protection of agricultural land from wild boar damage.

0-Hpothesis: None of the deterrents in question are effective for preventing agricultural land from wild boar damage.

Chapter 2: Methods

2.1 Study area

This thesis is based on data collected in a study conducted in several areas of the Canton of Basel-Land (47° 7' N, 7° 44' E) (Fig.8). The Canton of Basel-Land covers an area of 518 km^2 and is situated in north-western Switzerland at the Jura Mountains spur, bordering Germany in the north and France in the west. The topography is hilly and ranges in elevation from 246 m to 1169 m. The climatic conditions are continental with an average annual precipitation of 750–1300 mm. Average temperatures range from 2.1 °C in January to 19.6 °C in July. Forests, which are mostly used for the lumber industry, cover 42% of the study area and are patchy distributed with a total border length of about 2000 km^2. Forests are made up by 69% deciduous tree species, especially beech (47%), and by 31% conifers, most commonly sprunce (*Picea abies*). Agricultural land covers 41% of the area and consists mainly of pasture (50%), cropland (40%), and fruit and winegrowing (10%). Settlement and traffic infrastructure covers another 16% of the Canton's area. The population density is 536 inhabitants per km^2. The landscape is characterized by a high structural diversity. Except for the lynx (*Lynx lynx*), natural predators of the wild boar are absent in north-western Switzerland.

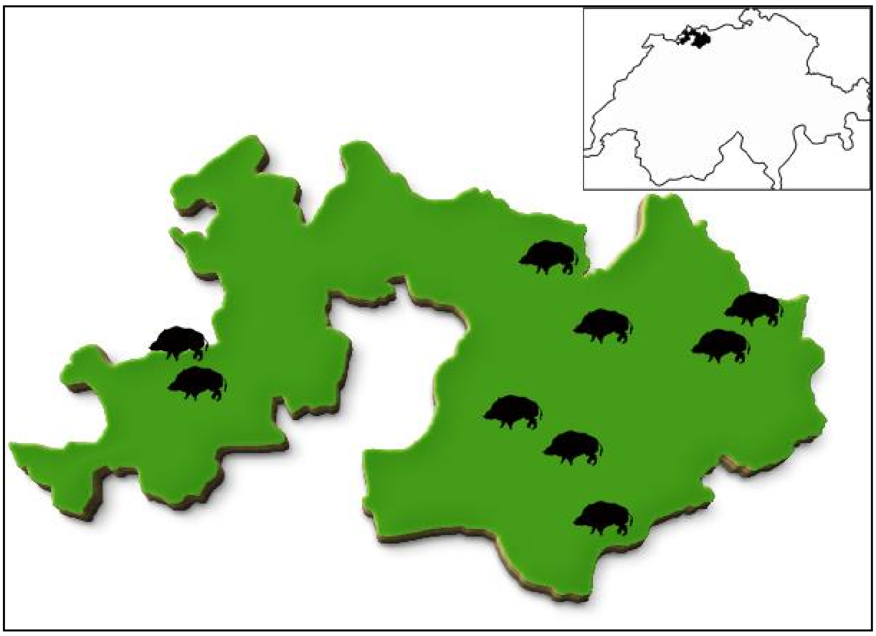

Fig. 8 Location of the study sites in the Canton Basel-Land, NW-Switzerland.

2.3 Design and approach

The data presented in this thesis were recorded from January 2007 to April 2009. Field experiments have been conducted at baited luring sites (I, II), and in cultivated fields (III). Wild boar visits at the luring sites and the experimental fields were recorded by detecting tracks. Additionally, I recorded the occurrence of damage caused by wild boar in the experimental fields. Controls were performed daily or at least every third day. An example of a bated luring site is shown in Figure 10. More detailed information on the design of the experiments and the characteristics of the deterrent systems is provided in Chapter 3 (papers I-III).

Fig. 9 Deterrent systems investigated. A: solar blinker, B: odour repellent, C: gustatory repellent

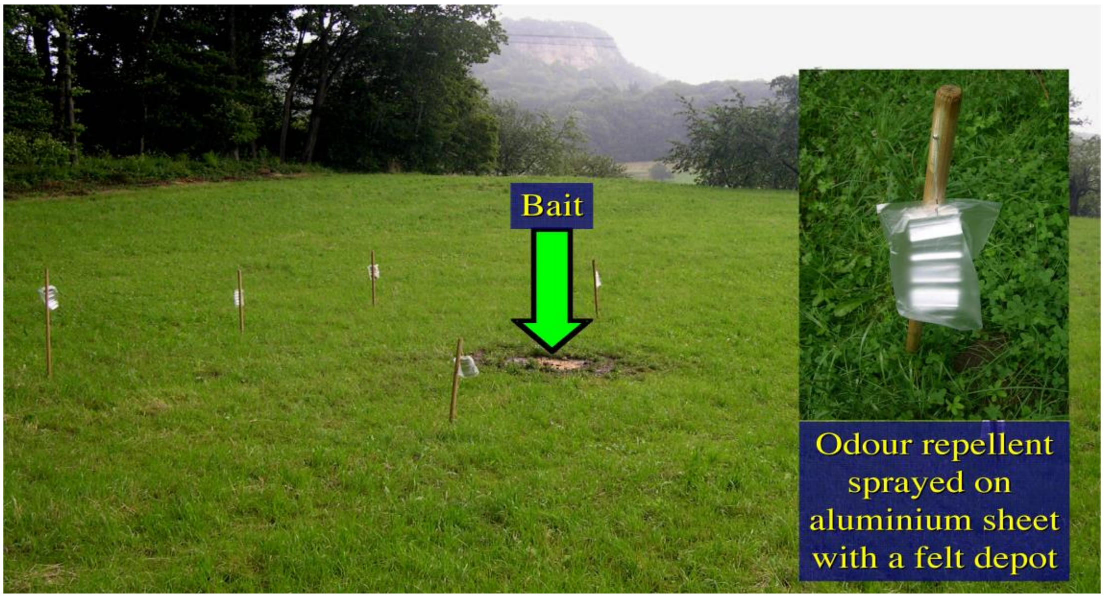

Fig. 10 Baited luring site at Sissach, Basel-Land, Switzerland. The bait consisted of attractive food such as maize grains and apples. This particular site was surrounded by the odour repellent which was sprayed on purpose-built aluminium sheets with felt depots that were fixed on eight posts surrounding the bait.

Chapter 3: Results

In the following chapter I present the results that underlie this thesis. Section 3.1 comprises the papers concerning the investigated deterrent systems, which were published in peer-reviewed scientific journals. The papers are presented chronologically, according to the date of publication.

3.1 Paper section

I. Schlageter A, Haag-Wackernagel D (2011). Effectiveness of solar blinkers as a means of crop protection from wild boar damage. *Crop Protection* 30: 1216–1222.

II. Schlageter A, Haag-Wackernagel D (2012). Evaluation of an odor repellent for protecting crops from wild boar damage. *Journal of Pest Science* 88: 209–215.

III. Schlageter A, Haag-Wackernagel D (2012). A Gustatory Repellent for Protection of Agricultural Land from Wild Boar Damage: An Investigation on Effectiveness. *Journal of Agricultural Science* 4(5): 61–68.

I

Schlageter A, Haag-Wackernagel D (2011)

Effectiveness of solar blinkers as a means of crop protection from wild boar damage.

Crop Protection 30: 1216–1222.

Crop Protection 30 (2011) 1216–1222

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Effectiveness of solar blinkers as a means of crop protection from wild boar damage

Adrian Schlageter*, Daniel Haag-Wackernagel

Department of Biomedicine, Institute of Anatomy, University of Basel, Pestalozzistrasse 20, CH-4056 Basel, Switzerland

A R T I C L E I N F O

Article history:
Received 5 January 2011
Received in revised form
9 May 2011
Accepted 10 May 2011

Keywords:
Crop protection
Damage
Deterrent
Solar blinkers
Sus scrofa
Wild boar

A B S T R A C T

The population density of wild boar (*Sus scrofa*) in Northern Switzerland has increased dramatically during the last three decades and the species has become a major threat to agriculture, causing severe damage to crops and grassland. Vulnerable fields have to be protected from wild boar incursion, which is in most cases achieved by using electric fences. Alternatively, deterrents basing on optical, acoustical or gustative effect are available. The effectiveness of most of these systems has not previously been scientifically tested in the field. In our study we investigated the effectiveness of solar blinkers at baited luring sites. We conducted field experiments at 4 different sites with free-ranging wild boars from January 2007 to January 2008. Data from 504 inspections of the luring sites indicate that solar blinkers reduced the probability of wild boar visits at the luring sites by 8.1% compared to the control sites. We therefore evaluate deterrence effect of solar blinkers to be insufficient for effective crop protection. Probability of wild boar visits at the luring sites changed throughout the study period, showing seasonal variation of the extent of wild boar activity in the fields.

1. Introduction

Today the wild boar (*Sus scrofa*) ranges over the entire European continent (Briedermann, 1990; Macdonald, 2001). Wild boars can cause considerable damage to crops, particularly maize and wheat, and grassland, mainly by foraging, but also by trampling of crops when using the fields as a shelter (Kristiansson, 1985; Schley and Roper, 2003; Herrero et al., 2006; Schley et al., 2008). In many European countries, governmental compensations for crop damage amount to millions of Euros every year (Mazzoni della Stella et al., 1995; Vassant, 1997; Calenge et al., 2004; Klein et al., 2007). Since about 1970, populations have also increased in Switzerland, and the species has naturally colonized new areas, leading to an extension of boar activity in farmland and intensified conflicts with humans. In 1988, 848 wild boars were shot, 2503 in 1998, and 8748 in 2008. Accordingly, crop damage has increased and became unacceptable for farmers and game authorities. In Switzerland, compensation for wild boar damage to crops and grassland increased from €695,500 in 1998 to €1,746,900 in 2008, with a maximum of €1,886,300 in 2002 (yearly published hunting statistics of the Federal Office for the Environment [www.wild.uzh.ch/jagdst/]). This is also true for the Canton Basel-Land, a region in Northwestern Switzerland, which suffers from high wild boar densities.

The national government has taken measures to prevent further increases in wild boar damage. The Federal Office for the Environment (FOEN) commissioned a guide for improvement in wild boar management, hunting, damage prevention, and population control (Schnidrig-Petrig and Koller, 2004). Its three fundamental conclusions are: 1) Hunting is crucial for regulating the populations, thus, hunting strategies need improvement. 2) Vulnerable fields need efficient- and adequate protection. 3) Damage compensation policy should provide an incentive for effective regulation of the populations, and for appropriate cultivation.

These approaches have already been adopted before in the Canton Basel-Land. New hunting strategies have been established to keep wild boar populations on a sustainable level. To achieve this goal the hunting season for wild boars has been prolonged. Additionally, hunting pressure has been increased and concentrated on the fields during the growth period.

In order to provide an incentive for appropriate cultivation and damage prevention farmers receive full compensation for damage only if the crops are protected adequately. In the case of unprotected fields the government compensates only the first occurrence of damage to the full extent. Game authorities can demand an adequate protection of particularly vulnerable fields from farmers. Repeated damage to unprotected fields will not be compensated. Furthermore, since measure of damage to crops is positively related to the density of wild boar populations (Geisser, 1998), hunters contribute to compensation payments.

* Corresponding author. Tel.: +41 61 267 27 12; fax: +41 61 267 27 91.
E-mail address: adrian.schlageter@unibas.ch (A. Schlageter).

0261-2194/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cropro.2011.05.008

Geisser and Reyer (2004) proved that hunting does reduce wild boar damage for the Canton Thurgau in Northeastern Switzerland. Nevertheless, since wild boar population reproductive rates can be up to 200% under ideal conditions (Briedermann, 1990), hunting mortality can be compensated within one year. Mild winters, warm springs, and the abundant crop of common acorn (*Quercus robur*) and common beech (*Fagus sylvatica*) during recent winters provided ideal conditions for wild boar reproduction over the past years (Geisser and Reyer, 2005).

Hence, protection of vulnerable fields will remain essential in the future. This preferably involves the use of electric fences, which have been shown to be an effective means to prevent access to crops for wild boars in the past (Boisaubert et al., 1983; Vassant and Boisaubert, 1984). However, regular surveillance is required to assure maintenance of both fences and batteries, which implies constant effort and therefore high costs for the farmers. In addition, electric fences are expensive and reimbursement by the government is not guaranteed. Farmers and authorities are highly interested in efficient alternatives to the expensive and labor-intensive electric fences. Several methods have been developed that claim to reduce the level of damage on crops. While some studies provide evidence for the success of supplemental feeding in reducing field damages (Vassant and Breton, 1986; Meynhardt, 1991; Vassant et al., 1992; Vassant, 1994a,b; Geisser, 1998; Calenge et al., 2004), others showed no positive effect (Hahn and Eisfeld, 1998; Geisser, 2000; Geisser and Reyer, 2004; Cellina, 2008) or even proved an increase in damage due to supplemental feeding (Groot Bruinderink et al., 1994). Supplemental feeding is practiced in the Canton Basel-Land mainly to bait wild boars for easier shooting. Furthermore, methods based on acoustic, olfactory or gustatory deterrence have not yielded satisfactory long-term results (Vassant and Boisaubert, 1984; Vassant, 1994a). These methods included radios, PIR-activated horns, gas cannons, and chemical treatment of corn seeds with several repellents. Still, various deterrents are available commercially today that claim to be effective in deterring wild boars. However, most of these are lacking scientific proof of efficiency, which particularly applies to optic devices. Information on the effectiveness mainly derives from the manufacturers of the deterrent systems themselves. In Switzerland optic devices are mainly used to reduce collisions with cervids and wild boars on frequented rural roads. Most common devices are reflectors, which direct the headlights of approaching cars sideward. Other optic devices include flashlights and PIR-activated floodlights. These are mostly used to deter roe deer. A deterrent commercially available that particularly claims to repulse wild boars are solar blinkers, which are solar-powered LEDs charging in daylight and constantly blinking during the night. Solar blinkers have already been tested in several unpublished trials in the past, which were conducted by hunters and game wardens. These trials reasoned that solar blinkers were effective in terms of wild boar deterrence and damage reduction. Yet, none of these have met scientific criteria. Nevertheless, the positive reports on solar blinkers attracted interest of game authorities of the Canton Basel-Land. Since wild boars become nocturnal in areas where they are hunted and, therefore, damage to agricultural land is exclusively caused at night, optic devices like solar blinkers might be an advantageous alternative to electric fences. The aim of this study was to investigate the effectiveness and sustainability of solar blinkers in field experiments with free-ranging wild boars. We believe this is preferable to trials with captive wild boars as the natural and uninfluenced behavior of the wild boars is crucial for effective testing.

2. Materials and methods

2.1. Study area

We performed field experiments between January 2007 and January 2008 at 4 different study sites in Sissach (47° 28′ 0.01″ N, 7° 49′ 0.01″ E), Rothenfluh (47° 27′ 43.98″ N, 7° 54′ 58.03″ E), two communities of the Canton Basel-Land, and Hofstetten (47° 28′ 39.98″ N, 7° 30′ 55.04″ E), an exclave of the Canton Solothurn surrounded by territory of the Canton Basel-Land, Switzerland. Two study sites were located in Rothenfluh (rot1 and rot2), one in Sissach (sis) and Hofstetten (hof) respectively (Fig. 1). The 3 communities have been seriously affected by wild boar damage in the recent past. Distance between rot1 and rot2 was 800 m, thus the two study sites were likely to lie within the home range of the same wild boar family group. Distances between sis–hof, sis–rot1+2, and hof–rot1+2 were 20 km, 15 km, and 36 km respectively. Hence, the 4 study sites lay within the home ranges of at least 3 different wild boar family groups. The Canton Basel-Land (518 km^2) ranges in elevation from 250 m to 1170 m. The climate was continental with an average annual precipitation from 750 mm to 1300 mm, and average temperatures ranged from 2.1 °C in January to 19.6 °C in July. The countryside was characterized by high structural diversity, hilly topography, and patchy forest distribution. Forests covered 42% of the study area and were mostly used for the lumber industry. Agricultural land covered 41% of the area and consisted mainly of pasture, wheat, and maize. Except for the extremely rare lynx (*Lynx lynx*), natural predators of the wild boar were absent in Northwestern Switzerland.

2.2. Deterrent system

Solar blinkers, model 'BAR' from Interplex Solar, Inc., East Haven, Connecticut consisted of 3 red LEDs spaced at intervals of 2.5 cm covered by an ultrasonic welded weatherproof case (dimensions: 8.5 × 4 × 2.5 cm) with a solar cell on top, an on/off switch, and an implied accumulator. During daytime the solar cell charged the accumulator, which energized the LEDs in the night. Once switched on, the LEDs automatically started blinking at a light intensity of 300 cd–400 cd, which approximately represented dusk and dawn respectively. Blinking rate was 2 Hz, viewing distance was 500 m under good conditions in clear nights without rainfall and/or interfering light.

2.3. Experimental design

Solar blinkers were investigated at baited luring sites setup in grassland near the forests harboring wild boar. The purpose of allurement was to generate a high motivation for the wild boars to surmount a particular deterrent system. Each of our 4 study sites consisted of 2 luring sites, one as a test site (hereinafter referred to as

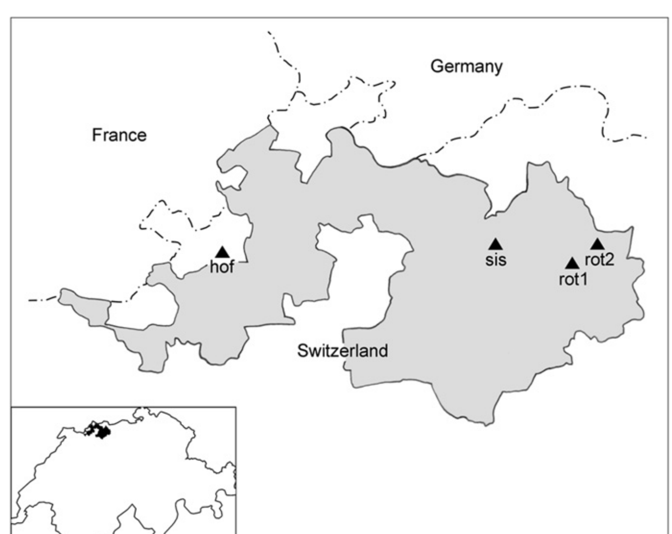

Fig. 1. Location of the four study sites. Gray: Canton Basel-Land, Switzerland.

T) and one as a control site (C). Luring sites were placed on known wild boar trails to maximize the chance of wild boars passing close to the experimental setup. T was surrounded with solar blinkers whilst C remained without a deterrent system. Blinkers were fixed on 8 posts at varying heights between 30 cm and 80 cm, spaced at intervals of 3 m around the luring sites, forming a 6-m^2 treatment area. Minimum distance between the two luring sites was 40 m and ranged up to 115 m to prevent interference of C by the deterrent system of T. We therefore also accounted for the topographic conditions to ensure that blinkers were not visible at C. For the purpose of allurement we provided an attractive food mixture composed of apples, maize grains, and protein rich food pellets (24% protein). Field experiments directly started with setup of the luring sites. We did not perform pre-baiting during an initial phase of the experiments to avoid habituation of the wild boars. In addition, we aimed at reproducing the situation of an emerging food source, which is protected, as it is most commonly the case in the field since farmers normally put up electric fences or other deterrence before ripening of the fruits. By initially baiting the wild boars to our test sites we would have created the inadequate situation of an already existing and unprotected food source. Therefore, we intended to avoid any artificial habituation. Tracks were recorded by a track band consisting of 50 cm broad and 10 cm deep ditch filled with soil and sand around the luring sites, representing a square of about 2 m^2. The track band was regularly dampened to ensure that every visit by wild boars or other animals would leave a mark. Inspection of the luring sites was performed every second day as far as possible and avoiding larger gaps of more than five days. Additionally, we installed infrared camera traps to investigate the reliability of the track record and to get more information about structure and size of the wild boar family groups as well as to document other animals that were attracted by the luring sites. Of a total of 50 wild boar visits at the luring sites documented by camera traps, there was a distinctive track record in 48 cases resulting in a 96% match. In two cases the camera trap photographed wild boars but no clearly identifiable tracks of wild boars on the track band could be recorded. In both cases track record was not distinct because of dryness of the soil in the track band. Hence, the track band surrounding the lure food proved to be a reliable means for detecting wild boar visits at the luring sites.

At each inspection tracks of wild boars at a luring site were recorded as present or not. After every inspection the lure food was replaced or filled up with fresh food and the track band was smoothed to remove old tracks and dampened to avoid drying. After each visit by wild boars at a luring site, C and/or T, we switched the experimental setup, i.e. the deterrent system was installed at the former C and vice versa. In choosing this regime of constant alternation between the two luring sites we aimed at preventing the wild boars from habituating themselves to the experimental setup. Furthermore we were able to account for the possibility of biased visits at one of the two luring sites compared to the other at each study site. Solar blinkers were considered to be effective if they fully prevented wild boars from entering a luring site. When wild boars surmounted the deterrent system, we compared the number of visits between C and T.

2.4. Statistical analysis

The effect of solar blinkers on the probability of wild boar visit at the luring sites was assessed by logistic regression analysis. The binary indicator variable of a wild boar visit was the dependent variable and the two-level factor treatment (T *vs.* C) was the predictor of interest. We controlled for the influence of month, duration of the experiment (*n* days), study site and the interactions treatment × month, treatment × duration, and treatment × site in the model. We started with a model including all predictors. In this full model, month was treated as a factor with 12 levels. We additionally included the quadratic- and cubic-effect of duration to account for non-linear effects. We gradually removed the non-significant interactions, quadratic- and cubic-effects from the model, leaving the main effects within it. At last, the 12-level factor month was aggregated to a 4 level factor "season" with spring = March, April, May, summer = June, July, August, fall = September, October, November, and winter = December, January, February. This further reduced the model by 8 parameters. Model comparisons were done using the Likelihood ratio test. The analyses were done using the R software for statistical computing. Checking for collinearity of explanatory variables produced VIF-values of 1.7 and less for all coefficients. Correlations of explanatory variables are shown in Fig. A.1. Analysis of residuals indicated that there were too many zero values in our data (days on which neither T nor C were visited). We therefore calculated a zero-inflated model to verify the *p*-values of the logistic regression model.

The zero-inflated model consisted of two Bernoulli-models with logistic link functions each. The first model described whether there were wild boars around which potentially could visit a luring site. Predictor in this model was day of the year alone. Because our data span over more than one year, day of the year has to be treated as a circular variable. Therefore, we included day of the year (t) as well as $\sin(t)$, $\cos(t)$, $\sin(2t)$, $\cos(2t)$, $\sin(3t)$ and $\cos(3t)$ as predictors to allow for periodic effects (Fisher, 1993). The second model described the probability of a visit conditionally on wild boars being around. In this model duration, the quadratic- and cubic-effect of duration, study site and treatment were predictors. We used Bayesian methods for model fitting. Parameters were estimated by Markov chain Monte Carlo simulations using WinBUGS (Spiegelhalter et al., 2003). WinBUGS was accessed by R via R-interface R2WinBUGS (Sturtz et al., 2005). We assessed the convergence of the Markov chains graphically and using the R_hat value (Gelman et al., 2004). Because Markov chain Monte Carlo simulations produced a random sample from the posterior distribution of the model parameters, we were able to directly calculate the effectiveness of solar blinkers in reducing probability of wild boar visits.

3. Results

An overview of duration of experiments, number of inspections, and number of visits for each study site is given in Table 1. Of a total of 504 inspections performed during the whole study period, we recorded 46 visits of wild boars at the study sites, resulting in a relative frequency of 9%. In most cases wild boars visited both C and T during the same night ($n = 39$). However, we recorded six cases where wild boars exclusively visited C, and there was one special case, where wild boars visited T whereas C remained untouched. In the majority of cases (94%) the lure food was completely consumed. Overall, we recorded successful surmounting of the deterrent system by wild boars in 40 cases whereas C was visited 45 times.

Table 1
Duration of field experiments, number of inspections, and numbers of wild boar visits at control sites (C), test sites (T), and both together during the same night (C + T) for the study sites at Sissach (sis), Rothenfluh (rot1, rot2), and Hofstetten (hof), Canton Basel-Land, Switzerland in 2007/2008.

Study site	sis	rot1	rot2	hof	Total
Duration of experiment (*d*)	194	382	292	223	1091
Inspections	103	194	152	55	504
Visits at C exclusively	4	1	0	1	6
Visits at T exclusively	0	0	0	1	1
Visits at C + T	9	8	8	14	39
Total	13	9	8	16	46

Fig. 2 demonstrates the results of the zero-inflated model. Probability of wild boar visits at T was 0.919 compared to C (Credible Interval: 0.673, 1.21). Thus, blinkers reduced the probability of wild boar visits at the luring sites by 8.1%. We are 74.4% certain that blinkers do reduce the probability of wild boar visits (74.4% of the a-posteriori distribution lies below 1). However, the effect was not significant.

Results of the logistic model are given in Table 2. Only month, duration and site did have significant effects on the probability of wild boar visits at the luring sites, whereas treatment and the interactions had no significant effects. Duration and month were strongly correlated ($r = 0.6478$). Duration showed a significant effect on probability of wild boar visits when previously corrected for month ($LR_1 = 7.52$, $P = 0.006$). When duration was tested without correcting for the effect of month, the linear trend was lacking, whereas a quadratic- and a cubic-effect emerged. Hence, it appears that the effect of duration was overlain by the differences between the months and a complete separation of the effect was impossible due to the correlation between duration and month. The cumulative effect of duration (duration + duration^2 + duration^3), however, was significant ($LR_3 = 40.8$, $P < 0.001$). Month significantly influenced the probability of wild boars visiting a luring site ($LR_{11} = 71.85$, $P < 0.001$). Because estimates of means were unconfident for February, March, and May we replaced month with season in an additional model to get more reliable estimates. Fig. 3 illustrates the differences in the probability of wild boar visits between the seasons, which were significant as well ($LR_3 = 15.9$, $P = 0.001$). Maximal probability of wild boar visits was reached in fall. However, comparison of the likelihood of a model containing a four-level factor “season” with one that contains a 12-level factor “month” revealed a significant difference ($LR_8 = 55.95$, $P < 0.001$). Conclusively, a significantly higher proportion of the variance can be explained when accounting for between-month variance than when the between-season variance is corrected for.

Fig. 4 demonstrates the differences of wild boar visits at the four test sites. Probability of visits differed between the sites (LR3 = 87.825, $P < 0.001$) with minimal values at rot1 and rot2 of 0.026 and 0.068 respectively and a maximum of 0.42 at hof.

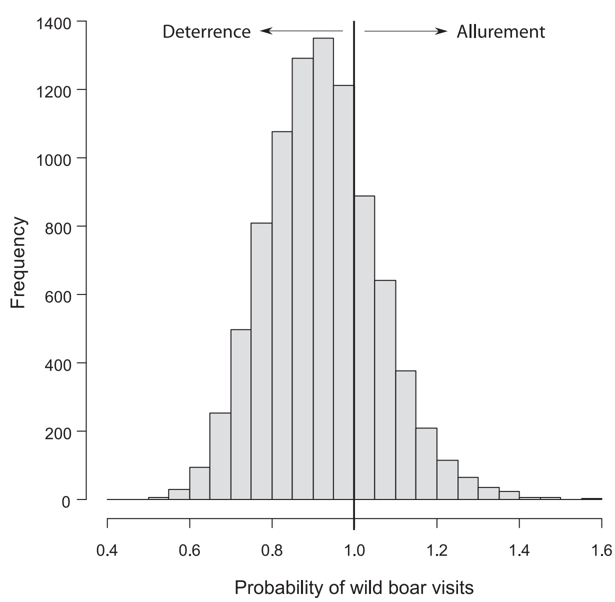

Fig. 2. Posterior probability distribution of wild boar visits at a luring site protected by solar blinkers. A value of 1 implies that probabilities of wild boar visits are the same at luring sites with or without blinkers. Values below 1 signify a reduced probability of wild boar visits at luring sites protected by solar blinkers. The distribution is slightly positively skewed, indicating a marginal effect of solar blinkers.

Table 2
Significance tests (Likelihood ratio tests) of the logistic regression to predict whether a luring site is likely to be visited by wild boars, or not. The interactions were omitted from the model to test the main effects. The effect of solar blinkers (Treatment) was not significant.

Predictor variables	*df*	LR	*P*-value	*P*-value of reduced model
Treatment	1	0.341	0.559	
Month	11	71.852	< 0.001	<0.001 (model without Duration)
Duration	1	7.523	0.006	0.212 (model without Month)
Duration^2	1	0.745	0.388	0.024 (model without Month)
Duration^3	1	0.358	0.550	0.031 (model without Month)
Site	3	87.825	< 0.001	
Treatment × Site	3	0.723	0.868	
Treatment × Month	11	0.98	1	
Treatment × Duration	1	0.104	0.747	
Treatment × Duration^2	1	0.001	0.976	
Treatment × Duration^3	1	0.009	0.924	

4. Discussion

The present study reveals that solar blinkers were not effective in deterring wild boars from luring sites. Scientific record on optic devices used for crop protection from mammal damage is scarce, which particularly applies to the wild boar. In general, effectiveness of optic devices is highly doubted in literature. Some reports indicate that strobe lights may frighten coyotes. However, the authors highlight that the effect is rather short-termed and dependent on spare use and frequent alternation of location of the device (Linhart et al., 1984). Trials conducted to evaluate the efficacy of a sonic device combined with strobe lights against white-tailed deer did not yield satisfactory results (Belant et al., 1998). There seems to be a general consensus that optic devices are not effective in deterring deer.

Visual repellents are mostly designed to affect birds, which have the most highly developed visual facility among vertebrates (Bowmaker, 1980). In contrast, mammals are often color blind or, at lest, have limited color vision (Jacobs, 1993). This is also true for the

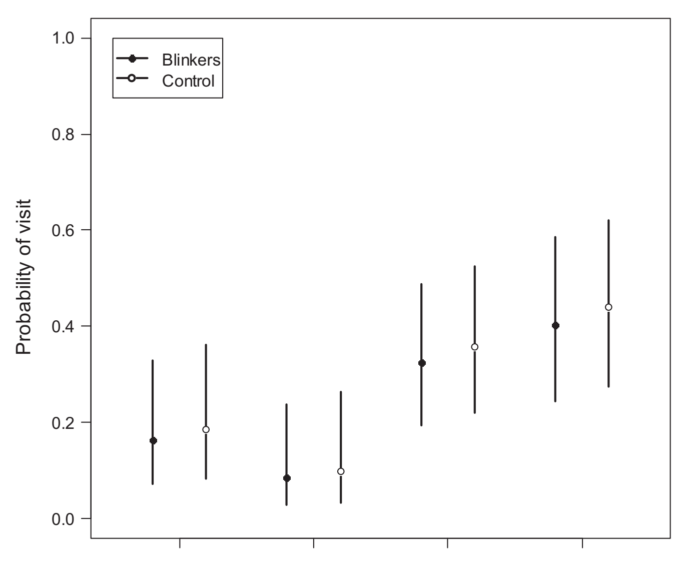

Fig. 3. Probability of wild boar visits at the luring sites averaged over the four seasons. Predicted values (incl. 95% CI) are applied for site = hof and duration = 136. Winter: Dec–Feb, spring: Mar–May, summer: Jun–Aug, fall: Sep–Nov.

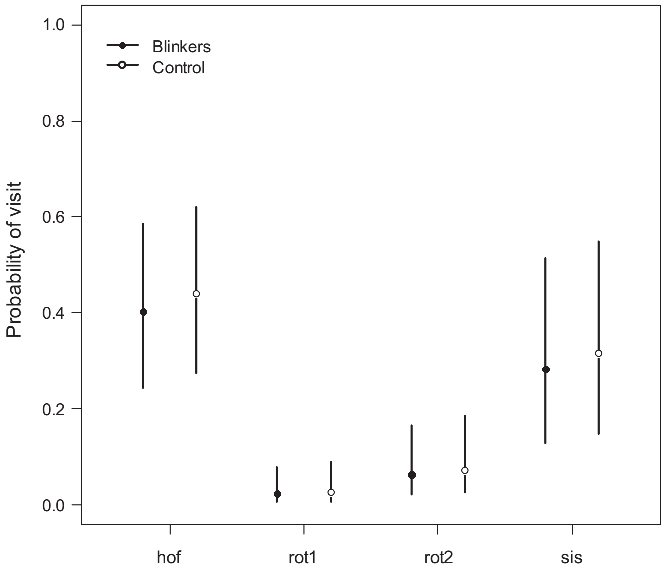

Fig. 4. Probability of wild boar visits at the study sites in Hofstetten (Hof), Rothenfluh (Rot1, Rot2), and Sissach (Sis). Predicted values (incl. 95% CI) are applied for season = fall and duration = 136.

wild boar. Eguchi et al. (1997) revealed that Japanese wild boars Sus scrofa leucomystax, a subspecies of the European wild boar, were only capable of recognizing bluish colors but failed to recognize red and green. The solar blinkers we investigated emitted red light. Given that wild boars are not able to discriminate red from gray light, we would expect a reduced deterrence effect of red blinkers.

Moreover, effects of visual deterrents rely on startle responses and neophobia by their target animals. Our results, however, do not confirm neophobia in the sense of an initial deterrence effect of solar blinkers, for neither the interaction treatment × duration nor treatment × month had significant effect on wild boar visits at the luring sites.

Our findings evidence seasonal changes in wild boar activity outside the forest, which may be related to changes in foraging behavior throughout the year. Maximum probability of visits at the luring sites in summer and fall coincides with ripening of crops and fruit. Several studies have revealed that wild boar damage to agricultural land peaks in summer and fall (Łabudzki and Wlazełko, 1991; Geisser, 2000; Herrero et al., 2006; Schley et al., 2008), which is in line with our study since it confirms enhanced activity of wild boar outside the forest during that time as a consequence of changed foraging behavior. The differences in probability of visits between the four study sites may indicate differences in wild boar activity and/or population density. Nevertheless, there was no significant difference in the effect of blinkers between the study sites (interaction treatment × site not significant, Table 2), thus, evidencing that site-specific factors such as remoteness, degree of anthropogenic impact, or wild boar density did not influence the effect of blinkers.

Frequency of wild boar visits at our luring sites was relatively low, especially during the initial phase of our field experiments. There may be several explanations for this. Even though we tried to minimize the influence of our experimental setup, it might have had impaired data collection by an intrinsic deterrence effect. Our results suggest that wild boars behave very cautiously concerning changes in their habitat.

Furthermore, the environmental conditions may have negatively interfered with our field experiments. Summer 2006 was extremely hot and dry in Northwestern Switzerland. Average temperature in July was 23.8 °C which is 4 °C above the 20-year average. Precipitation in July amounted about 30 mm, which is 60 mm below the 20-year average. As a consequence, especially common beech and common oak showed typical water stress responses by producing a huge abundance of mast crops in Autumn 2006. We believe that the increased food supply in the forests lead to a decrease in wild boar activity outside the forests during winter 2006/2007, which may be an explanation for the low probability of visits at our luring sites, especially during the first half of field experiments.

Moreover, hunting effects wild boar behavior and activity range (Baubet et al., 1998; Sodeikat and Pohlmeyer 2002). In Basel-Land, hunting of young boars up to 2 years of age is performed throughout the year on the fields and the close season lasts from 1st of April till 16th of June in the forests. Hunters had achieved an exceptional high hunting bag of 985 shot wild boars in 2005/2006, which was a new maximum by then (Yearly published hunting data of the Canton Basel-Land). Since hunting proved to reduce wild boar damage to fields and grassland (Geisser and Reyer, 2004), we suppose that the reduction of wild boar populations by hunting negatively impaired our data collection.

5. Conclusion

Our findings confirm the highly adaptive capabilities of wild boar since solar blinkers were ineffective in preventing the animals from entering our luring sites. Solar blinkers are therefore not recommendable for field protection. To date only the electric fence has been proven to protect fields adequately from wild boar damage. Therefore, compensation payment policy in the Canton Basel-Land will not be changed for the present, meaning that farmers are not encouraged to use other deterrent systems than electric fences to protect their fields. However, more investigation on different deterrent systems is needed since the issue of wild boar damage to agriculture is far from being solved. Even though reduction of wild boar populations by means of hunting is crucial for damage prevention, it is assumed that populations recover within a short time. Hence, field protection will remain important and the need of inexpensive alternative deterrents will last. Since wild boar foraging behavior changes throughout the year, which is reflected by our findings, we suggest to time field experiments to this critical phase of high wild boar activity outside the forest in summer and fall to achieve most fruitful data collection. Because of the sensitivity of wild boars concerning alterations in their natural habitat, interferences by the experimental setup should be avoided or kept as low as possible. Our simple methodological approach proved to be suitable for investigating the effectiveness of solar blinkers, but also applicable for other deterrent systems.

Acknowledgments

This study was funded by the Volkswirtschafts- und Sanitätsdirektion of Basel-Land, the Federal Office for the Environment (FOEN), and the Freiwillige Akademische Gesellschaft (FAG). We thank I. Bloch and D. Zopfi, head and deputy of the department Veterinär-, Jagd- und Fischereiwesen for bringing us into contact with game wardens, hunters, and farmers at our study sites. A. Ochsenbein gave technical support and valuable input for the field experiments. We thank C. Zentner and M. Küng, game wardens of Sissach and Rothenfluh, who provided valuable information on the local conditions, activity ranges, and trails of the wild boars in the study area. We also thank the farmers of Sissach, Rothenfluh, and Hofstetten for readily letting us perform our experiments on their land.

Appendix

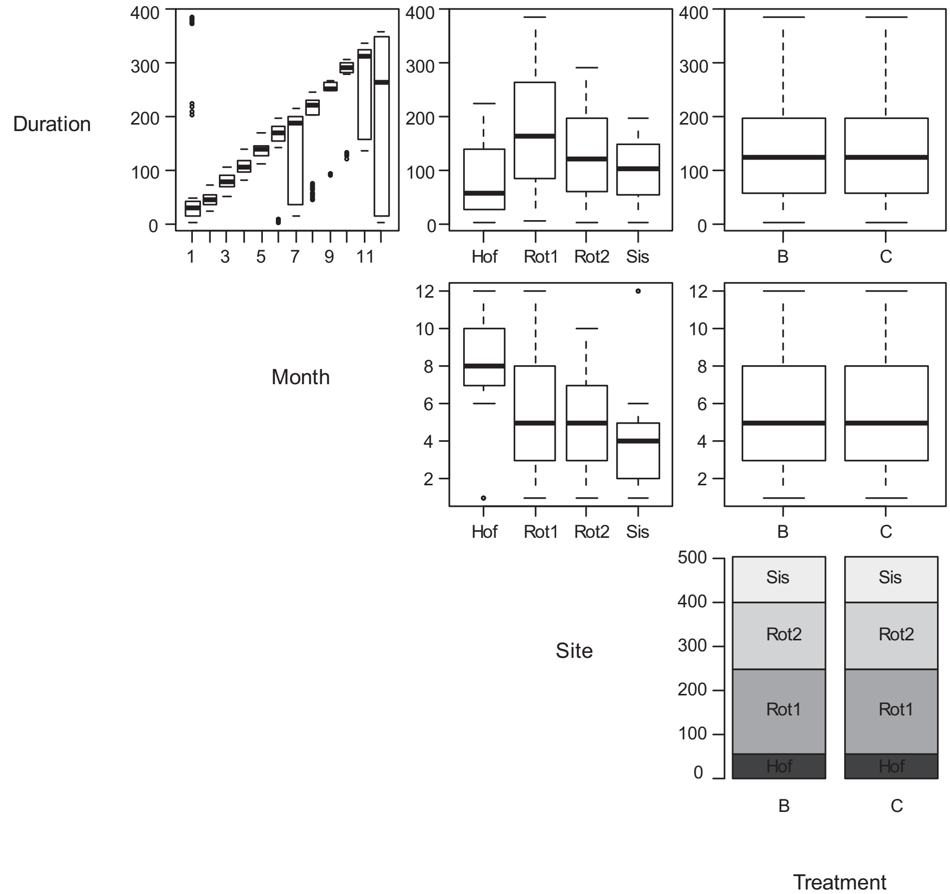

Fig. A.1. Correlation among the explanatory variables. Duration and month are strongly correlated. Sites differ in month and treatment. However, treatment does not differ in any other explanatory variable, thus, the effect of solar blinkers is clearly determinable.

References

Baubet, E., Brandt, S., Touzeau, C., 1998. Effet de la chasse sur les stratégies d'occupation de l'espace des sangliers (Sus scrofa). Analyses préliminaires. Gibier Faune Sauvage 15, 655–658.

Belant, J.L., Seamans, T.W., Tyson, L.A., 1998. In: Baker, R.O., Crabb, A.C. (Eds.), Evaluation of Electronic Frightening Devices as White-tailed Deer Deterrents. Proc 18th Vertebr Pest Conf. University of California, Davis.

Boisaubert, B., Bouldoire, J.L., Vassant, J., 1983. Bilan de cinq années d'expérimentation de protection des cultures par clôtures électriques dans le département de la Haut-Marne. Bull. Mens Off. Natl. Chasse 68, 15–26.

Bowmaker, J.K., 1980. Colour vision in birds and the role of oil droplets. Trends Neurosci. 3 (8), 196–199.

Briedermann, L., 1990. Schwarzwild, second ed. VFB Deutscher Landwirtschafts-Verlag, Berlin, Germany.

Calenge, C., Meillard, D., Fournier, P., Fouque, C., 2004. Efficiency of spreading maize in the garrigues to reduce wild boar (Sus scrofa) damage to Mediterranean vineyards. Eur. J. Wildl. Res. 50, 112–120.

Cellina, S., 2008. Effects of Supplemental Feeding on the Body Condition and Reproductive State of Wild Boar Sus Scrofa in Luxembourg. Dissertation, University of Sussex, Brighton, UK.

Eguchi, Y., Tanida, H., Tanaka, T., Yoshimoto, T., 1997. Color discrimination in wild boars. J. Ethol. 15, 1–7.

Fisher, N.I., 1993. Statistical Analysis of Circular Data. Cambridge University Press.

Geisser, H., 1998. The wild boar (Sus scrofa) in the Thurgau (northeastern Switzerland): population status, damages and the influence of supplementary feeding on damage frequency. Gibier Faune Sauvage 15, 547–554.

Geisser, H., 2000. Das Wildschwein (Sus scrofa) im Kanton Thurgau (Schweiz): Analyse der Populationsdynamik, der Habitatansprüche und der Feldschäden in einem anthropogen beeinflussten Lebensraum. Dissertation, University of Zurich, Zurich, Switzerland.

Geisser, H., Reyer, H.-U., 2004. Efficacy of hunting, feeding, and fencing to reduce crop damage by wild boars. J. Wildl. Manage. 68, 939–946.

Geisser, H., Reyer, H.-U., 2005. The influence of food and temperature on population density of wild boar Sus scrofa in the Thurgau (Switzerland). J. Zool. (Lond) 267, 89–96.

Gelman, A., Carlin, J.B., Stern, H.S., Rubin, D.B., 2004. Bayesian Data Analysis, second ed. CRC/Chapman&Hall, Boca Raton, FL.

Groot Bruinderink, G.W.T.A., Hazebroek, E., van der Voot, H., 1994. Diet and condition of wild boar, condition of wild boar, Sus scrofa scrofa, without supplementary feeding. J. Zool. (Lond) 233, 631–648.

Hahn, N., Eisfeld, D., 1998. Diet and habitat use of wild boar (Sus scrofa) in SW-Germany, Germany. Gibier Faune Sauvage 15, 595–606.

Herrero, J., García-Serrano, A., Couto, S., Ortuño, V.M., García-González, R., 2006. Diet of wild boar *Sus scrofa* L. and crop damage in an intensive agroecosystem. Eur. J. Wildl. Res. 52, 245–250.

Jacobs, G.H., 1993. The distribution and nature of colour vision among the mammals. Biol. Rev. 68 (3), 413–471.

Klein, F., Baubet, E., Toigo, C., Leduc, D., Saint-Andrieux, C., Saïd, S., Fréchard, C., Vallance, M., 2007. La gestion du sanglier. Des pistes et des outils pour réduire les populations. Brochure Technique. Off Natl Chasse, Paris, Auffargis, Bar-le-Duc, France.

Kristiansson, H., 1985. Crop damage by wild boars in Central Sweden. In: Proceedings of the XVIIth Congress of the International Union of Game Biologists. Brussels, Belgium, pp. 605–609.

Łabudzki, L., Wlazełko, M., 1991. Saisonale Dynamik der vom Schwarzwild im Feldanbau verursachten Schäden im Forschungsgebiet Zielonka. Z. Jagdwiss 37, 250–257.

Linhart, S.B., Sterner, J.D., Dasch, G.J., Theade, J.W., 1984. Efficacy of light and sound stimuli for reducing coyote predation on pastured sheep. J. Range Manage. 35, 276–281.

Macdonald, D., 2001. The New Encyclopedia of Mammals. Oxford University Press, Oxford, United Kingdom.
Mazzoni della Stella, R., Calovi, F., Burrini, L., 1995. The wild boar management in a province of Central Italy. IBEX JME 3, 188–191.
Meynhardt, H., 1991. Wildversorgung, Trophäen und Schadensverhütung. Schwarzwild-Bibliothek 4. Verlag Neumann-Neudamm, Melsungen, Germany.
Schley, L., Roper, T.J., 2003. Diet of wild boar Sus scrofa in Western Europe, with particular reference to consumption of agricultural crops. Mammal Rev. 33, 43–56.
Schley, L., Dufrêne, M., Krier, A., Frantz, A.C., 2008. Patterns of crop damage by wild boar (*Sus scrofa*) in Luxembourg over a 10-year period. Eur. J. Wildl. Res. 54, 589–599.
Schnidrig-Petrig, R., Koller, N., 2004. Praxishilfe Wildschwein-Management. Service romand de vulgarisation agricole, Lausanne, Switzerland.
Sodeikat, G., Pohlmeyer, K., 2002. Temporary home range modifications of wild boar Sus scrofa caused by drive hunts in Lower Saxony (Germany). Proceedings of the 25th Congress of the International Union of Game Biologists and the IXth International Symposium Perdix. E. Hadjisterkotis, editor, 3–7 September 2001. Lemesos, Cyprus. Z. Jagdwiss 48 (Suppl. 1), 161–166.
Spiegelhalter, D.J., Thomas, A., Best, N.G., Lunn, D., 2003. WinBUGS User Manual (Version 1.4). MRC Biostatistics Unit, Cambridge. www.mrcbsu.cam.ac.uk/bugs/.
Sturtz, S., Ligges, U., Gelman, A., 2005. R2WinBUGS: a package for running WinBUGS from R. J. Stat. Soft 12 (3), 1–16. http://www.jstatsoft.org/v12/i03/.
Vassant, J., 1994a. Les techniques de prévention des dégâts de sanglier. Bull. Mens Off. Natl. Chasse 191, 90–93.
Vassant, J., 1994b. L'agrainage dissuasif: résultats d'expériences. Bull. Mens Off. Natl. Chasse 191, 101–105.
Vassant, J., 1997. Le sanglier en France: ces quinze dernières années. Bull. Mens Off. Natl. Chasse 225, 32–35.
Vassant, J., Boisaubert, B., 1984. Bilan des expérimentations enterprises en Haut-Marne pour réduire les dégâts de sanglier (Sus scrofa) à l'encontre des cultures agrucoles. Smposium International sur le sanglier (International Wild boar symposium). F. Spitz, and D. Pépin, technical coordinators, Toulouse, France. pp. 187–199.
Vassant, J., Breton, D., 1986. Essai de reduction des dégâts de sangliers (Sus scrofa) sur blé (Triticum sativum) au stade laiteux par distribution de maïs (Zea mais) en forêt. Gibier Faune Sauvage 3, 83–95.
Vassant, J., Jullien, J.M., Brandt, S., 1992. Reducing wild boar damage to wheat and oats in summer: study of the effectiveness of maize distribution in the forest. In: Bobek, B., Perzanowski, K., Regelin, W.L. (Eds.), Proceedings of the 18th IUGB Congress, Global Trends in Wildlife Management. Jagdellonian University, Krakow, Poland.

II

Schlageter A, Haag-Wackernagel D (2012)

Evaluation of an odor repellent for protecting crops from wild boar damage.

Journal of Pest Science 88: 209–215.

J Pest Sci (2012) 85:209–215
DOI 10.1007/s10340-012-0415-4

ORIGINAL PAPER

Evaluation of an odor repellent for protecting crops from wild boar damage

Adrian Schlageter · Daniel Haag-Wackernagel

Received: 5 December 2011 / Accepted: 29 January 2012 / Published online: 12 February 2012

Abstract Wild boar populations have dramatically increased in the past decades and the species has spread all over Europe. As the wild boar expanded its activity range into agricultural land, conflicts with humans have intensified. Today, the damage caused by wild boar amounts to millions of dollars every year. In Switzerland, farmers usually protect fields with electric fences, which have proven to be effective in preventing damage, but are also expensive. Alternatively, various cheaper deterrents and repellents are commercially available. However, most of them lack scientific proof of efficacy. In the present study, we investigated the effectiveness of the odor repellent "Wildschwein-Stopp®" against wild boar. We conducted field experiments with free-ranging wild boars at baited luring sites, which were placed in three different regions of the Canton Basel-Land, Northwest Switzerland. The odor repellent was not able to prevent the wild boars from entering our luring sites. We recorded a minimal and non-significant deterrent effect of 0.4%. Our results lead to the conclusion that the repellent is ineffective and, therefore, not recommendable for crop protection. On the basis of the present study we generally doubt fear-inducing repellents to be effective against wild boars and feral pigs. Our findings may indicate seasonal variation in wild boar activity outside forests since the probability of wild boar visits at the luring sites differed according to the season. The visits at the luring sites peaked in spring and fall which coincides with the occurrence of damage to agricultural land.

Keywords Crop protection · Damage prevention · Human–wildlife conflict · Odor repellent · *Sus scrofa* · Wildschwein-Stopp

Communicated by M. Traugott.

A. Schlageter (✉) · D. Haag-Wackernagel
Department of Biomedicine, Institute of Anatomy, University of Basel, Pestalozzistrasse 20, 4056 Basel, Switzerland
e-mail: adrian.schlageter@unibas.ch

Introduction

The wild boar (*Sus scrofa*) is the fifth largest ungulate species in Europe and has an area-wide spread over the entire European continent (Briedermann 1990; Macdonald 2001). The species has naturally colonized new areas over the past decades. The spread and increase in population size of the highly opportunistic and omnivorous species, resulting in higher boar activity in farmland, have intensified conflicts with humans (Schley and Roper 2003). Wild boars can cause considerable damage to crops and grassland. In many European countries, governmental compensations for crop damage amount to millions of Euros every year (Mazzoni della Stella et al. 1995; Vassant 1997; Calenge et al. 2004). Since about 1970, the spread and size of populations have increased in Switzerland, which is manifested by continuously increasing wild boar bags. Accordingly, crop damage increased dramatically and became unacceptable to farmers and game authorities because of the financial implications relating to increasing compensation payments for wild boar damage to crops and grassland (Geisser 1998).

This is also true for the Canton Basel-Land, a region in Northwestern Switzerland, which has to cope with high wild boar densities (yearly published hunting data of the Canton Basel-Land (www.baselland.ch/main_statistik-htm.281141.0.html). Following the spread of the species over

Switzerland, the population started to grow in the early 80s, causing increasing problems in agriculture.

Three methods dominate among the attempts to reduce wild boar damage that are recommended in many scientific and popular articles (Briedermann 1990; Breton 1994; Mazzoni della Stella et al. 1995; Vassant 1997; Geisser 1998). First, wild boars are hunted intensively to keep population densities low. Second, farmers put up fences and other deterrent systems to prevent wild boars from entering the fields. Third, hunters offer supplemental food in the forest to keep the wild boars off the farmland. The effectiveness of supplemental feeding in terms of damage reduction is highly controversial and seems to depend on several aspects. While some studies provide evidence for the success of the method in reducing wild boar damage to agricultural crops (Vassant and Breton 1986; Meynhardt 1991; Vassant et al. 1992; Vassant 1994a, b; Calenge et al. 2004), others showed no, or even negative effects (Hahn and Eisfeld 1998; Geisser and Reyer 2004; Cellina 2008). Additional food enhances survival under poor environmental conditions and accelerates the onset of reproduction, which both can lead to population growth (Andrzejewski and Jezierski 1978; Briedermann 1990; Bieber and Ruf 2005). In those studies that reported successful damage reduction by means of supplemental feeding, food was supplied inside the forest at a distance of at least 1 km from the edge of the forest, the food supplied was spread out over large areas and was only provided during the critical period. These criteria are hard to be met in Switzerland with its highly fragmented landscape and patchy forest distribution. In the Canton Basel-Land, supplemental feeding is mainly practiced to bait wild boars for easier shooting. Hunting seems to clearly reduce wild boar damage (Geisser and Reyer 2004). Nevertheless, wild boar reproductive rates can increase up to 200% under ideal conditions (Briedermann 1990). Thus, populations are able to compensate the abatement inflicted by hunting within 1 year. Mild winters, warm springs, and the abundant crop of common acorn (*Quercus robur*) and common beech (*Fagus sylvatica*) during recent winters provided ideal conditions for the wild boars to thrive over the past years (Geisser and Reyer 2005). Hence, protection of the fields will remain essential in the future. Farmers preferably protect vulnerable fields with electrical fences, which have been proven to be an effective means to prevent access to crops for wild boars in the past (Boisaubert et al. 1983; Vassant and Boisaubert 1984). However, electrical fences require regular surveillance to assure maintenance of both fences and batteries, which is costly in terms of time. In addition, electrical fences are expensive and the government does not provide financial support. In the Canton Basel-Land, reimbursement for fencing costs repeatedly exceeded compensation payments in the past years and was therefore disestablished in 2008. The wildlife damage compensation fund is directly fed from the hunting licenses and the lease fees for hunting grounds. This commitment by the hunters provides an incentive for appropriate and intensive hunting.

However, farmers and authorities are highly interested in efficient alternatives to the expensive and labor-intensive electrical fence. Various deterrents are available today that claim to be effective in deterring wild boars. Methods based on acoustic, gustatory, and optic deterrence have not yielded satisfactory long-term results (Vassant and Boisaubert 1984; Vassant 1994a; Schlageter and Haag-Wackernagel 2011). These methods include radios, PIR-activated horns, gas cannons, chemical treatment of corn seeds with several repellents, and solar-powered LED-blinkers.

At present, there is little or no data to support claims of efficacy for the majority of commercially available deterrent systems, which particularly applies to odor repellents. Information on successful deterrence of wild boars mainly derives from the manufacturers of the deterrent systems themselves. In Switzerland, odor repellents are predominantly used to reduce collisions with game animals on frequented rural roads. The most common repellent is a scent fence called “Duftzaun®”, a chemical repellent that imitates predator urines, which is mainly used to deter roe deer. Many popular articles support the effectiveness of this repellent. Game authorities from several cantons of Switzerland but also in many regions in Germany and Austria use the scent fence to reduce wildlife collisions. Lutz (1994), however, could show that this odor repellent was not effective, neither in provoking startle responses by target animals, nor in reducing accidents with cervids on a rural road.

Olfaction is known to be the most pronounced sense in wild boar, playing an important role in the biology of the species. Wild boars not only use olfaction for orientation and foraging but also for intra-specific social interactions and for avoidance of natural enemies including man (Meynhardt 1978). Günterschulze (1979) found that the olfactory epithelium of wild boar has the largest surface area and most olfactory receptor cells of all species investigated so far. Humans make use of the well-developed olfaction of wild boar and its domesticated descendants using them as truffle pigs, sniffer pigs or “bloodhounds” (Zeuner 1967; Altevogt 1972; Briedermann 1990).

Against this background, odor repellents might be a promising means for deterring wild boar from agricultural crops. A deterrent commercially available that particularly claims to deter wild boar is “Wildschwein-Stopp®”, a chemical repellent imitating a mixture of several predator odors. “Wildschwein-Stopp®” has been tested in only a few unpublished trials in the past which were conducted by hunters and farmers. These tests reasoned that the repellent was effective in deterring wild boar and protecting fields.

Yet the positive reports are rather anecdotal and these studies did not meet scientific criteria. However, these field reports have attracted the interest of game authorities of the Canton Basel-Land. In the present study, we investigated the effectiveness of "Wildschwein-Stopp®" in field experiments with free-ranging wild boars.

Materials and methods

Study area

The present study was conducted in three municipal areas in the Canton Basel-Land, northwestern Switzerland. We performed field experiments between July 2007 and December 2008 at four different study sites in Sissach (47°28′0.01″N, 7°49′0.01″E), Rothenfluh (47°27′43.98″N, 7°54′58.03″E), and Hofstetten (47°28′39.98″N, 7°30′55.04″E). Two study sites were located in Rothenfluh (Rot1 and Rot2), one each in Sissach (Sis) and Hofstetten (Hof). These three municipal areas have been affected by repeated and severe wild boar damage in the recent past. The Canton Basel-Land is situated in northwestern Switzerland and covers an area of 518 km^2, which ranges in elevation from 250 to 1,170 m. The climate is continental with an average annual precipitation of 750–1,300 mm, and average temperatures range from 2.1°C in January to 19.6°C in July. Forests cover 42% of the study area and are mostly used for the lumber industry. Agricultural land covers 41% of the area and consists mainly of pasture (50%), cropland (40%), and fruit- and winegrowing (10%). The landscape is characterized by hilly topography, patchy forest distribution, and high structural diversity. Except for the Eurasian lynx (*Lynx lynx*), natural predators of the wild boar are absent in Northwestern Switzerland.

Deterrent system

The odor repellent spray "Wildschwein-Stopp®" from Hagopur Inc. is available in 500 ml aerosol spray. It claims to particularly deter wild boars by an offensive smell that should reflect a mixture of several predator odors. According to the manufacturer, the odor was composed of isobutane (30–60%), naphtha (1–15%), propane (1–10%), propane-2-ol (1–5%), 3-methyl butyric acid (1–5%), and non-hazardous additives. Hagopur Inc. also provides purpose built aluminum strips with felt depots on which the repellent can be sprayed. The manufacturer claims that these aluminum strips should have an additional deterrence effect by reflecting light and by making noise when moved by the wind. According to the instructions for use the repellent should be sprayed on the aluminum sheets, which are fixed on shrubs or posts at waist height in a spacing of 8–15 m. It is advised to refresh the repellent every 2–4 weeks.

Experimental design

The odor repellent was investigated at baited luring sites set up in grassland near the forests. Allurement was performed providing an attractive food mixture composed of apple, maize, and protein-enriched food pellets. The luring sites were placed on frequently used wild boar trails, which we had previously spotted with the help of local hunters. Wild boars use these trails when leaving the forest to forage in agricultural land, or when crossing the open land to get from one forest to another. We placed study sites within the known wild boar trail area aiming to achieve a high chance of wild boars to be attracted by the lure food. A study site always consisted of two luring sites, one as a test site (T) and one as a control site (C), 6 × 6 m each. The test site was surrounded by the deterrent system and the control site remained without protection. Distance between the two luring sites was 90–115 m to prevent interference of C by the odor repellent installed at T. We therefore also accounted for the topographic conditions, making intervisibility between C and T impossible, as well as for the common wind direction. Following the manufacturers' instructions, we sprayed the odor repellent on the felt depots of the purpose built aluminum sheets. The sheets were fixed on 8 posts at waist height spaced at intervals of 3 m around the luring sites, forming a 36-m^2 treatment area. Regardless of the manufacturers' advice to refresh the repellent every 2–4 weeks, we repeatedly treated the felt depots every week. Furthermore, we covered the aluminum strips with transparent plastic bags with a wide opening at the bottom side to protect the felt depots from precipitation but to allow for the optic, acoustic, and odor repellency.

We inspected the luring sites daily or at least every second day. At each inspection, any wild boar tracks were recorded. For this purpose we built a track-band consisting of a 50 cm broad and 10 cm deep ditch filled with soil and sand surrounding the bait. The track-band was regularly dampened to insure that visits by wild boars or other animals would leave a mark. Every time wild boars visited a luring site, C and T were switched by removing the deterrent system from T and installing it at former C and vice versa. In choosing this regime of constant alternation between the two luring sites we aimed at preventing the wild boars from habituating themselves to the experimental setup. Furthermore we were able to account for the possibility of biased visits at one of the two luring sites compared to the other.

Statistical analysis

We assessed by logistic regression analysis the effect of the "Wildschwein-Stopp®" on the probability of wild boar visits at the luring sites. The binary indicator variable of a wild boar visit was the dependent variable and the two-level factor treatment (T vs. C) was the predictor of interest. We further controlled the influence of month, the duration of the experiment (*n* days), the study site and the interactions treatment × month, treatment × duration, and treatment × site. We included the interactions to test whether there are differences in a potential effect of treatment between the months, the sites, or with ongoing duration of the experiments. The variable month was treated as a factor with 12 levels. To account for non-linear effects we also included the quadratic and cubic effect of duration. Starting with a model including all predictors, we gradually removed the non-significant interactions, the quadratic and cubic effects from the model, leaving the main effects within it. We used the Likelihood ratio test for model comparisons. The analyses were done using the R software for statistical computing.

In addition, we calculated a zero-inflated model to verify the *P* values of the logistic regression model, because analysis of residuals indicated that there were too many zero values in our data (days on which neither T nor C were visited). The zero-inflated model consisted of two Bernoulli models with logistic link functions each. The first model described whether there were wild boars around which potentially could visit a luring site. Predictor in this model was the day of the year. The second model described the probability of a visit conditional on wild boars being around. In this model duration, the quadratic and cubic effect of duration, study site and treatment were predictors. We used Bayesian methods for model fitting. Parameters were estimated by running Markov chain Monte Carlo simulations using WinBUGS (Spiegelhalter et al. 2003). WinBUGS was accessed by R via R-interface R2WinBUGS (Sturtz et al. 2005). Markov chain Monte Carlo simulations produced a random sample from the posterior distribution of the model parameters. Therefore, we were able to directly calculate the effectiveness of the odor repellent in reducing the probability of wild boar visits.

Results

Table 1 gives an overview of the duration of experiments, number of inspections, and number of visits for each study site. Of a total of 453 inspections performed during the whole study period, we recorded 80 visits of wild boars at the study sites (17.7%). In the majority of the cases both C and T were visited during the same night ($n = 76$). Overall, we recorded successful surmounting of the deterrent system (visits at T) by wild boars in 76 cases, whereas C was visited 80 times. Wild boars completely consumed the lure food in 92% of all visits.

The results of the logistic regression are given in Table 2. The odor repellent did not have a significant effect on wild boar visits at the luring sites. The interactions treatment × month, treatment × duration, and treatment × site did not have a significant influence on wild boar visits either. Only the month, the duration plus its quadratic- and cubic effect, and the site significantly influenced the probability of wild boar visits at the luring sites. Explanatory variables month and duration were slightly correlated ($r = 0.3288$, df = 451, $P < 0.001$). We

Table 1 Duration of field experiments (days), number of inspections, and numbers of wild boar visits at the luring sites (C control site, T test site, C + T both sites visited together during the same night) for the study sites at Sissach (Sis), Rothenfluh (Rot1, Rot2), and Hofstetten (Hof), Canton Basel-Land, Switzerland in 2007/2008

Study site	Sis	Rot1	Rot2	Hof	Total
Duration of experiment	539	329	391	187	1446
Inspections	190	91	125	47	453
Visits at C + T	29	15	22	10	76
Visits at C exclusively	3	0	1	0	4
Total	32	15	23	10	80

Table 2 Significance tests (likelihood ratio tests) of the logistic regression to predict whether a luring site is likely to be visited by wild boars, or not

Predictor variables	df	LR	*P* value	*P* value of reduced model
Treatment	1	0.136	0.712	
Month	11	35.165	<0.001	<0.001 (model without duration)
Duration	1	18.877	<0.001	<0.001 (model without month)
Duration^2	1	15.843	<0.001	<0.001 (model without month)
Duration^3	1	11.702	<0.001	<0.001 (model without month)
Site	3	10.600	0.014	
Treatment × site	3	0.096	0.992	
Treatment × month	11	0.065	0.996	
Treatment × duration	1	0.026	0.872	

Predictors "month" and "duration" were correlated. We, therefore, calculated the influence of these variables in two separate models

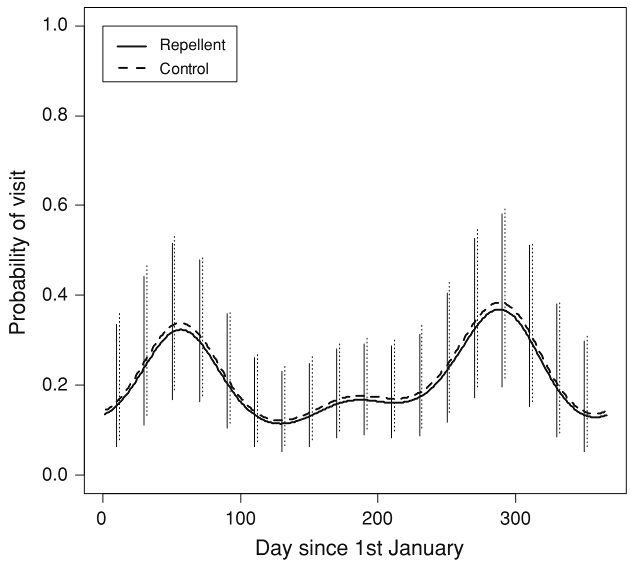

Fig. 1 Probability of wild boar visits at the luring sites as a function of the day of the year (including 95% CI)

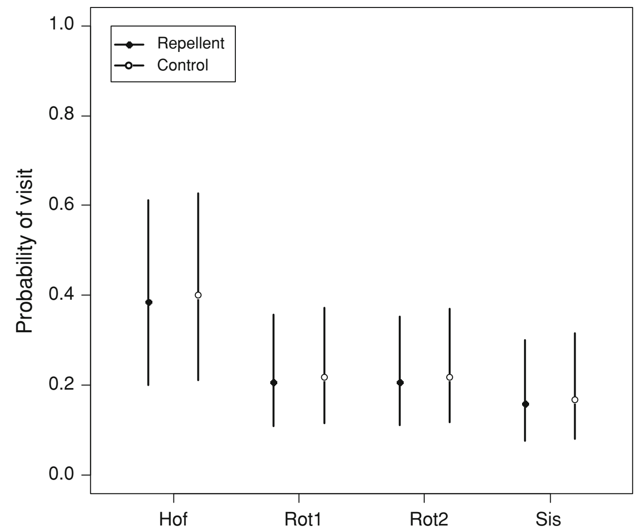

Fig. 2 Probability of wild boar visits at the study sites in Hofstetten (Hof), Rothenfluh (Rot1, Rot2), and Sissach (Sis). Predicted values (incl. 95% CI) are applied for month = 11 and duration = 200

therefore calculated two logistic models, one where the month was corrected for the effect of duration and a model where the duration was corrected for the effect of the month. It appears that the effect of the duration was overlain by the differences between the months and a complete separation of the effect was not feasible due to the correlation between the duration and month. However, neither of the two models was significantly more explanatory than the other.

Figure 1 shows the outcome of the zero-inflated model, which confirms the result of the logistic regression. The probability of wild boar visits at T was 0.996 compared to C (95% credible Interval: 0.779, 1.215). Thus, the odor repellent reduced the probability of wild boar visits at the luring sites by 0.4%. Figure 1 also demonstrates the seasonal variation in wild boar visits. The between-month difference of probability of wild boar visits was significant ($LR_{11} = 35.17$, $P < 0.001$). Maximum values for probability of visits was reached in March with 0.41–0.43 (T–C), and in fall (Sep, Oct) with 0.31–0.32, and 0.39–0.40, respectively. Probability of wild boar visits was also significantly different between the four study sites ($LR_3 = 10.6$, $P = 0.014$), which is demonstrated in Fig. 2. Probability of wild boar visits was highest in Hofstetten (Hof: 0.39–0.40).

Discussion

The present study proves that the tested odor repellent was not effective in deterring wild boar from our luring sites. Although there is a wide range of studies on olfaction in wild boar and other suids, confirming the species' excellent sense of smell (Zeuner 1967; Altevogt 1972; Meynhardt 1978; Günterschulze 1979; Briedermann 1990), scientific record on the effectiveness of odor repellents used for crop protection from wild boar damage is scarce.

Chemical repellents are widely used in wildlife damage management against a variety of species. In general, the effectiveness of chemical deterrents is conditionally confirmed in literature (Jordan and Richmond 1991; Milunas et al. 1994; El Hani and Conover 1995; Engeman et al. 1995; Belant et al. 1998; Mason 1998). However, there are big differences in efficacy between the repellents, depending on the species investigated, the population densities of target animals, and the functionality of the deterrent. Repellents causing pain are considered more effective, than those causing fear or sickness. The pain-causing sensory irritants are most effective when being directly applied to crops. On the other hand, there is no evidence that targeted species abandon areas due to the effect of sensory irritants, because animals usually do not learn to avoid treated foods (Mason 1997).

The repellent investigated in the present study belongs to the wide range of fear-provoking products. In general, sulfur containing mixtures like "Wildschwein-Stopp®" are—to a certain degree—effective against herbivores. However, the effect of fear-inducing repellents bases on neophobia and target animals usually habituate to them very quickly (Mason 1997). Our results, however, do not confirm neophobia in the sense of an initial deterrence effect of the tested repellent, since the interaction treatment × duration did not have significant effect on wild boar visits at the luring sites. At one particular study site (Sis) wild boars surmounted the deterrent setup immediately in the night after installation.

Our findings may indicate seasonal variation in wild boar activity outside forests. Maximum probability of visits at the luring sites is in spring and fall and coincides with the occurrence of damage to agricultural land. Several studies have revealed that wild boar damage to annual crops peaks in late summer and fall as a result of ripening of crops and fruit, which is in agreement with our results (Łabudzki and Wlazełko 1991; Geisser 2000; Herrero et al. 2006; Schley et al. 2008).

Previous studies evidenced that hunting effects wild boar behavior and activity range (Baubet et al. 1998; Sodeikat and Pohlmeyer 2002; Fernández-Llario et al. 2003). However, the interaction treatment × site did not significantly differ between the four study sites, which shows that site-specific factors such as remoteness, degree of anthropogenic impact, or wild boar density did not influence the effect of the odor repellent.

Since we neither found an overall- nor an initial effect of the tested odor repellent we conclude the repellent to be ineffective in deterring wild boars from agricultural fields. "Wildschwein-Stopp®" is therefore not recommendable for crop protection. Moreover, we suggest that any other odor repellent relying on fear-evocation would not be an effective deterrent against wild boar and feral swine, especially in areas where natural enemies like wolf (*Canis lupus*), brown bear (*Ursus arctos*), or lynx are absent or very rare.

Farmers of the Canton Basel-Land receive compensation for wildlife damage if their fields were adequately protected. To date only the electric fence has been proven to protect fields adequately from wild boar damage. On the basis of the present study, we suggest that compensation payment policies should not be changed for the present. We recommend that farmers should not be encouraged to use any deterrent systems other than electric fences to protect their fields.

However, more effort to develop new deterrent systems is needed since the problem of wild boar damage to agriculture is far from being solved. Without question, reduction and regulation of wild boar populations by means of hunting is crucial for preventing damage to agriculture. However, field protection will remain important and the need for inexpensive alternative deterrents will last since populations will recover within a short time also in the future.

Acknowledgments The present study was funded by the Volkswirtschafts- und Sanitätsdirektion of Basel-Land, the Federal Office for the Environment (FOEN), and the Freiwillige Akademische Gesellschaft (FAG). We thank I. Bloch and D. Zopfi, head and deputy of the department Veterinär-, Jagd- und Fischereiwesen for bringing us into contact with game wardens, hunters, and farmers at our study sites. A. Ochsenbein gave technical support and valuable input for the field experiments. C. Zentner and M. Küng, game wardens of Sissach and Rothenfluh, provided valuable information on the local conditions, activity ranges, and trails of the wild boars in the study area. We thank the farmers of Sissach, Rothenfluh, and Hofstetten for readily letting us perform our experiments on their land. F. Korner-Nievergelt calculated the logistic regression and the Bayesian model.

References

Altevogt R (1972) Zur Verhaltensökologie der Trüffelschweine des Perigords (AW-Frankreich). Wissenschaftliche Zeitschrift der Humboldt-Universität zu Berlin. Reihe Mathematik/Naturwissenschaften XXY 4:407–410

Andrzejewski R, Jezierski W (1978) Management of a wild boar population and its effect on commercial land. Acta Theriol 23:309–339

Baubet E, Brandt S, Touzeau C (1998) Effet de la chasse sur les stratégies d'occupation de l'espace des sangliers (*Sus scrofa*). Analyses préliminaires. Gib Faun Sauv 15:655–658

Belant JL, Seamans TW, Tyson LA (1998) Predator urines as chemical barriers to white-tailed deer. Proc 18th Vertebr Pest Conf 18:359–362

Bieber C, Ruf T (2005) Population dynamics in wild boar *Sus scrofa*: ecology, elasticity of growth rate and implications for the management of pulsed resource consumers. J Appl Ecol 42:1203–1213

Boisaubert B, Bouldoire JL, Vassant J (1983) Bilan de cinq années d'expérimentation de protection des cultures par clôtures électriques dans le département de la Haut-Marne. Bull Mens Off Natl Chasse 68:15–26

Breton D (1994) La limitation des dégâts de sanglier par la pose de clôtures électriques dans le département de la Haute-Marne. Bull Mens Off Natl Chasse 191 (Numéro special):96–100

Briedermann L (1990) Schwarzwild, 2nd edn. VFB Deutscher Landwirtschafts-Verlag, Berlin

Calenge C, Maillard D, Fournier P, Fouque C (2004) Efficiency of spreading maize in the garrigues to reduce wild boar (*Sus scrofa*) damage to Mediterranean vineyards. Eur J Wildl Res 50:112–120

Cellina S (2008) Effects of supplemental feeding on the body condition and reproductive state of wild boar *Sus scrofa* in Luxembourg. Dissertation, University of Sussex, Brighton

El Hani A, Conover MR (1995) Comparative analysis of deer repellents. Repellents in wildlife management conference proceedings, 8–10 Aug 1995, Denver, CO, USA, pp 147–155

Engeman RM, Campbell DL, Nolte D, Witmer G (1995) Some recent research results on non-lethal means for reducing animal damage to reforestation projects in the western United States. Proc 10th Aust Vertebr Pest Control Conf 10:150–154

Fernández-Llario P, Mateos-Quesada P, Silvério A, Santos P (2003) Habitat effects and shooting techniques on two wild boar (*Sus scrofa*) populations in Spain and Portugal. Z Jagdwiss 49: 120–129

Geisser H (1998) The wild boar (*Sus scrofa*) in the Thurgau (northeastern Switzerland): population status, damages and the influence of supplementary feeding on damage frequency. Gib Faun Sauv Game Wildl 15((Special Number Pts 2 and 3)): 547–554

Geisser H (2000) Das Wildschwein (*Sus scrofa*) im Kanton Thurgau (Schweiz): Analyse der Populationsdynamik, der Habitatansprüche und der Feldschäden in einem anthropogen beeinflussten Lebensraum. Dissertation, University of Zurich, Zurich

Geisser H, Reyer H-U (2004) Efficacy of hunting, feeding, and fencing to reduce crop damage by wild boars. J Wildl Manag 68:939–946

Geisser H, Reyer H-U (2005) The influence of food and temperature on population density of wild boar *Sus scrofa* in the Thurgau (Switzerland). J Zool (Lond) 267:89–96

Günterschulze J (1979) Studien zur Kenntnis der Regio olfactoria von Wild-und Hausschwein. Zool Anz (Jena) 202(3/4):256–279

Hahn N, Eisfeld D (1998) Diet and habitat use of wild boar (*Sus scrofa*) in SW-Germany. Gib Faun Sauv 15:595–606

Herrero J, García-Serrano A, Couto S, Ortuño VM, García-González R (2006) Diet of wild boar *Sus scrofa* L. and crop damage in an intensive agroecosystem. Eur J Wildl Res 52:245–250

Jordan DM, Richmond ME (1991) Effectiveness of a vertical 3-wire electric fence modified with attractants or repellents as a deer exclosure. Proc East Wildl Damage Control Conf 5:44–47

Łabudzki L, Wlazełko M (1991) Saisonale Dynamik der vom Schwarzwild im Feldanbau verursachten Schäden im Forschungsgebiet Zielonka. Z Jagdwiss 37:250–257

Lutz W (1994) Ergebnisse der Anwendung eines sogenannten Duftzauns zur Vermeidung von Wildverlusten durch den Strassenverkehr nach Gehege-und Freilandorientierungen. Z Jagdwiss 40:91–108

Macdonald DW (2001) The new encyclopedia of mammals. Oxford University Press, Oxford

Mason JR (1997) Repellents. In: Wagner KK, Nolte DL (eds) Wildlife damage management for natural resource managers. Western Forestry and Conservation Association, Olympia, pp 11–16

Mason JR (1998) Mammal repellents: options and considerations for development. Proc Vertebr Pest Conf 18:325–329

Mazzoni della Stella R, Calovi F, Burrini L (1995) The wild boar management in a province of Central Italy. IBEX JME 3:188–191

Meynhardt H (1978) Schwarzwildreport. Neumann-Verlag, Leipzig (in German)

Meynhardt H (1991) Wildversorgung, Trophäen und Schadensverhütung. Schwarzwild-Bibliothek 4, Verlag Neumann-Neudamm, Melsungen (in German)

Milunas MC, Rhoads AF, Mason JR (1994) Effectiveness of odour repellents for protecting ornamental shrubs from browsing by white-tailed deer. Crop Prot 13:393–397

Schlageter A, Haag-Wackernagel D (2011) Effectiveness of solar blinkers as a means of crop protection from wild boar damage. Crop Prot 30:1216–1222

Schley L, Roper TJ (2003) Diet of wild boar *Sus scrofa* in Western Europe, with particular reference to consumption of agricultural crops. Mammal Rev 33:43–56

Schley L, Dufrêne M, Krier A, Frantz AC (2008) Patterns of crop damage by wild boar (*Sus scrofa*) in Luxembourg over a 10-year period. Eur J Wildl Res 54:589–599

Sodeikat G, Pohlmeyer K (2002) Temporary home range modifications of wild boar *Sus scrofa* caused by drive hunts in Lower Saxony (Germany). Z Jagdwiss 48(supplement 1):161–166

Spiegelhalter DJ, Thomas A, Best NG, Lunn D (2003) WinBUGS user manual (version 1.4). MRC Biostatistics Unit, Cambridge

Sturtz S, Ligges U, Gelman A (2005) R2WinBUGS: a package for running WinBUGS from R. J Stat Softw 12(3):1–16

Vassant J (1994a) Les techniques de prévention des dégâts de sanglier. Bull Mens Off Natl Chasse 191:90–93

Vassant J (1994b) L'agrainage dissuasif: résultats d'expériences. Bull Mens Off Natl Chasse 191:101–105

Vassant J (1997) Le sanglier en France: ces quinze dernières années. Bull Mens Off Natl Chasse 225:32–35

Vassant J, Boisaubert B (1984) Bilan des expérimentations enterprises en Haut-Marne pour réduire les dégâts de sanglier (*Sus scrofa*) à l'encontre des cultures agrucoles. Smposium International sur le sanglier (international wild boar symposium). F. Spitz, and D. Pépin, technical coordinators. Toulouse, France, pp 187–199

Vassant J, Breton D (1986) Essai de reduction des dégâts de sangliers (*Sus scrofa*) sur blé (*Triticum sativum*) au stade laiteux par distribution de maïs (*Zea mais*) en forêt. Gib Faun Sauv 3:83–95

Vassant J, Jullien JM, Brandt S (1992) Reducing wild boar damage to wheat and oats in summer: study of the effectiveness of maize distribution in the forest. In: Bobek B, Perzanowski K, Regelin WL (eds) Proceedings of the 18th IUGB congress, global trends in wildlife management. Jagdellonian University, Krakow

Zeuner FE (1967) Geschichte der Haustiere. BLV-Verlag, München

III

Schlageter A, Haag-Wackernagel D (2012)

A Gustatory Repellent for Protection of Agricultural Land from Wild Boar Damage.

Journal of Agricultural Science 4(5): 61–68.

A Gustatory Repellent for Protection of Agricultural Land from Wild Boar Damage: An Investigation on Effectiveness

Adrian Schlageter (Corresponding author) & Daniel Haag-Wackernagel

Integrative Biology, Department Biomedicine, University of Basel

Anatomisches Institut, Pestalozzistrasse 20, 4056 Basel, Switzerland

Tel: 41-61-276-2712 E-mail: adrian.schlageter@unibas.ch

Received: November 25, 2011 Accepted: December 21, 2011 Online Published: April 1, 2012

doi:10.5539/jas.v4n5p61 URL: http://dx.doi.org/10.5539/jas.v4n5p61

Abstract

Following the spread and increase of wild boar populations in Europe during the last decades, conflicts with humans have intensified also in Switzerland. Damage to crops and grassland augmented considerably and became unacceptable. Farmers and authorities are highly interested in efficient alternatives to the installation of costly and time consuming electric fences for crop protection. In the present study we investigated the effectiveness of a gustative repellent in field experiments with free-ranging wild boars in clover sowings, meadows, and wheat fields. Although we observed a slight trend towards a damage reduction, the results show, that the repellent was not able to prevent damage at a significant level. We further could not detect any area avoidance by the wild boars as a response to the repellent. On the basis of our findings we conclude that gustative repellents relying on learned avoidance as a consequence of negative experience are not a promising means for protection of crops and grassland from wild boar damage. We further discuss the effects of different agricultural crops and the anthropogenic influence on the frequency of damage.

Keywords: Crop protection, Crop damage, Gustatory repellent, SUCROSAN, *Sus scrofa*, Wild boar

1. Introduction

During the last three decades, populations of the wild boar (*Sus scrofa*) in Europe have increased remarkably and almost simultaneously and the species has spread into new areas over the entire continent. Following the spread and increase in population size, the wild boar extended its activity into agricultural land, which intensified conflicts with humans. Wild boars cause considerable damage to crops and grassland. In many European countries, governmental compensations for crop damage amount to millions of Euros every year (Mazzoni della Stella et al. 1995, Vassant 1997, Calenge et al. 2004). Since about 1970, the spread and size of populations have increased in Switzerland, which is manifested by continuously increasing wild boar bags. Accordingly, crop damage increased dramatically and became unacceptable to farmers and game authorities as compensation for wild boar damage to crops and grassland simultaneously increased (Geisser 1998). This is also true for the Canton Basel-Land in Northwestern Switzerland. The region suffers from high wild boar densities and high amounts of damage to agriculture.

Three methods dominate among the attempts to reduce wild boar damage that are recommended in many scientific and popular articles (Briedermann 1990, Breton 1994, Mazzoni della Stella et al. 1995, Vassant 1997, Geisser 1998). First, wild boars are hunted intensively to keep population densities low. Second, hunters offer supplemental food in the forest to keep the wild boars off the farmland. Third, farmers put up fences and other deterrent systems to prevent wild boars from entering the fields. Hunting proved to reduce wild boar damage (Geisser & Reyer 2004). However, wild boar reproductive rates can increase up to 200% under ideal conditions and, therefore, populations can recover within one year (Briedermann 1990). The scientific debate on the effectiveness of supplemental feeding in terms of damage reduction is controversial. While some studies proved the method to be successful (Vassant & Breton 1986, Meynhardt 1991, Vassant et al. 1992, Vassant 1994a, Vassant 1994b, Geisser 1998, Calenge et al.2004), others found no effect (Geisser & Reyer 2004), or even showed supplemental feeding to enhance wild boar damage (Hahn & Eisfeld 1998, Cellina 2008). The latter revealed considerable amounts of artificial food in the stomachs of shot wild boars of 40% and 50% respectively, concluding that supplemental feeding increases reproductive potential and therefore rather supports higher populations than reduces damage to crops by a dissuasive effect. In the Canton Basel-Land, supplemental feeding is exclusively practiced to bait wild boars for easier shooting.

Field protection is still essential for damage prevention. Farmers preferably protect vulnerable crops with electrical fences, which have been proven effective in preventing wild boars from entering the fields (Boisaubert et al. 1983, Vassant & Boisaubert 1984). However, electrical fences require regular surveillance to assure maintenance of both fences and batteries, which is costly in terms of time. Additionally, electrical fences are expensive and the government does not provide financial support. In the Canton Basel-Land, reimbursement for fencing costs repeatedly exceeded compensation payments in the past years and was therefore disestablished in 2008. Farmers and authorities are therefore highly interested in efficient alternatives to the expensive and labor-intensive electrical fence. Several deterrents against wild boar have been investigated so far. Methods based on acoustic, gustatory, odor, and optic deterrence have not yielded satisfactory long-term results (Vassant & Boisaubert 1984, Vassant 1994a, Schlageter & Haag-Wackernagel 2011, Schlageter & Haag-Wackernagel 2012). These methods include radios, PIR-activated horns, gas cannons, chemical treatment of corn seeds with several repellents, and solar-powered LED-blinkers. However, various deterrents are commercially available today that claim to be effective in protecting crops from wild boar damage. At present, there is little or no data to support claims of efficacy for the majority of these deterrent systems. Information on successful deterrence of wild boars mainly derives from the manufacturers of the deterrent systems themselves.

Since wild boars become nocturnal in areas where they are hunted, damage to agricultural land is exclusively caused during the night. A gustatory repellent might therefore be a promising alternative to the electric fence, because its deterrence effect does not rely on visibleness. Against this background, gustatory repellents are a promising means for deterring wild boar from agricultural land, not only crops but also meadows and pasture. A deterrent commercially available that particularly claims to deter wild boar is "SUCROSAN®". According to the manufacturer, the effectiveness of the repellent has been proved in an investigation in the field that was conducted by game wardens. However, these results have not been published and the company was not able to provide us with detailed information on the study in question. We therefore conclude this study rather to be an anecdotal report, which does not meet scientific criteria. However, local farmers have tested the repellent on their own and their positive reports have attracted the interest of game authorities of the Canton Basel-Land. In the present study we investigated the gustatory repellent "SUCROSAN®" in field experiments with free-ranging wild boars with respect to the following objectives:

1a) Is the repellent effective in preventing agricultural land from being damaged by wild boars? 1b) Does the distance to the nearest occupied building (e.g. barnyard) have an effect on the frequency of damage events? 1c) Are there differences in effectiveness of the repellent between different cultures? 1d) Does the probability of wild boar damage change with the seasons? 2) Does the time-span between two consecutive damage events prolong conditionally on wild boars having eaten the gustatory repellent pellets?

2. Materials and Methods

2.1 Study Area

The present study was conducted in several areas of the Canton Basel-Land, a region in northwestern Switzerland. Our field experiments took place at 11 experimental plots, which were located in 5 municipal areas (Fig. 1). The Canton Basel-Land is situated in northwestern Switzerland and covers an area of 518km^2. The topography is hilly and ranges in elevation from 250m to 1170m. The climatic conditions are continental with an average annual precipitation of 750–1300mm. Average temperatures range from 2.1°C in January to 19.6°C in July. Forests cover 42% of the study area, are patchy distributed, and are mostly used for the lumber industry. Agricultural land covers 41% of the area and consists mainly of pasture (50%), cropland (40%), and fruit- and winegrowing (10%). Settlement and traffic infrastructure covers another 16% of the Canton's area. The landscape is characterized by a high structural diversity. Except for the lynx (*Lynx lynx*), natural predators of the wild boar are absent in Northwestern Switzerland.

2.2 Repellent

The gustatory repellent "SUCROSAN®" are food pellets on the basis of wheat and maize with phosphorous acid as the active ingredient (Ph value = 2). The detailed composition of the pellets was not communicated by the manufacturer. According to the manufacturer, these pellets should attract wild boars by its odor. Once wild boars have eaten the pellets the phosphorous acid would unfold its flavor. This being a disagreeable experience for the animals would lead to a future avoidance of the area by a learning effect. The gustatory repellent was available in 15 kg-bags. Average weight of one pallet was 1 g giving a quantity of 15'000 pellets per bag. Costs per kilogram was € 14.

2.3 Experimental Design

We performed field experiments in clover sowings, meadows, and wheat-cultures. The experimental plots were selected on the basis of the presence of at least one event of damage by wild boars during a pre-experimental phase of 30 days. In choosing this selection criterion we aimed at a higher chance of repeated damage events during our experiments. The acreage of experimental plots varied between 1700 m^2 and 200 000 m^2. For each plot we recorded the distance to the nearest barnyard or other occupied building respectively (herein after referred to as barnyard). The duration of each trial on a particular experimental plot was 40 days. During the first 20 days the experimental plot was left untreated. After this initial pretreatment phase the experimental plot was treated with the gustatory repellent for another 20 days. Inspections of the experimental plots were performed every second day. At each inspection, new wild boar damage events were recorded. During the pretreatment phase we only recorded the damage events, during the following treatment phase we also recorded if the gustatory repellent pellets were eaten (removal) by wild boars or not. Pellet removal by wild boars was recorded by detecting tracks. Except for one case where pellets were removed by carrion crows (*Corvus corone corone*), wild boar tracks were clearly detectable in all other cases of pellet removal. According to the manufacturers advice, we treated the experimental plots with a quantity of some 5 pellets per m^2. Because the gustatory repellent was only weather resistant to a certain degree, we refreshed the treatment every 10 days or immediately after pellet removal by wild boars.

2.4 Statistical Analysis

Objektives 1a) – 1d) were assessed by a generalized linear mixed model (GLMM). The binary indicator variable of a damage event was the dependent variable. The predictors of interest were "treatment" (SUCROSAN Yes/No), "culture", the interaction "treatment–culture", "duration" of the experiment, "season", and the distance to the "barnyard". The coefficient "site" was implemented in the model as a random factor to correct for the dependence of multiple measurements at the same site. Because samples per month were to small we aggregated the months in a two-level factor "season" with spring and summer (March – August) and fall and winter (September – February). Our logistic regression model had a binomial error distribution and as link function we used the logit link. We fitted the model with the *glmer*-function of the Ime4-package (Bates 2005) using the R 2.12.0 software for statistical computing (R Development Core Team 2010). We assessed significance levels of the terms of the model by simulating the a-posteriori distribution with the *sim*-function of the arm-package (Gelman & Hill 2007). We started with a model including all predictors and then gradually removed the non-significant interactions from the model, leaving the main effects within it. We used Bayesian methods to assess parameter estimate uncertainties because this is recommended as the most accurate method for generalized linear mixed models (Bolker et al. 2008). As a consequence we report 95% credible intervals (CrI) instead of confidence intervals or classical p-values. The CrI gives the 95% range of the posterior distribution of the parameter, where the posterior distribution expresses our knowledge of the parameter after having looked at the data.

The influence of the gustatory repellent on the time-span between two consecutive damage events (objective 2) was assessed by a cox proportional hazard model. The dependent variable was the time-span between two damage events or between a damage event and the end of an experiment, the latter being treated as censored observations (i.e. minimal time). All analysis was performed using the R software for statistical computing.

3. Results

An overview of the numbers of damage events, numbers of removal events and the distances for our experimental plots is given in Table1. We recorded damage events in all of our experimental plots. During the pretreatment phase every plot was damaged at least once, whereas during the treatment phase four plots remained without damage. Overall we recorded 24 damage events during the pretreatment phase and 19 damage events during the treatment. Pellet removal occurred in 47.4% of all cases of damage during treatment.

We found a non-significant trend towards a lower frequency of damage events during the treatment phase (GLMM, b=0.032, CrI: -2.549, 0.068). The results of the cox proportional hazard model confirm this finding (Fig. 2). We measured 8 out of 33 time-spans between two consecutive damage events and one out of 10 minimal times respectively where the pellets have been removed by wild. The gustatory repellent had no significant effect on the time-span between two damage events (LRT=1.56, df=1, p=0.211).

We found a significant positive effect of the distance to the barnyard on the frequency of damage events (GLMM, b=0.019, CrI: 0.0007, 0.011). Wild boars caused more damage when the experimental plot was situated more distant from a barnyard (Fig. 3).

There was a trend towards differences in frequency of wild boar damage between the cultures (Fig. 4). The damage frequency was highest in meadows and lowest in clover sowings, though, these differences were not significant (GLMM, b=0.046, CrI: -0.374, 6.469). Moreover, there was no significant difference in effect of the treatment on the frequency of damage events between the cultures.

We further found a positive trend in effect of the duration of the experiment on the frequency of damage events (GLMM, b=0.44, CrI: -0.009, 0.107). Damage frequency augmented with continuing experiment. In contrast, the season did not have an effect on the frequency of damage events.

4. Discussion

The gustatory repellent investigated in the present study did not have a significant effect on the frequency of damage events, nor did it prologue the time span between two consecutive damage events. According to the manufacturer, the gustatory repellent should work on two different sensory levels, an olfactory and a gustatory level. First, the repellent should allure or attract wild boars by its smell. Second, the pellets should deter wild boars from the treatment area by its acetous taste. A wide range of studies on olfaction in wild boar and other suids confirm the species' excellent sense of smell (Zeuner 1967, Altevogt 1972, Meynhardt 1978, Günterschulze 1979, Briedermann 1990). Based on the fact that olfaction plays a major role in foraging of wild boars, the olfactory attractiveness of the repellent investigated in our study is doubtable since the pellets were eaten in only 47.4% of all cases of damage during treatment.

The effectiveness of chemical deterrents against vertebrates is conditionally confirmed in literature (Jordan Jr. & Richmond 1991, Milunas et al. 1994, el Hani & Conover 1995, Engeman et al. 1995, Belant et al. 1998, Mason 1997, Mason 1998). However, the efficacy of repellents varies strongly, depending on the functionality of the deterrent, the species investigated, and the population densities of target animals. Repellents causing pain are considered more effective than those causing fear or sickness. The pain-causing sensory irritants are most effective when being directly applied to crops. On the other hand, there is no evidence in literature that sensory irritants effect targeted species to abandon areas. Animals usually do not learn to avoid treated foods. Repellents relying on taste are rarely, if ever, effective. Products that claim effectiveness solely because of an acetous taste are doing so in the absence of reliable evidence.

However, we found a slight trend that the gustatory repellent reduced the frequency of damage events. The manufacturer claims that the wild boars should be deterred by the acetous taste of the pellets and, moreover, should avoid the treatment area in the future as a result of a learning effect. We would therefore have expected to find a positive effect of the pellet removal on the time-span between two damage events. Since we could not prove such an effect, we would therefore interpret the result of the GLMM rather to be ascribed to an olfactory- than a gustatory effect. The trend towards a lower frequency of damage events on treated areas we observed may be based on cautious behavior of the wild boars confronted with an odor not used to. This could have been either the odor of the repellent itself or a disturbance caused by our presence during the treatments. In a previous study (Schlageter & Haag-Wackernagel 2012) on the effectiveness of a fear evocating odor repellent we could, however, not show any neophobia or startle responses of wild boars.

The damage frequency was positively correlated with the distance of the experimental plot to the barnyard. This is in line with previous studies, which have revealed that wild boar damage is negatively correlated with the grade of anthropogenic influence (e.g. Schley et al. 2008). We think that the distance to the nearest occupied building (i.e. barnyard) was an accurate measure for remoteness of an experimental plot from human activity in the present study. Damage frequency was highest in meadows (trend: Fig. 3). This is in line with other studies that showed grassland to be damaged at higher proportions than cereal crops and other seasonal cultures (Schley 2000, Schley *et* al. 2008). Our result also corresponds with the yearly damage statistics of the hunting and fishing agency of the Canton Basel-Land, which amounts damage to grassland at approximately 50% of all damage caused by wild boars (unpubl. data).

5. Conclusion

We could show that the gustatory repellent "SUCROSAN®" was ineffective in reducing damage to the experimental plots, regardless of the culture that was treated. The weak trend of lower frequency of damage events we observed during treatment could not be explained by any gustative repellency of the deterrent since the time-span between two consecutive damage events did not prolong during treatment compared to the pretreatment phase. We rather ascribe this trend to a general cautious behavior of the wild boars facing an unknown odor, which could have been either the odor of the gustatory repellent itself or the odor of the first author. However, the effect was small and not significant. We therefore conclude the gustatory repellent to be inefficient in deterring wild boars from agricultural areas. Taking further into account that the repellent is very costly, we clearly advise against the use of this product.

In the Canton Basel-Land, farmers receive compensation for wildlife damage only if their fields were adequately protected. We recommend that farmers should not be encouraged to use any deterrent systems other than electric fences, which have been proven effective in protecting crops. On the basis of the present study, we suggest that compensation payment policies should not be changed for the present.

Yet, the problem of wild boar damage to agriculture is far from being solved and, therefore, more effort in developing new repellents is needed. Wild boar populations will recover from losses by hunting within a short time also in the future. Thus, field protection will remain essential and the need for inexpensive alternative deterrents will last.

Acknowledgments

The present study was funded by the Volkswirtschafts- und Sanitätsdirektion of Basel-Land, the Federal Office for the Environment (FOEN), and the Freiwillige Akademische Gesellschaft (FAG). I. Bloch and D. Zopfi, head and deputy of the department Veterinär-, Jagd- und Fischereiwesen provided the gustative repellent and brought us into contact with farmers that recently suffered wild boar damage. A. Ochsenbein gave technical support and valuable input for the field experiments. We thank the farmers at our study sites for readily letting us perform our experiments on their land. F. Korner-Nievergelt calculated the GLMM and the cox proportional hazard model.

References

Altevogt, R. (1972). Zur Verhaltensökologie der Trüffelschweine des Perigords (AW-Frankreich). *Wissenschaftliche Zeitschrift der Humboldt-Universität zu Berlin. Reihe Mathematik/Naturwissenschaften XXY*, *4*, 407–410.

Authors. Date. Evaluation of an odor repellent for protecting crops from wild boar damage. *in prep.*

Bates, D. (2005). Fitting linear mixed models in R – using the lme4 package. *R News – The Newsletter of the R Project*, *5*, 27–30.

Belant, J. L., Seamans, T. W., & Tyson, L. A. (1998). Predator urines as chemical barriers to white-tailed deer. *Proceedings 18th Vertebrate Pest Conference*, *18*, 359–362.

Boisaubert, B., Bouldoire, J. L., & Vassant, J. (1983). Bilan de cinq années d'expérimentation de protection des cultures par clôtures électriques dans le département de la Haut-Marne. *Bulletin Mensuel de l'Office National de la Chasse*, *68*, 15–26.

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, H. H., & White, J.-S. (2008). Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology and Evolution, 24*, 127–135. http://dx.doi.org/10.1016/j.tree.2008.10.008

Breton, D. (1994). La limitation des dégâts de sanglier par la pose de clôtures électriques dans le département de la Haute-Marne. *Bulletin Mensuel de l'Office National de la Chasse*, *191*, (Numéro special). 96–100.

Briedermann, L. (1990). *Schwarzwild*. (3rd ed.). Berlin: VFB Deutscher Landwirtschafts-Verlag.

Calenge, C., Meillard, D., Fournier, P., & Fouque, C. (2004). Efficiency of spreading maize in the garrigues to reduce wild boar (Sus scrofa) damage to Mediterranean vineyards. *European Journal of Wildlife Research*, *50*, 112–120. http://dx.doi.org/10.1007/s10344-004-0047-y

Cellina, S. (2008). Effects of supplemental feeding on the body condition and reproductive state of wild boar Sus scrofa in Luxembourg. Dissertation, University of Sussex, Brighton, UK.

El Hani, A., & Conover, M. R. (1995). Comparative Analysis of Deer Repellents. Pages 147–155 *in* Repellents in Wildlife Management Conference Proceedings, 8–10 August 1995, Denver, Colorado, USA.

Engeman, R. M., Campbell, D. L., Nolte, D., & Witmer, G. (1995). Some recent research results on non-lethal means for reducing animal damage to reforestation projects in the western United States. *Proceedings of the 10th Australian Vertebrate Pest Control Conference*, *10*, 150–154.

Geisser, H. (1998). The wild boar (Sus scrofa) in the Thurgau (northeastern Switzerland): Population status, damages and the influence of supplementary feeding on damage frequency. *Gibier Fane Sauvage - Game and Wildlife*, *15* (Special Number Pts 2 and 3), 547–554.

Geisser, H., & Reyer, H-U. (2004). Efficacy of hunting, feeding, and fencing to reduce crop damage by wild boars. *Journal of Wildlife Management*, *68*, 939–946. http://www.bioone.org/doi/abs/10.2193/0022-541X%282004%29068%5B0939%3AEOHFAF%5D2.0.CO%3B2

Gelman, A., & Hill, J. (2007). *Data analysis using regression and multilevel/hierarchical models*. Cambridge: Cambridge University Press. http://dx.doi.org/10.2277/052168689X

Günterschulze, J. (1979). Studien zur Kenntnis der Regio olfactoria von Wild- und Hausschwein. *Zoologischer Anzeiger, Jena*, *202* (3/4), 256–279.

Hahn, N., & Eisfeld, D. (1998). Diet and habitat use of wild boar (Sus scrofa) in SW-Germany. *Gibier Faune Sauvage, 15*, 595–606.

Jordan, D. M., & Richmond, M. E. (1991). Effectiveness of a vertical 3-wire electric fence modified with attractants or repellents as a deer exclosure. *Proceedings of the Eastern Wildlife Damage Control Conference*, *5*, 44–47.

Mason, J. R. (1997). *Repellents in Wildlife Management*. (447 pp.). Ft. Collins, CO: Colorado State University Press.

Mason, J. R. (1998). Mammal repellents: Options and considerations for development. *Proceedings of Vertebrate Pest Conference*, *18*, 325–329.

Mazzoni della Stella, R., Calovi, F., & Burrini, L. (1995). The wild boar management in a province of Central Italy. *IBEX Journal of Mountain Ecology*, *3*, 188–191.

Meynhardt, H. (1978). *Schwarzwildreport*. Leipzig, Germany: Neumann-Verlag.

Meynhardt, H. (1991). Schwarzwild-Bibliothek 4. *Wildversorgung, Trophäen und Schadensverhütung*. Melsungen, Germany: Verlag Neumann-Neudamm.

Milunas, M. C., Rhoads, A. F., & Mason J. R. (1994). Effectiveness of odour repellents for protecting ornamental shrubs from browsing by white-tailed deer. *Crop Protection*, *13*, 393–397. http://dx.doi.org/10.1016/0261-2194%2894%2990056-6

R Development Core Team. (2010). *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Schlageter, A., & Haag-Wackernagel, D. (2011). Effectiveness of solar blinkers as a means of crop protection from wild boar damage. *Crop Protection*, *30*, 1216–1222. http://dx.doi.org/10.1016/j.cropro.2011.05.008

Schlageter, A., & Haag-Wackernagel, D. (2012). Evaluation of an odor repellent for protecting crops from wild boar damage. *Journal of Pest Science*. DOI: 10.1007/s10340-012-0415-4

Schley, L. (2000). *The badger Meles meles and the wild boar Sus scrofa: distribution and damage to agricultural crops in Luxembourg*. Brighton, UK: University of Sussex.

Schley, L., Dufrêne, M., Krier, A., & Frantz, A. C. (2008). Patterns of crop damage by wild boar (Sus scrofa) in Luxembourg over a 10-year period. *European Journal of Wildlife Research*, *54*, 589–599. http://dx.doi.org/10.1007%2Fs10344-008-0183-x

Vassant, J., & Boisaubert, B. (1984). Bilan des expérimentations enterprises en Haut-Marne pour réduire les dégâts de sanglier (Sus scrofa) à l'encontre des cultures agrucoles. Smposium International sur le sanglier (International Wild boar symposium). F. Spitz, and D. Pépin, technical coordinators. Toulouse, France, pp. 187–199.

Vassant, J., & Breton, D. (1986). Essai de reduction des dégâts de sangliers (Sus scrofa) sur blé (Triticum sativum) au stade laiteux par distribution de maïs (Zea mais) en forêt. *Gibier Faune Sauvage*, *3*, 83–95.

Vassant, J. (1994a). Les techniques de prévention des dégâts de sanglier. *Bulletin Mensuel de l'Office National de la Chasse*, *191*, 90–93.

Vassant, J. (1994b). L'agrainage dissuasif: résultats d'expériences. *Bulletin Mensuel de l'Office National de la Chasse*, *191*, 101–105.

Vassant, J. (1997). Le sanglier en France: ces quinze dernières années. *Bulletin Mensuel de l'Office National de la Chasse*, *225*, 32–35.

Zeuner, F. E. (1967). *Geschichte der Haustiere*. Munich, Germany: BLV-Verlag.

Table 1. Numbers of damage events during pre-treatment, and treatment (including pellet removal events) and distances [m] to the Barnyard and the forest for each experimental plot

Culture		Clover		Meadow								Wheat
Experimental Plot		**C1**	**C2**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**W1**
Damage	**Pretreatment**	4	2	1	2	1	1	1	2	2	6	2
	Treatment	4	2	0	0	1	0	1	0	6	2	3
	(Removal)	(3)	(2)	(0)	(0)	(0)	(0)	(0)	(0)	(2)	(0)	(2)
Distance	**Barnyard**	530	800	125	170	170	350	230	440	375	400	600
	Forest	100	25	10	10	20	5	10	10	5	5	5

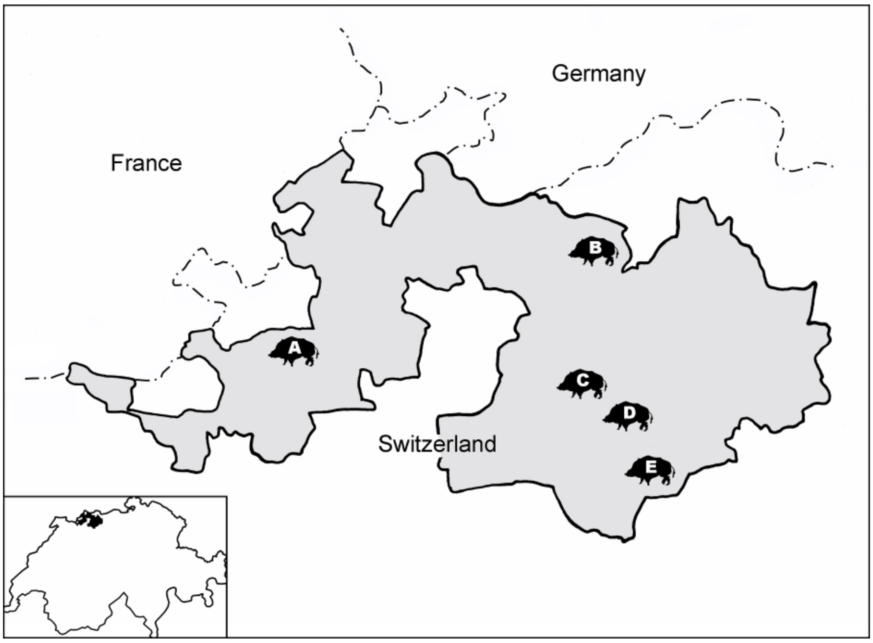

Figure 1. Location of the study sites. Grey: Canton Basel-Land, Switzerland. A = Blauen (5 experimental plots), B = Arisdorf (1 plot), C = Lampenberg (2 plots), D = Bennwil (1 plot), E = Eptingen (2 plots)

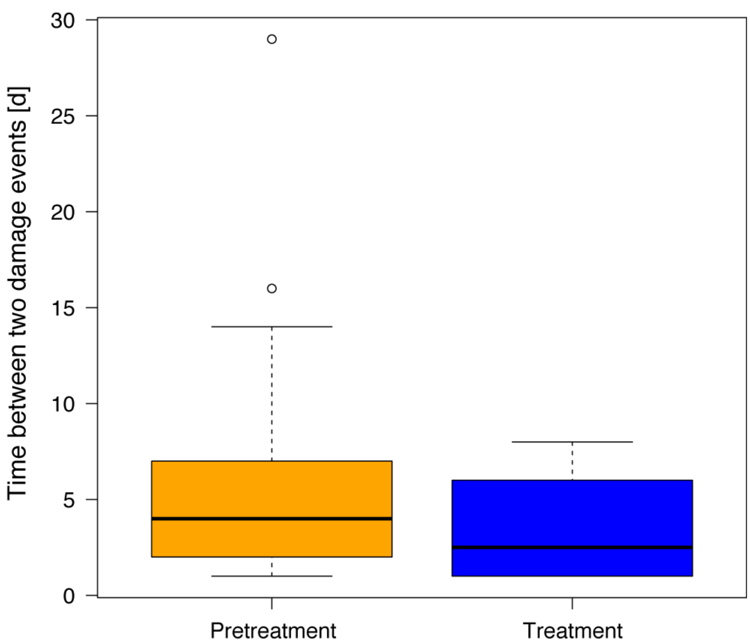

Figure 2. Time-span between two consecutive damage events for the pretreatment phase and the treatment phase

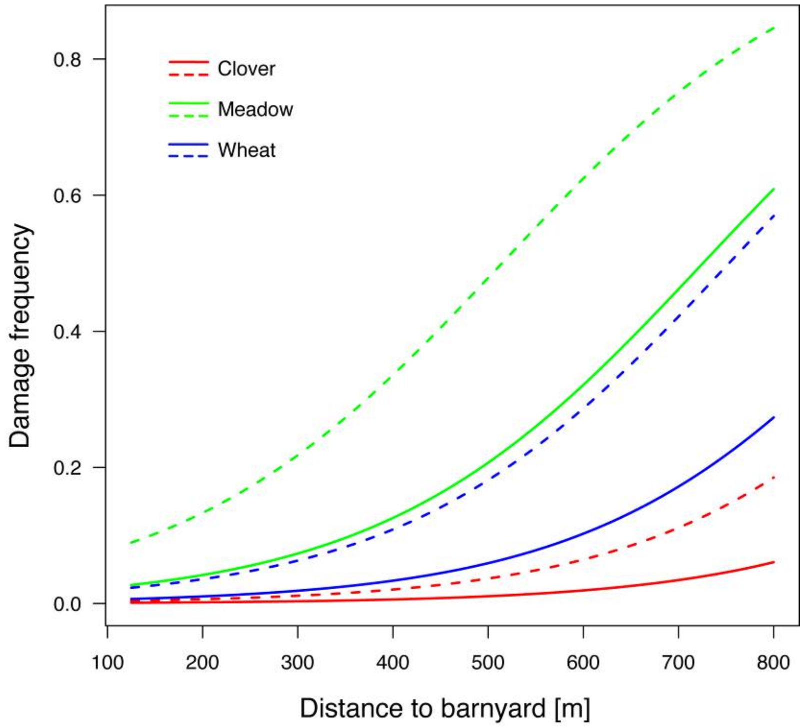

Figure 3. Influence of the distance between the experimental plots and occupied buildings (Barnyard) on the damage frequency for the three different cultures
Dashed lines: pretreatment, solid lines: treatment

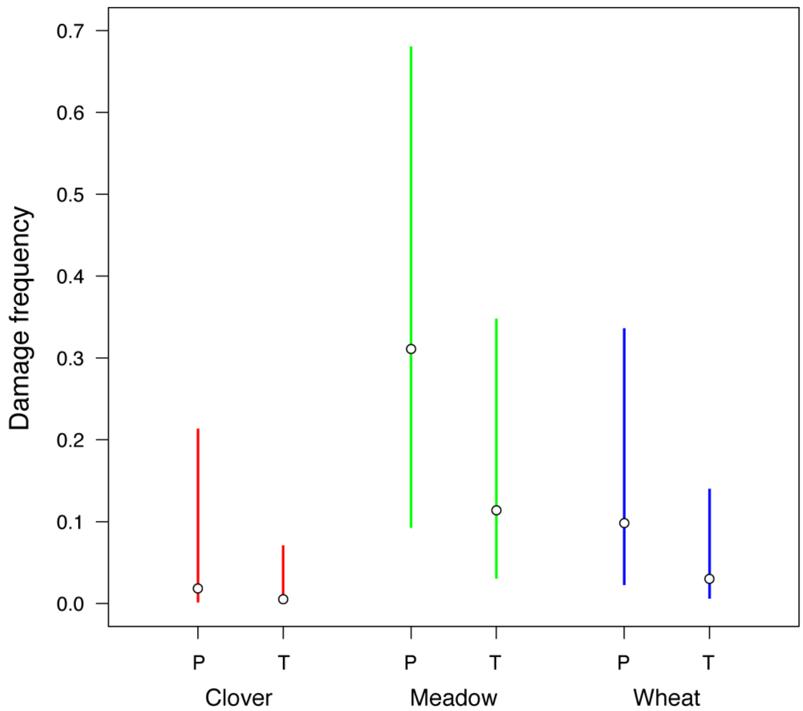

Figure 4. Difference in damage frequency between the cultures. P = pretreatment, T = Treatment

Chapter 4: Discussion

4.1 Wild boar biology

The very social wild boar shows a high flexibility and individuality of behavioral patterns depending on several external and intrinsic factors (e.g. Boitani *et al.* 1994, Baubet *et al.* 1998, Santos *et al.* 2004). High variation of social grouping, spatial usage, and activity allows for optimal exploitation of resources.

The reproductive success of wild boars is based on an early sexual maturity and large litters, compared to other ungulates (Kaminski *et al.* 2005). The wide plasticity enables the omnivore wild boar to customize easily to various environments, to colonize new habitats and enlarge the species distribution (Genov 1981a, Acevedo *et al.* 2006). Due to optimal foraging and by reacting to changing environmental conditions, wild boars exploit available food resources at the best (Genov 1981a, Genov 1981b, Santos *et al.* 2004). Although mainly described as forest or forest edge species in near natural habitats (e.g. Genov 1981a, Briedermann 1990, Fernández *et al.* 2006, Fonseca 2008), wild boars are able to use arable land optimally (Dardaillon 1987, Schley & Roper 2003, Geisser & Reyer 2004, Herrero *et al.* 2006, Keuling *et al.* 2008a, Keuling *et al.* 2009) and do not have the need for large forests (Gerard *et al.* 1991, Herrero *et al.* 2006) as long as food, shelter and water are available (Massei *et al.* 1996, Baubet *et al.* 1998, Sodeikat & Pohlmeyer 2007).

4.2 Wild boar management considerations

Wild boar population management is necessary to counteract economic problems arising from high populations. Regulation of populations seems to be inevitable in order to reduce crop damages and the risk of disease transmission to livestock. In recent years, all age classes of females have shown to be highly reproductive. Thus mainly piglets and females, yearlings as well as adults, have to be shot (e.g. Bieber & Ruf 2005, Gethöffer *et al.* 2007). Predation, natural mortality and road mortality have only small impact on wild boar populations, whereas the environment, especially the abundance of food or hunting, is mainly decisive

(Okarma *et al.* 1995, Nores *et al.* 2008). Variations of group structure, divisions, space use, and activity cycles seem to be induced rather by seasonal changes (Boitani *et al.* 1994, D'Andrea *et al.* 1995, Keuling *et al.* 2008a, Keuling *et al.* 2009) than by hunting. Keuling *et al.* (2008b) assumed the effect of hunting on wild boar behaviour and space use as negligible under moderate hunting pressure and optimal evenly distributed nutritional conditions. Other studies, however, have shown that battues with high beating pressure could cause temporary shift or increase of home ranges (Maillard & Fournier 1995, Sodeikat & Pohlmeyer 2002, Sodeikat & Pohlmeyer 2003, Sodeikat & Pohlmeyer 2007).

The reduction of wild boar populations in woodland during winter as well as the intense hunting of juveniles inside agricultural fields in summer has been proposed as precondition for prevention of damage in agricultural land (Briedermann 1977, Meynhardt 1991, Mazzoni della Stella *et al.* 1995, Henning 1998, Happ 2002). Some studies reported that up to 80% of wild boar groups live predominantly within fields in summer, causing high damages (Gerard *et al.* 1991, Cahill *et al.* 2003, Keuling *et al.* 2009). To avoid or reduce crop damages, this proportion of animals, has to be decreased.

These approaches were adopted in the management policy of the Canton Basel-Land and are implemented in hunting practice as revealed by a detailed analysis of hunting statistics data. Hunting in the fields has been intensified and the proportion of wild boars shot in the field increased during the past years (see Supplementary Information, Fig. S2).

Many authors suggested that in order to reduce wild boar populations it is of crucial importance to concentrate hunting efforts primarily on juveniles, especially females, because juveniles make the largest fraction of the population and therefore contribute the most to overall reproduction (e.g. Briedermann 1977, Meynhardt 1991, Henning 1998, Happ 2002). A look on the composition of age classes of annual hunting bags of the last 16 years shows that this criterion is well met by the hunters of the Canton Basel-Land (see Supplementary Information, Fig. S1).

Wild boars are well known to be difficult to count at an absolute level because of their mainly nocturnal activity and preference for wooded habitats, which limits direct observation (Boitani *et al.* 1994, Fattebert 2005). Consequently, most wild boar population size or density estimates have used relative indices of abundance rather than direct observations or counts. Most estimates depend on hunting or culling statistics data (e.g. Geisser & Reyer 2005, Acevedo *et al.* 2006, Melis *et al.* 2006). These data have shown to provide reliable relative population estimates.

Thus, the annual fluctuations of the hunting bags of the canton Basel-Land indicate increasing and decreasing of wild boar populations (see Fig. S1). Years of small hunting bags directly following years of big hunting bags are an indirect measure for the regulative impact of hunting on population size and, thus, the reducing effect on wild boar damage to agriculture, which is reflected by the simultaneously fluctuating yearly amount of damage.

As mentioned in section 1.4.1.1, one of the main disadvantages of battues is its reduced selectivity. Hunters must react quickly once the wild boars pass by and the time to choose which animal to shoot or not to shoot is very short. Thus, battues are a less appropriate hunting technique for achieving the goal of high proportions of shot juveniles, compared to hide hunting and stalk hunting, which is also evidenced by analysis of the hunting data of the Canton Basel-Land.

Currently, hunting in the forest is still more effective in achieving a higher proportion of shot juveniles because of the selectivity of hide hunting, which accounts for the majority of shot wild boars in the forest. However, since the stalk hunting, which is also suitable for achieving high juvenile proportions (59% of shot wild boars by stalk were juveniles), became more and more relevant in recent years, the difference between field and forest in terms of juvenile proportions is likely to diminish.

4.3 Damage prevention

The investigated deterrents can be categorised into three classes, according to the way they operate: solar blinkers rely on startle response or neophobia; the odour repellent relies on fear-evocation by imitating predator stenches, and the gustatory repellent relies on conditioned avoidance by its acetous taste. The results of the present study reveal, that solar blinkers, the odour repellent, and the gustatory repellent were not effective in deterring wild boars.

In general, effectiveness of optic deterrents is highly doubted in literature (e.g. Mason 1998). Strobe lights have been shown to frighten coyotes. However, the authors point out that the effect is rather short-termed and dependent on spare use and frequent alternation of location of the device (Linhart 1984, Linhart *et al.* 1984). Trials conducted to evaluate the effectiveness of a sonic device combined with strobe lights against white-tailed deer did not yield satisfactory results (Belant *et al.* 1998). To date, there is no scientific proof for the effectiveness of optic deterrents against deer, which is also true for wild boars (I). In contrast

to birds, which have the most highly developed visual facility among vertebrates (Bowmaker, 1980), mammals are often colour blind or, at least, have limited colour vision (Jacobs 1993). The visual facility of the wild boar is described as relatively weakly developed, especially compared to olfaction (e.g. Briedermann 1990, Eguchi *et al.* 1997).
Since, visual deterrence mainly relies on startle responses, habituation is inevitable. Thus, the effectiveness diminishes with time. In my study I could not even find an initial deterrence effect (I).

A wide range of studies on olfaction in wild boars and other suids confirm the species' pronounced sense of smell (Altevogt 1972, Meynhardt 1978, Günterschulze 1979, Briedermann 1990). The effectiveness of chemical deterrents against vertebrates is conditionally confirmed in literature (Jordan Jr. & Richmond 1991, Milunas *et al.* 1994, El Hani & Conover 1995, Engeman *et al.* 1995, Belant *et al.* 1998, Mason 1998). However, the efficacy of repellents varies strongly, depending on the functionality of the deterrent, the species investigated, and the population densities of the target animals. Repellents causing pain are considered more effective than those causing fear or sickness. The pain-causing sensory irritants are most effective when being directly applied to crops (Mason 1998).
On the other hand, there is no evidence in literature that sensory irritants effect targeted species to abandon areas. Animals usually do not learn to avoid treated foods. Repellents relying on taste are rarely, if ever, effective. Products that claim effectiveness solely because of an acetous taste are doing so in the absence of reliable evidence (Mason 1997), which is perfectly in line with my findings (III).
The major limitation with the use of fear-evocating deterrents is that animals habituate rather quickly to external stimuli after a short time (Bomford & O'Brien 1990, Nolte 1994, Craven & Hygnstrom 1994, II). Furthermore, my results do not confirm startle response or neophobia in the sense of an initial deterrence effect of the odour repellent investigated (II). Moreover, I suggest that any other odour repellent relying on fear-evocation would not be an effective deterrent against wild boar and feral swine, especially in areas where natural enemies like wolf, brown bear *Ursus arctos*, or lynx are absent or very rare.

4.4 Conclusions

The wild boar is a valuable component of the indigenous European fauna. Ecological benefits of the wild boar are diverse and include dispersal of seeds, forest regeneration, consumption of pest insects and carrion, and providing prey for predators. In addition, wild boars are an economically important game species and serve as a source of high quality meat. The species is very popular amongst hunters because of its broad behavioural repertoire and has gained popularity also in the public opinion in recent years.

The problems associated with increased wild boar population, especially the increasing damage in agriculture bears a challenge for game authorities, hunters and farmers. To date, wild boar population management by means of hunting and field protection with electric fences are the most important tools for damage control. The present study revealed that deterrents based on fear-provocation or startle response such as odour repellents and optic deterrents, as well as repellents based on conditioned avoidance such as gustatory repellents are not effective for field protection. To date, scientific evidence for effectiveness only exists for electric fences. Farmers must therefore be discouraged from using deterrents other than the electric fence to protect their fields. In addition, I recommend that damage compensation should be subject to the condition of appropriate fencing of the fields, as handled by the Canton Basel-Land.

When dealing with wild boar damage in agriculture, the principal object is to achieve a balance between management effort, damage prevention, and compensation policy. Hunting should aim at regulating populations on an ecologically and economically sustainable level. Field protection should aim at a cost-effective reduction of wild boar damage. Therefore, I suggest that future research should focus on holistic economical evaluations of wild boar management systems, aiming at well balanced policies including population control, damage prevention, and compensation. The development of models to evaluate particular management systems could support authorities in their decisions on which management policies to implement.

As the issue of wild boar damage affects several stakeholders, mainly farmers, hunters and game authorities, the evaluation and implementation of management systems needs to be part of an integrative multi stakeholder process. Authorities should be encouraged to establish platforms such as regularly meeting working groups including all stakeholders as well as wildlife experts and scientists to promote the exchange and understanding.

The wide eco-ethological plasticity of wild boars enables the species to colonize new habitats and enlarge its distribution. In Switzerland, wild boar populations are expected to spread and increase further, particularly into the central parts of Switzerland, as new wildlife crossings are in construction or in process of planning. Therefore, farmers, hunters and wildlife authorities of these regions will face challenges similar to those in already densely populated regions in the near future.

References

Abaigar T, del Barrio G, Vericad J R (1994). Habitat preference of wild boar (*Sus scrofa* L., 1758) in a Mediterranean environment. Indirect evaluation by signs. *Mammalia* 58: 201–210.

Acevedo P, Vicente J, Höfle Ú, Cassinello J, Ruiz-Fons F, Gortazar C (2007). Estimation of European wild boar relative abundance and aggregation: a novel method in epidemiological risk assessment. *Epidemiology and Infection* 135: 519–527.

Aguilera E, Knight R L, Cummings J L (1991). An evaluation of two hazing methods for urban Canada geese. *Wildlife Society Bulletin* 19: 32–5.

Altevogt R (1972). Zur Verhaltensökologie der Trüffelschweine des Perigords (AW-Frankreich). *Wissenschaftliche Zeitschrift der Humboldt-Universität zu Berlin. Reihe Mathematik/Naturwissenschaften XXY* 4: 407–410.

Andrzejewski R, Jezierski W (1978). Management of a wild boar population and its effects on commercial land. *Acta Theriologica* 23: 309–339.

Artois M, Depner K R, Guberti V, Hars J, Rossi S, Rutili D (2002). Classical swine fever (hog cholera) in wild boar in Europe. *Revue scientifique et technique (International Office of Epizootics)* 21(2): 287–303.

Aumaître A, Queré J P & Peiniau J (1984). Influence du milieu sur la reproduction hivernale et la prolificité de la laie. Symposium international sur le sanglier, F. Spitz & D. Pépin, eds. *Colloques de l´I.N.R.A.*, Toulouse (France): 69–78.

Avery M L (1992). Evaluation of methyl anthranilate as a bird repellent in fruit crops. *Proceedings of the Fifteenth Vertebrate Pest Conference*: 130–133.

Baubet E, Brandt S, Touzeau C (1998). Effet de la chasse sur les stratégies d'occupation de l'espace des sangliers (*Sus scrofa*). Analyses préliminaires. *Gibier Faune Sauvage* 15: 655–658.

Belant J L, Seamans T W, Tyson L A (1998). Predator urines as chemical barriers to white-tailed deer. *Proceedings of the 18th Vertebrate Pest Conference* 18: 359–362.

Blanchard R J, McKittrick C R, Blanchard D C (2001). Animal models of social stress: Effects on behavior and brain neurochemical systems. *Physiology & Behavior* 73: 261–271.

Boitani L, Mattei L, Nonis D, Corsi F (1994). Spatial and activity patterns of wild boars in Tuscany, Italy. *Journal of Mammalogy* 75: 600–612.

Boitani L, Trapanese P, Mattei L (1995). Demographic patterns of a wild boar (*Sus scrofa* L.) population in Tuscany, Italy. *IBEX - Journal of Mountain Ecology* 3: 197–201.

Bomford M, O'Brien P H (1990). Sonic deterrents in animal damage control. *Wildlife Society Bulletin* 18: 41-422.

Bouldoire J L (1984). Le statut du sanglier en France. Evolution entre 1975 et 1982. *Symposium international sur le sanglier*, Toulouse (France): 173–186.

Bouldoire J-L, Havet P (1981). Nature et importance des dégâts aux cultures causés par les grands gibiers et les sangliers. *Bulletin Mensuel de l'Office National de la Chasse* 48: 10–16.

Boutin S (1990). Food supplementation experiments with terrestrial vertebrates: patterns, problems, and the future. *Canadian Journal of Zoology* 68: 203–220.

Bowmaker, J K (1980). Colour vision in birds and the role of oil droplets. *Trends in Neurosciences* 3: 196–199.

Brandt E (1974). Probleme der praktischen Schwarzwildbewirtschaftung. *Beiträge zur Jagd- und Wildforschung* 8: 89–95.

Bratton S P (1975). The effect of the European wild boar, *Sus scrofa*, on gray beech forest in the Great Smoky Mountains. *Ecology* 56: 1356–1366.

Brauer A, Lange E, Kaden V (2006). Oral immunisation of wild boar against classical swine fever: uptake studies of new baits and investigations on the stability of lyophilised C-strain vaccine. *European Journal of Wildlife Research* 52: 271–276.

Breton D (1994). La limitation des de´ga ˆts de sanglier par la pose de clôtures électriques dans le département de la Haute-Marne. *Bulletin Mensuel de l'Office Nationale de la Chasse* 191 (Nume´ro special): 96–100.

Brooks J E, Ahmad E, Hussain I & Khan M H (1989). The agricultural importance of the wild boar (*Sus scrofa* L.) in Pakistan. *Tropical Pest Management* 35: 278–281.

Briedermann L (1971). Zur Reproduktion des Schwarzwildes in der Deutschen Demokratischen Republik. *Tagungsbericht der deutschen Akademie für Landwirtschafts-wissenschaften Berlin* 113: 169–186.

Briedermann L (1990). Schwarzwild. Second ed. VFB Deutscher Landwirtschafts-Verlag, Berlin, Germany.

Bruggers R L, Brooks J E, Dolbeer R A, Woronecki P P, Pandit R K, Tarimo T, All-India Co-ordinated Research Project on Economic Ornithology, Hoque M (1986). Responses of pest birds to reflecting tape in agriculture. *Wildlife Society Bulletin* 14: 161–70.

Cabon K (1958). Das Massensterben von Wildschweinen im Naturstaatpark von Bialowieza im Winter 1955/56. *Acta Theriologica II* 4: 71–82.

Cahill S, Llimona F (2002). Demographics of a wild boar *Sus scrofa* Linnaeus, 1758 population in a metropolitan park in Barcelona. *Wild boar research 2002. A selection and edited papers from the "4th international wild boar symposium"*, Lousa, Portugal: 37–52.

Calenge C, Maillard D, Fournier P, Fouque C (2004). Efficiency of spreading maize in the garrigues to reduce wild boar (*Sus scrofa*) damage to Mediterranean vineyards. *European Journal of Wildlife Research* 50: 112–120.

Caley P, Hone J (2004). Disease transmission between and within species, and the implications for disease control. *Journal of Applied Ecology* 41: 94-104.

Campbell D J, Rudge M R (1984). Vegetation Changes Induced over 10 Years by Goats and Pigs at Port Ross, Auckland Islands (Sub-Antarctic). *New Zealand Journal of Ecology* 7: 103–118.

Cellina S (2008). Effects of Supplemental Feeding on the Body Condition and Reproductive State of Wild Boar *Sus Scrofa* in Luxembourg. Dissertation, University of Sussex, Brighton, UK.

Choquenot D (1998). Testing the relative influence of intrinsic and extrinsic variation in food availability on feral pig populations in Australia's rangelands. *Journal of Animal Ecology* 67: 887–907.

Conover M R (1984). Comparative effectiveness of avitrol, exploders, and hawk-kites in reducing blackbird damage to corn. *Journal of Wildlife Management* 48:109–16.

Conover M R (1998). Behavioral principles governing conditioned food aversions based on deception. In J. R. Mason, ed. Repellents in Wildlife Management, Colorado State University Press, Ft. Collins, CO. 29–41.

Conover D O, Conover M R (1989). Wildlife management by the Puritans. *Massachusetts Wildlife* 39: 2–8.

Conover M R, Dolbeer R A (1989). Reflecting tapes fail to reduce blackbird damage to ripening cornfields. *Wildlife Society Bulletin **17***: 441–3.

Conover M R, Kessler K K (1994). Diminished producer participation in an aversive conditioning program to reduce coyote predation on sheep. *Wildlife Society Bulletin* 22: 229–233.

Cousse S, Spitz F, Hewson M, Janeau G (1994). Use of space by juveniles in relation to their post-natal range, mother, and siblings: an example in the wild boar, *Sus scrofa* L. *Canadian Journal of Zoology* 72: 1691–1694.

Cowled B D , Giannini F, Beckett S D, Woolnough A, Barry S, Randall L, Garner G (2009). Feral pigs: predicting future distributions. *Wildlife Research* 36(3): 242–251.

Craven S R (1983). Deer. Pages D23–D33 in R. M. Tirnm, ed., Prevention of wildlifd damage. Great Plains Agricultural Council, University of Nebraska, Lincoln, NE.

Csányi S (1995). Wild boar population dynamics and management in Hungary. *IBEX - Journal of Mountain Ecology* 3: 222–225.

Cugnasse J M, Teillaud P, Bon R (1987). Résultats préliminaires sur l'activité diurne et sur la structure des groupes de sangliers (*Sus scrofa* L.) dans les Monts de l'Espinouse. *Gibier Faune Sauvage* 4: 267–277.

D'Andrea L, Durio P, Perrone A, Pirone S (1995). Preliminary data of the wild boar (*Sus scrofa*) space use in mountain environment. *IBEX Journal of Mountain Ecology* 3: 117–121.

Dardaillon M (1988). Wild boar social groupings and their seasonal changes in the Camargue, southern France. *Zeitschrift für Säugetierkunde* 53: 22–30.

Dexter N (2003). Stochastic models of foot and mouth disease in feral pigs in the Australian semi-arid rangelands. *Journal of Applied Ecology* 40: 293–306.

Dinter U (1991). Das Raum-Zeit-Verhalten von Schwarzwild im Grunewald in den Sommermonaten unter besonderer Berücksichtigung menschlicher Störungen. Ludwig-Maximilians-Universität, München. Dissertation.

Dobrowolska A, Melosik M (2008). Bullet-derived lead in tissues of the wild boar (*Sus scrofa*) and red deer (*Cervus elaphus*). *European Journal of Wildlife Research* 54: 231–235.

Doerr ML, McAninch JB, Wiggers EP (2001). Comparison of four methods to reduce white-tailed deer abundance in an urban community. *Wildlife Society Bulletin* 29: 1105–1113.

Dolbeer R A, Woronecki P P, Bruggers R C (1986). Reflecting tapes repel blackbirds from millet, sunflowers, and sweet corn. *Wildlife Society Bulletin* ***14***: 418–25.

Eguchi Y, Tanida H, Tanaka T, Yoshimoto T (1997). Color discrimination in wild boars. *Journal of Ethology* 15: 1–7.

El Hani A, Conover M R (1995). Comparative analysis of deer repellents. *Repellents in wildlife management conference proceedings*, 8–10 Aug 1995, Denver, CO, USA. 147–155.

Eisfeld D, Hahn N (1998). Raumnuntzung und Ernährungsbasis von Schwarzwild, Abschlussbericht an das Ministerium Ländlicher Raum Baden-Württemberg, März 1998.

Erkinaro E, Heikura K, Lindgren E, Pulliainen E, Sulkava S (1982). Occurrence and spread of the wild boar (*Sus scrofa*) in eastern Fennoscandia. *Memoranda Society Fauna Flora Fennica* 58: 39–47.

Fattebert J, Fischer C, Hebeisen C, Baubet E (2005). Efficiency of supplemental feeding and fencing to diminish wild boar (*Sus scrofa*) damages to agricultural crop in the basin of Geneva, Switzerland. in: *XXVIIth Congress of IUGB*, 28. Aug. – 3. Sept. Extended abstracts: 325

Feichtner B (1998). Ursachen der Streckenschwankungen beim Schwarzwild im Saarland. *Zeitschrift für Jagdwissenschaft* 44: 140–150.

Fernández-Llario P, Carranza J (2000). Reproductive performance of the wild boar in a Mediterranean ecosystem under drought conditions. *Ethology Ecology & Evolution* 12: 335–343.

Fernández-Llario P, Mateos-Quesada P (1998). Body size and reproductive parameters in the wild boar *Sus scrofa*. *Acta Theriologica* 43: 439–444.

Fernández-Llario P, Mateos-Quesada P, Silverio A, Santos P (2003). Habitat effects and shooting techniques on two wild boar (*Sus scrofa*) populations in Spain and Portugal. *Zeitschrift für Jagdwissenschaft* 49: 120–129.

Fernández-Llario P, Mateos-Quesada P (2005). Influence of rainfall on the breeding biology of wild boar (*Sus scrofa*) in a Mediterranean ecosystem. *Folia Zoologica* 54: 240–248.

Fischer C, Gourdin H, Obermann M (2002). Spatial behaviour of the wild boar in Geneva, Switzerland: testing the methods and first results. *Wild boar research 2002. A selection and edited papers from the "4th international wild boar symposium"*, Lousa, Portugal: 149–155.

Focardi S, Capizzi D, Monetti D (2000). Competition for acorns among wild boar (*Sus scrofa*) and small mammals in a Mediterranean woodland. *Journal of Zoology* 250: 329–334.

Fonseca C, Santos P, Monzón A, Bento P, Alves da Silva A, Alves J, Silvério A, Soares A M V M, Petrucci-Fonseca F (2002). Reproduction in the wild boar (*Sus scrofa* Linnaeus, 1758) populations of Portugal. *Wild boar research 2002. A selection and edited papers from the "4th international wild boar symposium"*, Lousa, Portugal: 53–65.

Fournier-Chambrillon C, Maillard D, Fournier P (1995). Diet of the wild boar (*Sus scrofa* L.) inhabiting the Montpellier garrigue. IBEX *Journal of Mountain Ecology,* 3: 174–179.

Frings H (1964). Sound in vertebrate pest control. *Proceedings of the 2nd Vertebrate Pest Conference* 2: 50–56.

Fruzinski B (1995). Situation of wild boar population in western Poland. *IBEX - Journal of Mountain Ecology* 3: 186–187.

Geisser H (2000). Das Wildschwein (*Sus scrofa*) im Kanton Thurgau (Schweiz): Analyse der Populationsdynamik, der Habitatansprüche und der Feldschäden in einem anthropogen beeinflussten Lebensraum. Universität Zürich. Dissertation.

Geisser H, Reyer H-U (2004). Efficacy of hunting, feeding, and fencing to reduce crop damage by wild boars. *Journal of Wildlife Management* 68: 939–946.

Geisser H, Reyer H-U (2005). The influence of food and temperature on population density of wild boar *Sus scrofa* in the Thurgau (Switzerland). *Journal of Zoology* 267: 89–96.

Genov P (1981a). Food composition of wild boar in north-eastern and western Poland. *Acta Theriologica* 26: 185–205.

Genov P (1981b). Significance of natural biocenoses and agrocenoses as the source of food for wild boar (*Sus scrofa* L.). *Ekologia Polska* 29: 117–136.

Genov P (1984). Préférences alimentaires du sanglier vis-à-vis de diverses variétés de pomme de terre. *Symposium international sur le sanglier, Colloques de l'I.N.R.A.*, Toulouse (France): 201–204.

Gerard J F, Campan R (1988). Variabilité éco-ethologique chez le sanglier europeén: comparision des travaux francaise. *Cahiers d'Ethologie Appliquee* 8: 63–130.

Gethöffer F (2005). Reproduktionsparameter und Saisonalität der Fortpflanzung des Wildschweins (*Susscrofa*) in drei Untersuchungsgebieten Deutschlands. Dissertation. Institut für Wildtierforschung. Tierärztliche Hochschule Hannover: 143.

Gethöffer F, Sodeikat G, Pohlmeyer K (2007). Reproductive parameters of wild boar (*Sus scrofa*) in three different parts of Germany. *European Journal of Wildlife Research* 53: 287–297.

Gilsdorf J M, Hygnstrom S E, VerCauteren K C (2002). Use of frightening devices in wildlife damage management. *Integrated Pest Management Reviews* 7: 29–45.

Gilsdorf J M, Hygnstrom S E, VerCauteren K C, Clements G M, Blankenship E E, Engeman R M (2004). Evaluation of a Deer-Activated Bio-Acoustic Frightening Device for Reducing Deer Damage in Cornfield. *Wildlife Society Bulletin* 32(2): 515–523.

Giuffra E, Kijas J M H, Amarger V, Carlborg Ö, Jeon J-T, Andersson L (2000). The origin of the domestic pig: Independent domestication and subsequen introgression. *Genetics* 154: 1785–1791.

Gomez J M, Garcia D, Zamora R (2003). Impact of vertebrate acorn- and seedling-predators on a Mediterranean *Quercus pyrenaica* forest. *Forest Ecology and Management* 180: 125–134.

Gortázar C, Pelayo A, Ruiz-Fons F, Vicente J (2006). Disease risks and overabundance of game species. *European Journal of Wildlife Research* 52: 81–87.

Goryńska W (1981). Method of determining relations between the extent of damage in farm crops, big game numbers, and environmental conditions. *Acta Theriol*ogica 26: 469–481.

Goulding M J (2001). Possible genetic sources of free-living wild boar (*Sus scrofa*) in southern England. *Mammal Review* 31: 245–24

Green J S, Henderson F R, Collinge M D (1994). Coyotes. *In* S E Hygnstrom, R M Timm and G E Larson (eds). *Prevention and Control of Wildlife Damage*: 51–76. Lincoln, NE, USA: University of Nebraska Cooperative Extension Service.

Groot Bruinderink G W, Hazebroek E, Van der Voot A (1994). Diet and condition of wild boar, *Sus scrofa scrofa*, without supplementary feeding. *Journal of Zoology* 233: 631–648.

Günterschulze J (1979). Studien zur Kenntnis der Regio olfactoria von Wild-und Hausschwein. *Zoologischer Anzeiger (Jena)* 202: 256–279.

Hahn N, Eisfeld D (1998). Diet and habitat use of wild boar (Sus scrofa) in SW-Germany. *Gibier Faune Sauvage* 15: 595–606.

Hahn N, Kech G (1995). Literaturübersicht zur Schwarzwildforschung.

Happ N (2002). Hege und Bejagung des Schwarzwildes. Franckh-Kosmos Verlags-GmbH & Co., Stuttgart.

Hemmer H (1990). Domestication: The Decline of Environmental Appreciation. Cambridge University Press, Cambridge.

Henry V G (1968). Fetal development in European wild hogs. *Journal of Wildlife Management* 32: 966–970.

Herrero J, García-Serrano A, Couto S, Ortuño V M, García-González R (2006). Diet of wild boar *Sus scrofa* L. and crop damage in an intensive agroecosystem. *European Journal of Wildlife Research* 52: 245–250.

Hohmann U, Huckschlag D (2004). Forschungsbericht – Grenzwertüberschreitende Radiocäsiumkontamination von Wildschweinfleisch in Rheinland-Pfalz – Eine Mageninhaltsanalyse erlegter Wildschweine aus dem westlichen Pfälzerwald. Internetdokument der Forschungsanstalt für Waldökologie und Forstwirtschaft Rheinland-Pfalz.

Holst D (1972). Renal failure as the cause of death inTupaia belangeri exposed to persistent social stress. *Journal of comparative physiology* 78: 236–273.

Hone J (1990). How many feral pigs in Australia? *Australian Wildlife Research* 17: 571–572.

Howe T D, Singer F J, Ackerman B B (1981). Forage relationships of European wild boar invading Northern Hardwood Forest. *Journal of Wildlife Management* 45: 748–754.

Jaksic F M, Iriarte J A, Jiménez J E, Martínez D R (2002). Invaders without frontiers: cross-border invasions of exotic mammals. *Biological Invasions* 4: 157–173.

Janeau G, Spitz F (1984). L'espace chez le sanglier (*Sus scrofa scrofa* L.): occupation et mode d'utilisation. *Gibier Faune Sauvage* 1: 73–89.

Jullien J-M, Brandt S, Vassant J (1988). L'apport de maïs, à points fixes, est-il un moyen efficace de dissuader les sangliers de fréquenter les céréales en lait? *Bulletin Mensuel de l'Office National de la Chasse* 130: 19–26.

Kaberghs J (2004). Sanglier - Impact du nourrissage artificiel. *Chasse & Nature* Mai 2004: 29-32.

Kabudi P, Fetter S, Libois R M, Schumacker R, Ruwet J C (1987). Etude du régime alimentaire du sanglier (*Sus scrofa* L.) dans les Ardennes belges. *Cahiers d'Ethologie appliquée* 7: 223–246.

Kaden V (1999). Bekämpfung der Klassischen Schweinepest beim Schwarzwild. *Zeitschrift für Jagdwissenschaft* 45: 45–59.

Kern B, Depner KR, Letz W, Rott M, Thalheim S, Nitschke B, Plagemann R, Liess B (1999). Incidence of classical swine fewer (CSF) in wild boar in a densely populated area indicating CSF virus persistence as a mechanism for virus perpetuation. *Journal of Veterinary Medicine B* 46: 63–67.

Keuling O, Stier N, Roth M (2008). Annual and seasonal space use of different age classes of female wild boar *Sus scrofa* L. *European Journal of Wildlife Research* 54: 403–412.

Keuling O, Stier N, Roth M (2008). How does hunting influence activity and spatial usage in wild boar *Sus scrofa* L.? *European Journal of Wildlife Research* 54: 729–737.

Keuling O, Stier N, Ihde J, Lampe T, Lauterbach K, Saebel J (2009). Schwarzwild - Untersuchungen zu Raum- und Habitatnutzung des Schwarzwildes (*Sus scrofa* L. 1758) in Südwest-Mecklenburg unter besonderer Berücksichtigung des Bejagungseinflusses und der Rolle älterer Stücke in den Rotten. Abschlussbericht 2002-2006 an die Oberste Jagdbehörde im Ministerium für Landwirtschaft, Umwelt und Verbraucherschutz Mecklenburg-Vorpommern und die Stiftung „Wald und Wild in Mecklenburg-Vorpommern".

Kijas J M H, Andersson L (2001). A Phylogenetic Study of the Origin of the Domestic Pig Estimated from the Near-Complete mtDNA Genome. *Journal of Molecular Evolution* 52: 302–308.

Klein F, Baubet E, Toigo C, Leduc D, Saint-Andrieux C, Saïd S, Fréchard C, Vallance M (2007). La gestion du sanglier. Des pistes et des outils pour réduire les populations. Office national de la chasse et de la faune sauvage. Paris, Auffargis, Bar-le-Duc, France.

Klemm M (1951). Das Schwarzwild und die biologische Bekämpfung unserer Forstschädlinge. *Nachrichtenblatt Deutscher Pflanzenschutzdienst* 5: 231–233.

Koehler A E, Marsh R E, Salmon T P (1990). Frightening methods and devices/stimuli to prevent mammal damage – a review. *Proceedings of the 14th Vertebrate Pest Conference* 14: 168–73.

Koslo P (1975). Dikij kaban. Verlag Uradshai, Minsk.

Kramer-Schadt S, Fernández N, Thulke H-H (2007). Potential ecological and epidemiological factors affecting the persistence of classical swine fever in wild boar *Sus scrofa* populations. *Mammal Review* 37: 1–20.

Krier A (2005). Zur Problematik der Entwicklung der Schalenwildbestände und der Wildschäden im Großherzogtum Luxemburg unter besonderer Berücksichtigung des Schwarzwildes (*Sus scrofa*). *Beiträge zur Jagd- und Wildforschung* 30: 14.

Kristiansson H (1985). Crop damage by wild boars in Central Sweden. *Proceedings of the XVIIth Congress of the International Union of Game Biologists*, Brussels: 605–609.

Krüger T (1998). Entwicklung der Jagdstrecken des Schwarzwildes (*Sus scrofa* L.1758) und möglicher Einflußfaktoren im heutigen Freistaat Sachsen. *Zeitschrift für Jagdwissenschaft* 44: 151–166.

Labudzki L, Wlazelko M (1991). Saisonale Dynamik der vom Schwarzwild im Feldanbau verursachten Schäden im Forschungsgebiet Zielonka. *Zeitschrift für Jagdwissenschaft* 37: 250–257.

Lemel J, Truvé J, Söderberg B (2003). Variation in ranging and activity behaviour of European wild boar *Sus scrofa* in Sweden. *Wildlife Biology* 9: 29–36.

Linderoth P, Elliger A (2002). Schwarzwildschäden an landwirtschaftlichen Kulturen in Baden-Württemberg im Jagdjahr 2000/2001. *WFS-Mitteilungen 1(2002)*: 1–4.

Linhart S B (1984). Strobe light and siren devices for protecting fenced pasture and range sheep from coyote predation. *Proceedings of the Vertebrate Pest Conference* 1: 154–156.

Linhart S B, Dasch G J, Johnson R R, Roberts J D, Packham C J (1992). Electric frightening devices for reducing coyote depredation on domestic sheep: Efficacy under range conditions and operational use. *Proceedings of the 15th Vertebrate Pest Conference* 15: 386–92.

Linhart S B, Sterner J D, Dasch G J, Theade J W (1984). Efficacy of light and sound stimuli for reducing coyote predation upon pastured sheep. *Protection Ecology* 6: 75–84.

Mackin R (1970). Dynamics of damage caused by wild boar to different agricultural crops. *Acta Theriologica* 15: 447–458.

Maillard D, Fournier P (1995). Effect of shooting with hounds on home range size of wild boar (*Sus scrofa* L.) groups in Mediterranean habitat. *IBEX Journal of Mountain Ecology* 3: 102–107.

Markov N I, Neifel'd N D, Estaf'ev A A (2004). Ecological aspects of dispersal of the wild boar, *Sus scrofa* L., 1758, in the northeast of European Russia. *Russian Journal of Ecology* 35: 131–134.

Mason J R (1997). Repellents. In: Wagner KK, Nolte DL (eds) Wildlife damage management for natural resource managers. Western Forestry and Conservation Association, Olympia: 11–16.

Mason J R (1998). Mammal repellents: options and considerations for development. *Proceedings of the 18th Vertebrate Pest Conference* 18: 325–329.

Massei G, Genov P V (2002). The environmental impact of wild boar. *Wild boar research 2002. A selection and edited papers from the "4th international wild boar symposium"*, Lousa, Portugal: 135–145.

Massei G, Genov P, Staines B W (1996). Diet, food availability and reproduction of wild boar in a Mediterranean coastal area. *Acta Theriologica* 41: 307–320.

Matschke G H (1964). The influence of oak mast on European wild hog reproduction. *Annual Conference Southeastern Association Game Fish Commission*: 35–39.

Mattioli L, Apollonio M, Lovari C, Siemoni N, Crudele G (1995). Wild boar as the main prey of wolf in an area of Northern Apennines (Italy). *IBEX - Journal of Mountain Ecology* 3: 212.

Mauget R (1979). Mise en evidence, par captures-recaptures et radiotracking, du domaine vital chez le sanglier (*Sus scrofa* L.) en foret de Chize. *Biology of Behaviour* 4(1): 25–42.

McLennan J A, Langham N P E, Porter R E R (1995). Deterrent effect of eye-spot balls on birds. *New Zealand Journal of Crop and Horticultural Science* 23: 139–144.

Melis C, Szafranska P A, Jedrzejewska B, Barton K (2006). Biogeographical variation in the population density of wild boar (*Sus scrofa*) in western Eurasia. *Journal of Biogeography* 33: 803–811.

Meynhardt, H. (1978). Schwarzwildreport. Leipzig, Germany: Neumann-Verlag.

Meynhardt H (1990). Schwarzwild-Report: Mein Leben unter Wildschweinen. Leipzig, Radebeul, Neumann Verlag.

Meynhardt, H. (1991). Schwarzwild-Bibliothek 4. Wildversorgung, Trophäen und Schadensverhütung. Melsungen, Germany: Verlag Neumann-Neudamm.

Milunas M C, Rhoads A F, Mason J R (1994). Effectiveness of odour repellents for protecting ornamental shrubs from browsing by white-tailed deer. *Crop Protection* 13: 393–397.

Minagawa M, Matsui A, Ishiguro N (2005). Patterns of prehistoric boar *Sus scrofa* domestication, and inter-islands pig trading across the East China Sea, as determined by carbon and nitrogen isotope analysis. *Chemical Geology* 218: 91–102.

Möllers F (2003). Wildschweine. Stuttgart, Schärtlein, Markus.

Moretti M (1995). Birth distribution, structure and dynamics of a hunted mountain population of wild boars (*Sus scrofa* L.) in Ticino, Switzerland. *IBEX - Journal of Mountain Ecology* 3: 192–196.

Mott D F, Timbrook S K (1988). Alleviating nuisance Canada goose problems with acoustical stimuli. *Proceedings of the 13th Vertebrate Pest Conference* 13: 301–304.

Náhlik A, Sándor G (2003). Birth rate and offspring survival in a free ranging wild boar *Sus scrofa* population. *Wildlife Biology* 9: 37–42.

Nicolaus L K (1987). Conditioned aversions in a guild of egg predators: implications for aposematism and prey defense mimicry. *American Midland Naturalist 1* 17: 405–4 19.

Niethammer G (1963). Die Einbürgerung von Säugetieren und Vögeln in Europa. Paul Parey, Hamburg und Berlin.

Nogueira-Filho S, Nogueira S, Fragoso J (2009). Ecological impacts of feral pigs in the Hawaiian Islands. *Biodiversity and Conservation* 18: 3677–3683.

Nolte D L, Mason J R, Epple G, Aronov E, Campbell D L (1994). Why are predator urines aversive to prey? *Journal of Chemical Ecology* 20: 1505–1516.

Nores C, Llaneza L, Álvares M A (2008). Wild boar (*Sus scrofa*) mortality by hunting and wolf (*Canis lupus*) predation. An example in Northern Spain. *Wildlife Biology* 14: 44–51.

Norman D M, Mason J R, Clark L (1992). Capsaicin effects on consumption of feed by cedar waxwings, and house finches. *Wilson Bulletin* 104: 549–551.

Oliver W L R, Ed. (1993). Pigs, peccaries and hippos: Status survey and conservation action plan. Cambridge and Gland.

Okarma H, Jedrzejewska B, Jedrzejewski W, Krasinski Z A & Milkowski L (1995). The roles of predation, snow cover, acorn crop, and man-related factors on ungulate mortality in Bialowieza Primeval Forest, Poland. *Acta Theriologica* 40: 197–217.

Ozoga J J & Verme L J (1982). Physical and reproductive characteristics of a supplementally-fed white-tailed deer herd. *Journal of Wildlife Management* 46(2): 281–301.

Pavlov P M, Crome F H J, Moore L A (1992). Feral pigs, rainforest conservation and exotic disease in North Queensland. *Wildlife research* 19: 179–193.

Putman R J, Staines B W (2004). Supplementary winter feeding of wild red deer *Cervus elaphus* in Europe and North America: justifications, feeding practice and effectiveness. *Mammal Review* 34: 285–306.

Randi E (2005). Management of wild ungulate populations in Italy: Captive-breeding, hybridisation and genetic consequences of translocations. *Veterinary Research Communications* 29: 71–75.

Roemer G W, Coonan T J, Garcelon D K, Bascompte J, Laughrin L (2001). Feral pigs facilitate hyperpredation by golden eagles and indirectly cause the decline of the island fox. *Animal Conservation* 4: 307–318.

Ruiz-Fons F, Vicente J, Vidal D, Hofle U, Villanúa D, Gauss C, Segalés J, Almería S, Montoro V, Gortázar C (2006). Seroprevalence of six reproductive pathogens in European wild boar (*Sus scrofa*) from Spain: The effect on wild boar female reproductive performance. *Theriogenology* 65: 731–743.

Sáez-Royuela C, Tellería J L (1986). The increased population of the wild boar (*Sus scrofa* L.) in Europe. *Mammal Review* 16: 97–101.

Sáez-Royuela C, Tellería J L (1987). Reproductive trends of the wild boar (*Sus scrofa*) in Spain. *Folia Zoologica* 36: 21–25.

Santilli F, Mazzoni della Stella R (2006). Electrical fencing of large farmland area to reduce crops damages by wild boars *Sus scrofa*. *Agricoltura Mediterranea* 136: 1–6.

Santos P, Mexia-de-Almeida L, Petrucci-Fonseca F (2004). Habitat selection by wild boar *Sus scrofa*, L. in Alentejo, Portugal. in: Wild Boar Research 2002. *A selection and edited papers from the "4th International Wild Boar Symposium"*. Galemys, 16 Special Issue: 167–184.

Schley L (2000). The badger *Meles meles* and the wild boar *Sus scrofa*: distribution and damage to agricultural crops in Luxembourg. Biological Sciences. Falmer, University of Sussex: 285.

Schley L, Dufrêne M, Krier A, Frantz AC (2008). Patterns of crop damage by wild boar (*Sus scrofa*) in Luxembourg over a 10-year period. *European Journal of Wildlife Research* 54: 589–599.

Schley L, Krier A, Wagner M, Roper T J (1998). Changes in the wild boar *Sus scrofa* population in Luxembourg during the period 1946 to 1996. *Bulletin de la Société des Naturalistes Luxembourgeois* 99: 77–85.

Schley L, Roper T J (2003). Diet of wild boar *Sus scrofa* in Western Europe, with particular reference to consumption of agricultural crops. *Mammal Review* 33: 43–56.

Scillitani L, Monaco A, Toso S (2010). Do intensive drive hunts affect wild boar (*Sus scrofa*) spatial behaviour in Italy? Some evidences and management implications. *European Journal of Wildlife Research* 56: 307–318.

Scott J D, Townsend T W (1985). Methods used by selected Ohio growers to control damage by deer. *Wildlife Society Bulletin* 13: 234–40.

Simon O, Goebel W (1999). Zum Einfluß des Wildschweines (*Sus scrofa*) auf die Vegetation und Bodenfauna einer Heidelandschaft. *Natur- und Kulturlandschaft* 3: 172–177.

Singer F J, Otto D K, Tipton A R, Hable C P (1981). Home ranges, movements, and habitat use of European wild boar in Tennessee. *Journal of Wildlife Management* 45: 343–353.

Singer F J, Swank W T, Clebsch E E C (1984). Effects of wild pig rooting in a deciduous forest. *Journal of Wildlife Management* 48: 464–473.

Sodeikat G, Pohlmeyer K (2002). Temporary home range modifications of wild boar *Sus scrofa* caused by drive hunts in Lower Saxony (Germany). *In* Proceedings of the 25th Congress of the International Union of Game Biologists and the IXth International Symposium Perdix. E. Hadjisterkotis, editor, 3.–7. September 2001. Lemesos, Cyprus. *European Journal of Wildlife Biology* 48: Supplement: 161–166.

Sodeikat G, Pohlmeyer K (2003). Escape movements of family groups of wild boar *Sus scrofa* influenced by drive hunts in Lower Saxony, Germany. *Wildlife Biology* 9: Supplement 1: 43–49.

Sodeikat G, Pohlmeyer K (2004). Und hab kein weit Revier. *In*: Sauen im Jahreslauf. DLV, München.

Spitz F, Lek S (1999). Environmental impact prediction using neural network modelling. An example in wildlife damage. *Journal of Applied Ecology* 36:317–326.

Steinfeldt A (2004). Sauen im Überfluss. *Niedersächsischer Jäger* 24: 12–15.

Stickley A R Jr, King J O (1995). Long-term trial of an inflatable effigy scare device for repelling cormorants from catfish ponds. *Eastern Wildlife Damage Control Conference* 6: 89–92.

Stone C P, Shake W F, Langowski D J (1974). Reducing bird damage to highbush blueberries with a carbamate repellent. *Wildlife Society Bulletin* 2: 135–139.

Strein M, Burghardt F, Suchant R (2006). Erarbeitung einer Massnahmenkonzeption für den Nordhang des Belchens unter Berücksichtigung wildökologischer, naturschutz-relevanter und schutzfunktionenbezogener Aspekte. *Wildtier-Management in Baden-Württemberg, Neue Erkenntnisse und Perspektiven*, Denzlingen, Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg: 78–80.

Stubbe W, Stubbe M (1977). Vergleichende Beiträge zur Reproduktions- und Geburtsbiologie von Wild- und Hausschwein- *Sus scrofa* L., 1758. *Beiträge zur Jagd- und Wildforschung* 10: 153–179.

Sulkowski P, Smyd-Golba K, Wisniowska L (2004). Characteristics of damage caused by wild boar in various regions of Poland. *5th international wild boar and suidae symposium*, Kraków, Poland, Department of Ecology, Wildlife Research and Ecotourism, Pedagogical University of Kraków: 47–48.

Taylor R B, Hellgren E C, Gabor T M, Ilse L M (1998). Reproduction of feral pigs in southern Texas. *Journal of Mammalogy* 79: 1325–1331.

Tellería J L, Sáez-Royuela C (1985). L'évolution démographique du sanglier (*Sus scrofa*) en Espagne: Gestion du sanglier. *Mammalia* 49: 195–202.

Terman C R (1965). A study of population growth and control exhibited in the laboratory by prairie deermice. *Ecology* 46(6): 890–895.

Thompson R D, Grant C V, Pearson E W, Corner G W (1968a). Cardiac response of starlings to sound: Effects of lighting and grouping. *American Journal of Physiology* 214: 41–4.

Thompson R D, Grant C V, Pearson E W, Corner G W (1968b). Differential heart rate response to starlings to sound stimuli of biological origin. *Journal of Wildlife Management* 32: 888–93.

Uzal A, Nores C (2002). Endogenous and exogenous constraints in the population changes of wild boar (*Sus scrofa* Linnaeus, 1758). *Wild boar research 2002. A selection and edited papers from the "4th international wild boar symposium"*, Lousa, Portugal: 83–98.

Vassant J (1994). L'agrainage dissuasif : résultats d'expériences. *Bulletin Mensuel de l'Office National de la Chasse* 191 (Numéro spécial): 101–105.

Vassant J, Boisaubert B (1984). Bilan des expérimentations entreprises en Haute-Marne pour réduire les dégâts de sangliers (*Sus scrofa*) à l'encontre des cultures agricoles. *Symposium international sur le sanglier, Colloques de l´I.N.R.A.*, Toulouse (France): 187–199.

Vassant J, Jullien J-M, Brandt S (1987). Réduction des dégâts de sangliers sur blé et avoine en été. Etude de l'efficacité de l'épandage de maïs en grain en forêt. *Bulletin Mensuel de l'Office National de la Chasse* 113: 23–33.

Vicente J, Ruiz-Fons F, Vidal D, Höfle U, Acevedo P, Villanúa D, Fernández-de-Mera I G, Martin M P, Gortázar C (2005). Serosurvey of Aujezky's disease virus infection in European wild boar in Spain. *Veterinary Record* 156: 408–412.

Wilke K, Pohlmeyer K, Lotthammer K-H (2000). Konzentration von Blei und Cadmium beim Schalenwild in autobahnnahen Revieren im Raum Gudow, Schleswig-Holstein. *Zeitschrift für Jagdwissenschaft* 46: 31–44.

Wilson C J (1999). Wild boar in south west England. In: *Proceedings of the International Union of Game Biologists XXIVth Congress, 20–24 September 1999* (Ed. by C. Thomaidis & N. Kypridemos), pp. 490–492. International Union of Game Biologists, Thessaloniki, Greece.

Wilson C J (2005). Feral wild boar in England - Status, impact and management - A report on behalf of DEFRA European Wildlife Division, Department for environment, food and rural affairs.

Wolff J O (1997). Population Regulation in Mammals: An Evolutionary Perspective. *Journal of Animal Ecology* 66(1): 1–13.

Yalden D (1999). The History of British Mammals. Poyser, London.

Supplementary information

1. Hunting data

1.1 Annual hunting bags

Figure S1 provides an overview of the annual hunting bags, the amount of the different age classes, and the yearly amount of damage in the Canton Basel-Land. Annual hunting bags as well as damages increased during the past 16 years. However, there are pronounced fluctuations in hunting bags and damages between consecutive years. Over the whole period, juveniles accounted for 60% of the total hunting bag. The proportion of juveniles ranged from 39% in the hunting season 06/07 to 71% in season 05/06. Lower proportions of shot juveniles occurred in years where the overall hunting bag was relatively small. Years with small hunting bags followed years with big hunting bags.

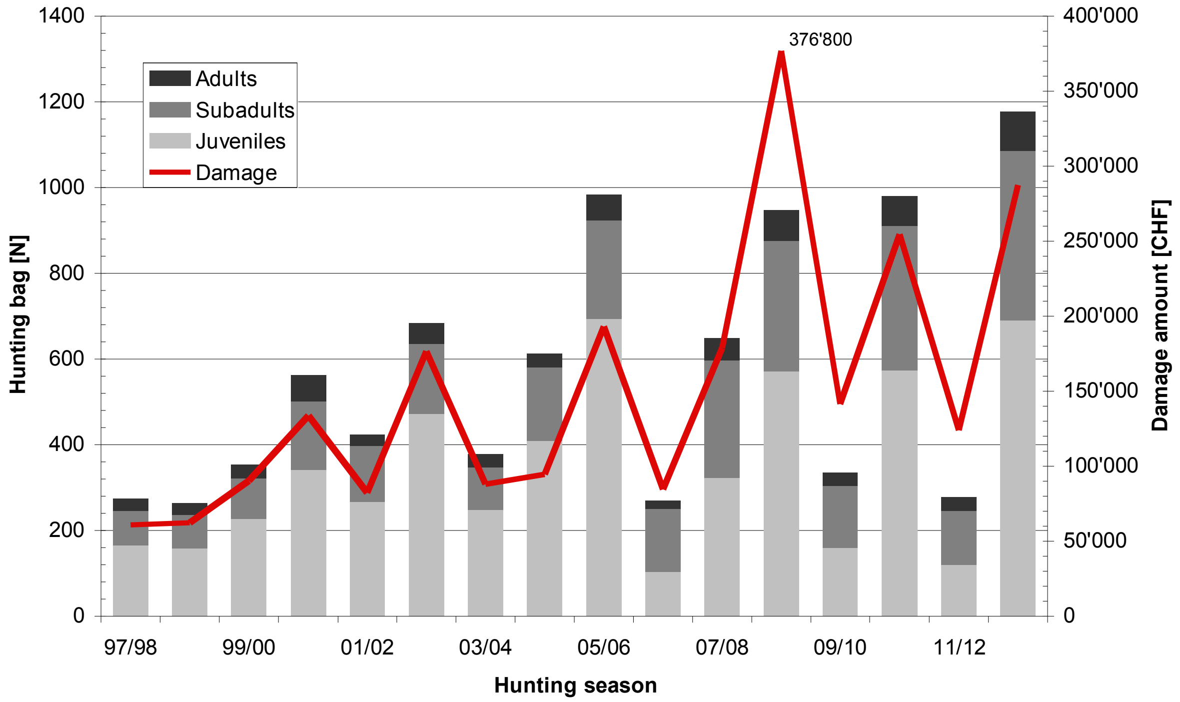

Fig. S1. Annual hunting bags, age classes, and damage for the hunting seasons of the past 16 years in the Canton Basel-Land, Switzerland. Adults > 2 years, subadults between 1–2 years, juveniles < 1 year of age. Data obtained from the *Amt für Veterinär-, Jagd- und Fischeiwesen, Kanton Basel-Landschaft*.

1.2 Hunting techniques and locations

The proportions of wild boars shot in the field, compared to the total hunting bag is shown in Figure S2. The field proportion augmented by 1.7% ($p < 0.001$) every year from 1997 to 2012 (Linear regression model: 80.5% of the variance is explained by the year. Residuals normally distributed). In 2012, the field proportion of shot wild boars was 38.5% of the total hunting bag, whereas in 1999 the proportion was 10.5%.

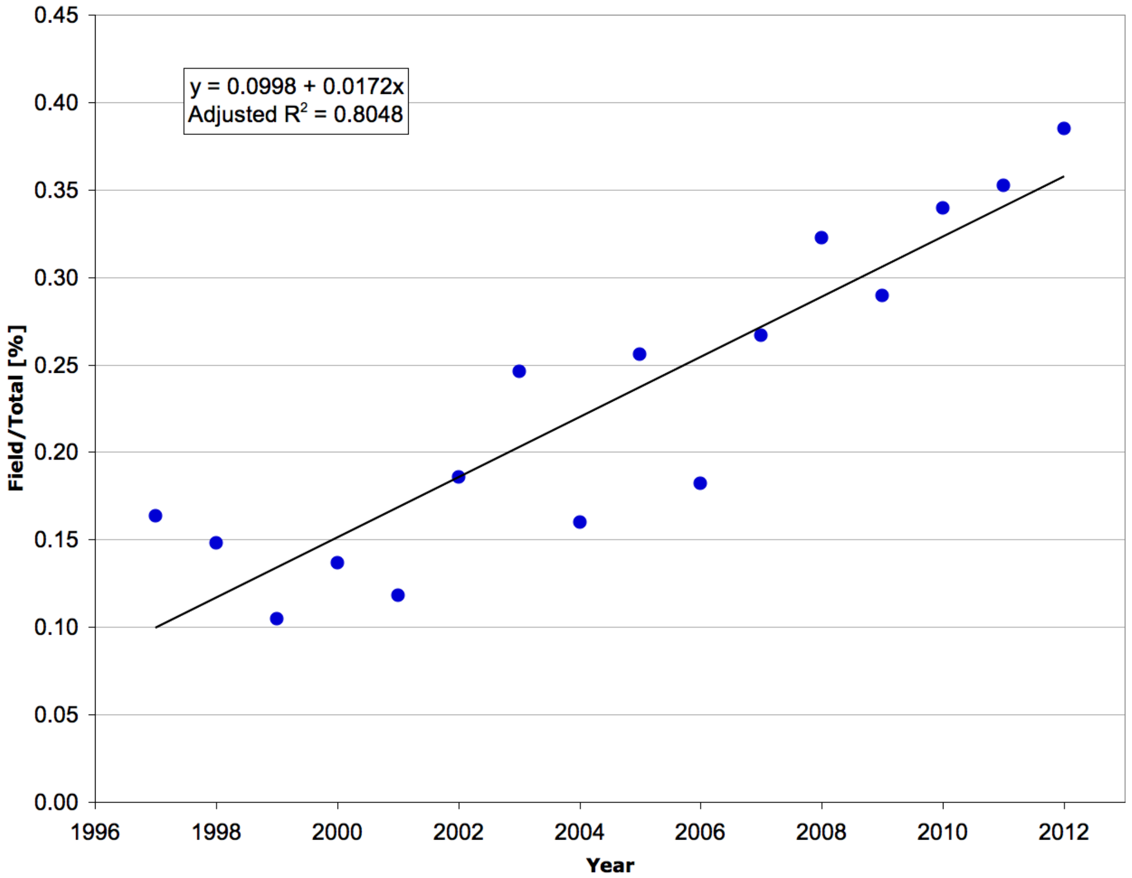

Fig. S2 Proportion of wild boars shot in the fields contributing to the total yearly hunting bag of the Canton Basel-Land, Switzerland. Data obtained from the *Amt für Veterinär-, Jagd- und Fischeiwesen, Kanton Basel-Landschaft*.

The major part of the increase in field proportion was realised by stalk hunting as shown in Figure S3. The contribution of stalk hunting to the annual hunting bag as performed from 1997 to 2005 was rather marginal. Therefore, the technique was not separately recorded in hunting statistics until 2005. The contribution of each hunting technique to the hunting bag varied strongly between field and forest. Between 2005 and 2012 stalk hunting made up 56% of all shot wild boars in the field, but only for 2% in the forest ($Z = 42.22$, $p < 0.001$).
The majority of the annual hunting bag was made up by wild boars shot from raised hides at baited sites (78%). The amount of hide hunting differed significantly between field (64%) and forest (83%) in the last 16 years ($Z = 19.96$, $p < 0.001$). The same is true for the proportions of battues in the field (5%) and in the forest (16%), which also differed significantly ($Z = 13.01$, $p < 0.001$).

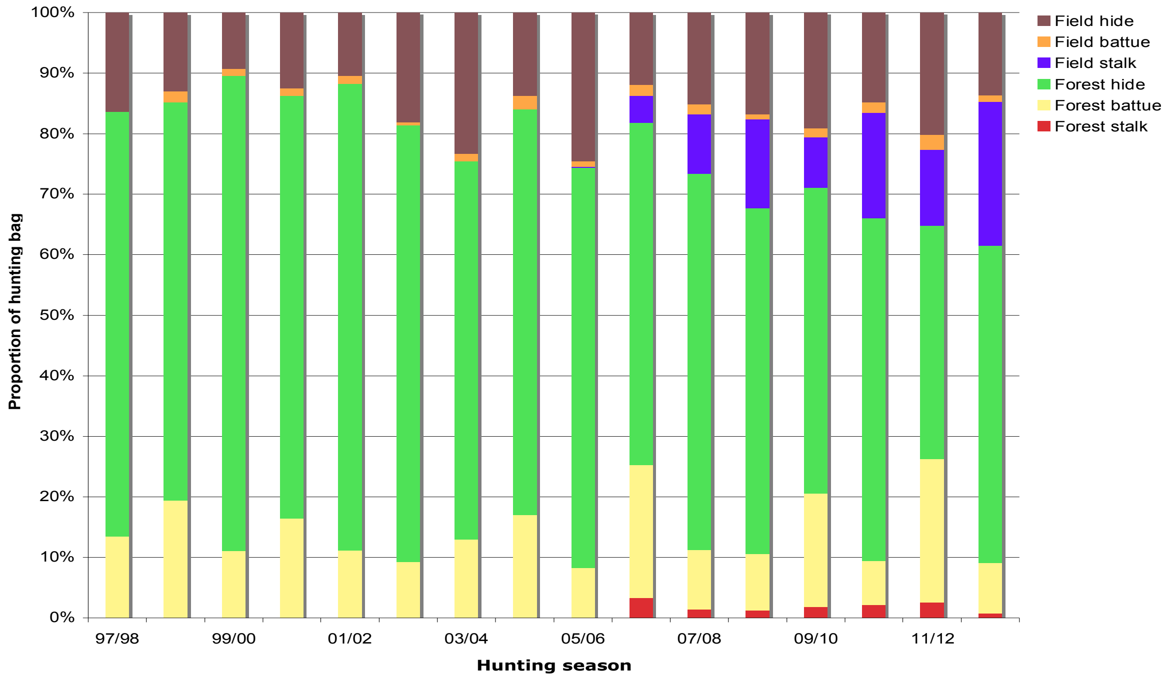

Fig. S3 Proportions of shot wild boars by location (field, forest) and by hunting technique (hide hunting, battue, stalk hunting) for the hunting seasons of the last 16 years in the Canton Basel-Land, Switzerland. A hunting season lasts from the 1st of April to the 31st of March. Data obtained from the *Amt für Veterinär-, Jagd- und Fischeiwesen, Kanton Basel-Landschaft*.

The proportions of shot juveniles between field (57%) and forest (61%) differed significantly ($Z = 3.12$, $p < 0.01$). This difference was mainly due to the lower relative amount of wild boars shot by hide hunting in the field compared to the forest. On the other hand, the proportion of juveniles shot on battues (54%), which are predominantly performed in the forest, was significantly lower than the overall proportion of shot juveniles, which was 60% ($Z = 4.30$, $p < 0.001$).