NORTH-WESTERN JOURNAL OF ZOOLOGY 10 (2): 325-332 ©NwjZ, Oradea, Romania, 2014
Article No.: 141102 http://biozoojournals.ro/nwjz/index.html

Ecology of the field cricket (Gryllidae: Orthoptera) in farmland: the importance of livestock grazing

Monika GAWAŁEK[1], Krzysztof DUDEK[2], Anna EKNER-GRZYB[3], Zbigniew KWIECIŃSKI[4] and Joanna H. SLIWOWSKA[1,*]

1. Laboratory of Neurobiology, Institute of Zoology, Poznań University of Life Sciences, Wojska Polskiego 71 C, 60-625 Poznań, Poland.
2. Department of Zoology, Institute of Zoology, Poznań University of Life Sciences, Wojska Polskiego 71 C, 60-625 Poznań, Poland.
3. Department of Behavioural Ecology, Faculty of Biology, Adam Mickiewicz University, Umultowska 89, 61-614 Poznań, Poland.
4. Zoological Garden, Browarna 25, 61–063 Poznań, Poland.
*Corresponding author, J.H. Sliwowska, E-mail: joanna.sliwowska@gmail.com

Received: 28. March 2013 / Accepted: 14. February 2014 / Available online: 20. July 2014 / Printed: December 2014

Abstract. The field cricket *Gryllus campestris* used to be very common throughout Europe, but in recent decades its population has declined. We study ecology and behavior of crickets near the Odolanów, Poland, between 2009 - 2011, with emphasis on the effects of grazing of cattle and horses on insects population. We compared the number of burrows per square meter on both grazed and non-grazed areas and examined the size of the arena in front of the burrow. We hypothesized that juvenile crickets would have smaller arenas in front of the burrows compared to adults. We also hypothesized that crickets would prefer burrows with entrances facing southwards. We found that: (1) the number of burrows in area grazed by cattle and horses was higher compared to non-grazed areas; (2) there was the interindividual variation in arena size in front of the burrows, with adult insects having bigger arenas in comparison to the arenas of the young; (3) there was diversity in geographical direction of the burrow entrance with the south being the preferred one. We propose that grazing may have a positive impact on biodiversity of meadows biocenosis and is important for the protection of the field cricket populations.

Key words: *Gryllus campestris*, behaviour, arena, burrow, biodiversity, farmland.

Introduction

The field cricket *Gryllus campestris* used to be very common throughout Europe in farmland (Honegger 1981, Lobhart 1999, Scheuber et al. 2003, Jacot et al. 2005, Rillich et al. 2009, Zuk 2010). However, during recent decades population of cricket shows serious decline in many parts of its geographical distribution. It is endangered in many parts of Central and Northern Europe (Hochkirch et al. 2007), especially in Belgium (Decleer et al. 2000), Denmark (http://redlist.dmu.dk 2006), Germany (Ingrisch et al. 1997), Lithuania (Budrys et al. 2007), Luxembourg (Proess & Meyer 2003), Netherlands (Kleukers et al. 1997), UK (Pearce-Kelly et al. 1998) and Poland (Głowaciński & Nowacki 2004). Thus, not surprisingly, it is on the National Red List of threatened taxa. The main reason for this dramatic decline in the population in a field cricket seems to be change in size of habitats, often a result of the intensification of agriculture.

A field cricket lives in dry, oligotrophic habitats, like heathland and dry grassland with a variable microclimate. One of the factors changing the microclimate and food sources can be grazing of animals like horses, cattle and sheep (Rada et al. 2014). Changes in the environment resulting from grazing animals, may be similar to those, which are a consequence of mechanical mowing (Gardiner & Hill 2006). This may contribute to a decrease crickets' populations, as well as their displacement from the natural habitats by humans.

Making burrows is a common behaviour among insects like: ants (Tschinkel 1987, Mikheyev & Tschinkel 2004, Tschinkel 2004,), wasps (Brockmann 1979), bees (Packer & Knerer 1986) and crickets (How-Jing & Loher 1996, Holzer et al. 2003, Ritz & Köchler 2007). Many species of the genus *Gryllus*, dig burrows by themselves, or use naturally-occurring gaps and slots as a shelter (Huber et al. 1989, Endo 2007, Endo 2008). Burrows are not only used as a shelter from predators like birds or lizards, but also for seasonal mating and oviposition, as well as calling sites and place for hibernation (Turcek 1967, Hack 1997, Rodriguez-Muñoz et al. 2010, Bretman et al. 2011). They are also suitable places for eggs development, due to the constant, humid environment of the burrows (How-Jing & Loher 1996). To build the burrows crickets developed a variable adaptation to digging, e.g. mole crickets use their transformed forelegs (Bennet-Clark 1970), while crickets without special tools, use their mouthparts to bite off the soil or remove it with hindlegs (How-Jing &

Loher 1996). Moreover, the area in front of the burrow, cleared of vegetation and sometimes covered with sand, called the arena, is used by adult male to produce mating calls to attract females (Zippeus, 1949, Holzer et al. 2003). Mating calls are generated by rubbing the wing together, using specialized regions in their forewings (Ewig 1989, Scheuber et al. 2003, Kostarakos et al. 2009). Besides using the arena as a calling site, crickets perform many other activities there, such as food provision, removal of faeces, fighting for females, or territory, and copulation (Bretman et al. 2011). Despite the fact that an arena plays such an important role in crickets' life, interindividual differences in its construction are very poorly studied.

It is well known that livestock grazing can affect the biocenosis and the degree of its influence depends on types of grazing and trampling intensity on vegetation (Etienne 2005, Dumont et al. 2009, Metera et al. 2010). Therefore, the first goal of this research is to describe population density based on the number of burrows per square meter (Sutherland, 1996) both on grazed and non-grazed areas, and on the basis of the obtained data, define the impact of the farm animals (cattle and horses) grazing on the density of field crickets population. Additionally, this approach allow us to compare the population density with other populations and will be therefore a good indicator of the population quality. The density of burrows strongly correlates with the population size, which may be used as a proxy as it influenced by the digging activity of crickets. The second aim of this paper is to focus on age differences, studding the variation in size of arenas between juveniles and adults individuals in a wild population of the field cricket. We hypothesize that juvenile crickets have smaller arenas compared to adult insects. Finally, we intend to find out if field crickets prefer to build entrances in the burrows and arenas in a specific geographical direction. It was demonstrated that most of both young and adult *Gryllus bimaculatus* crickets prefer sunny and warm places, where they performed the highest physical activity (Remmert 1985). It is also widely known that the insolation is the highest in the southern direction. However, we intended to verify this finding in the population of field crickets in Poland, where different insolations and latitudes are present. We hypothesize that crickets prefer burrows with an entrance to the south.

Materials and Methods

Life cycle of crickets

Every year, before first ground frost, penultimate instar nymphs of *Gryllus campestris* dig burrows into the soil and hibernate there until late April and early May (Köchler & Reinghardt 1992, Hahn & Lorch 2005). When nymphs emerge they continue their development until final molt, and start the reproductive season. During this season, males and females mate, often with different partners, and lay hundreds of eggs into the soil around May and June (Rost & Honegger 1987, Rodriguez- Muñoz et al. 2010). After mating, males associate with their mates, perform the so called guarding behavior (Sakaluk 1991, Alcoc 1994) and after copulation the sexual partner stay on the males' arena. As males never share their territory and a burrow, they are frequently fighting for a burrow. In late summer, adult crickets die, and the only ones left are nymphs, which reproduce in the next summer.

Study site

The studies took place between April 1st and June 10th 2009 and 2011, near the town of Odolanów, Poland (51°34'N, 17°40'E, elevation 110 - 170 m). This area is characterized by intensively farmed land, with a varied mosaic of arable fields, meadows, small woodlots and scattered trees and shrubs of different ages. It contains both dry and moist areas (for details see Antczak et al. 2004, Ekner et al. 2008). Individuals captured for this study came from areas approximately 10 km away from each other. Thus, we believe that the effect of crickets migration have no influence on our results, especially on population size (Witzenberger & Hochkirch 2008).

Data collection

The study sites were visited once a day because crickets *G. campestris* are most active in the daytime (Alexander & Meral 1967, Ritz & Köchler 2007). Data sampling lasted from 3 to 4 hours at each study site, depending on population size and weather conditions. Research activities included: searching for burrows, rouse crickets from burrows, determination of life stadium of every individual, and taking photos of individuals and areas in front of the burrows. Habitats were divided into two main categories: (1) meadows and other habitats without domestic animals grazing, or non-grazed habitats (286 squares), and (2) areas grazed by cattle and horses, or grazed habitats (41 squares). To investigate burrow density, we randomly selected study plots of one square meter size, and the number of burrows on each square was counted (Sutherland 1996). Because of the activity of domestic animals and pasture owners more detailed data on burrows were collected in non-grazed habitats. In order to avoid to the re-investigation of already researched burrows a marking code was used. Geographical direction of the entrance to the burrow was determined using a compass and was divided into eight main directions: South (S), South East (SE), South West (SW), West (W), North (N), North East (NE), North West (NW), and East (E).

Figure 1. Examples of arena in front of the cricket burrows.

In order to locate burrows the ground was carefully searched. The crickets were luring out from their burrows using blade of grass (Ritz & Köchler 2007). Immediately after the cricket had left the burrow, it was caught in front of its burrow and photographed. Photos were individually calibrated in the computer program Image J (NIH, USA), which allowed precise measurements. Life stadium determination was based on the presence of completely developed forewings, and individuals were released to burrows. Finally, photos of each arena in front of the burrow, with a number corresponding to the number of cricket lured out from it, were taken (Fig. 1). The geographical direction of a burrow entrance was assessed. All examined burrows were marked using a stick placed in the ground behind the entrance of the burrow.

Data analysis

Photos of arenas were analyzed using Image J program (NIH, USA) and their sizes were measured (Abràmoff et al. 2004, Stevens et al. 2009). We assumed that an arena has a shape of an ellipse. The arena was measured according to formula of the area enclosed by an ellipse which is equal to $\pi*a*b$, where "a" and "b" are one-half of the ellipse's major and minor axes respectively.

The data regarding geographical orientations was analyzed and presented using the ORIANA software (RockWere, Golden, USA) (Kovach 2009). Rayleigh's Uniformity Test was used to calculate the probability of the null hypothesis that the data is distributed in a uniform manner. The Z value was calculated simply as $Z = nr^2$, where "n" is the number of observations and "r" is the length of the mean vector. A longer mean vector (and the resulting larger value of "Z") means a greater concentration of the data around the mean, and thus less likelihood of the data being uniformly distributed. A probability less than chosen significance level (in our case = 0.05) indicates that the data are not distributed uniformly and that they show evidence of a preferred direction.

The data on density and arena size were analyzed using SPSS 18 PL (New York, USA) and the results are presented as mean values ± 1 standard error of the mean (SEM).

Results

Population density

During the study, 327 squares of ground were investigated, both in grazed and non-grazed areas. The burrows were variously aggregated. Burrows density in 1 m squares ranged from 0 – 21 (grazed areas) and from 0 – 9 (non-grazed areas) (Fig. 2).

We have found that the number of burrows in grazed areas (Fig. 2B) was significantly higher compared to non-grazed (Fig. 2A) areas, with means of 8.2 ± 6.4 vs. 1.6 ± 1.4, respectively, n = 41 and n = 286, respectively; Mann-Whitney U-test, z = - 7.037, $p < 0.0001$.

Differences in size of arenas in front of the burrows

Animals were randomly captured and sexed. Out of 75 individuals captured there were 25 females (13 juvenile and 12 adults) and 50 males (36 juvenile and 14 adults). The size of male arena ranged from 384 - 8560 mm^2 (Fig. 3). There was a significant difference in arena size between young and adult male crickets, with adult insects having bigger arenas compared to young insects, with means of 2431 ± 186 mm^2 (n=14) vs. means of 1778 ± 172 mm^2 (n=36), respectively; t-test, t = - 2.052, df = 68, $p = 0.044$; Fig. 3 A vs. B.

Geographical directions of crickets' burrow entrances

Both burrows, where luring out and where no luring out cricket were performed were taken into account for statistical analysis of the geographical direction of crickets' burrow entrance. The crickets usually entered the burrows from the south direction, with estimated mean vector SSW (μ 161.503),

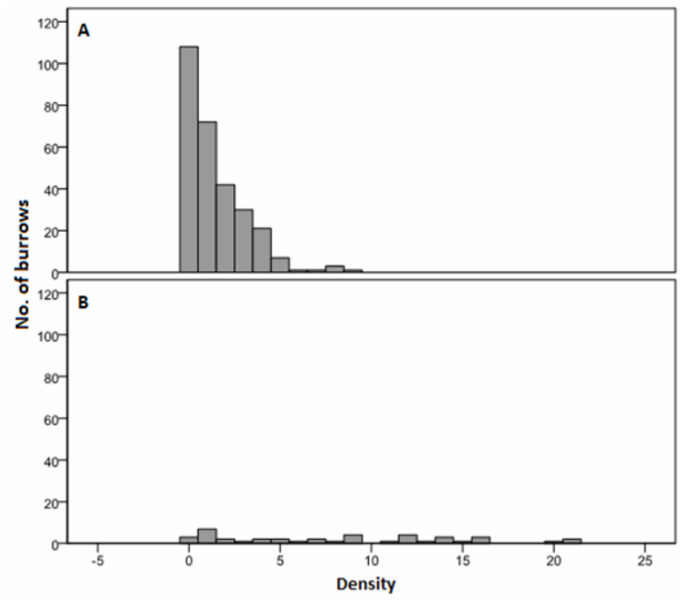


Figure 2. Distribution of the number of cricket burrow per 1 square meter in the study area, in (A) non-grazed meadows and other habitats (n = 286 squares), and (B) pastures with domestic animals grazing (n = 41 squares).

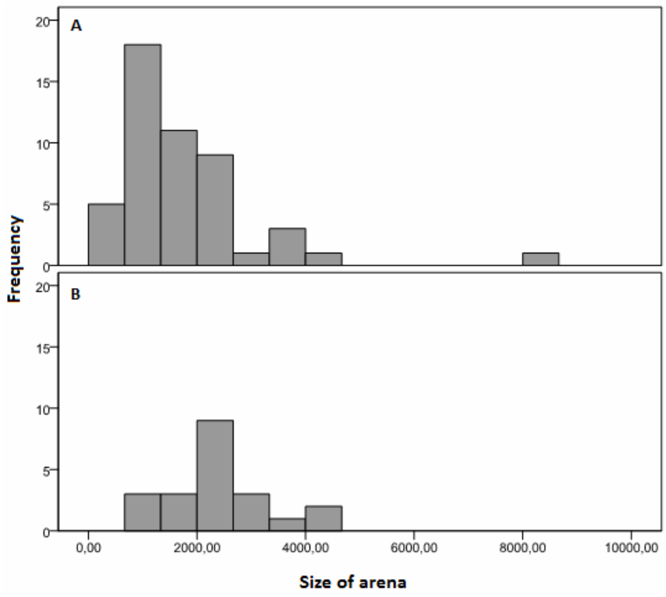
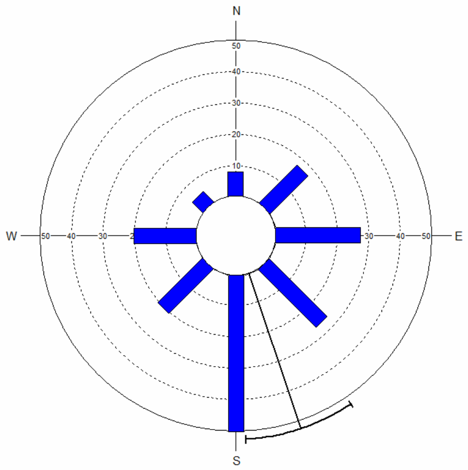


Figure 3. Distribution of male arena size (mm²) in adults (A) and juvenile (B) in the local cricket population.

which significantly differs from random distribution (Rayleigh Test Z = 23,536, $p < 0.00001$); Fig. 4.

Discussion

According to our best knowledge this is the first study to show interindividual variations in arena size in front of the burrow of in *G. campestris*. We have found that the size in front of the burrow, the so called arena, depends upon the stadium of individuals. We have also found that local population density of crickets was almost 6 times higher in areas grazed by cattle and horses compared to non-grazed areas. Studies of livestock effects like grazing on arthropods can be various (Batáry et al. 2007, Braschler et al. 2009, Holmquist et al. 2010). Our finding may be explained by the fact that



Figre 4. Geographical distribution of burrow entrances in the local filed cricket population (n = 173). Bars represent number of burrows in each geographical direction.

grazing animals improve environmental conditions essential for the live of crickets (Hahn & Lohn 2005, Jerrentrup et al. 2014). In the meadows and grasslands, low plants provide bare ground exposed to sunlight, and the degree of shading is low (Grime & Jeffrey 1965) and thus provide better heating for the ground on which the crickets dwell. This situation is especially beneficial to adult crickets. In contrast to the larvae, they are not able to climb grass or other small plants, and are forced to search other possibility of basking and they need open spots or stones (Remmert 1985). Many studies have shown negative effects of grazing on insects (e.g. Willot 1997, Gardiner & Hassall 2009, Branson et al. 2014). It was found that low grass makes insects more vulnerable to overheating and simultaneous desiccation, which occurs due to changes in microclimate, especially an increase in temperature and insolation degree. In addition food-limited competition between insects and vertebrates led to reduced survival, femur length, and functional ovarioles in grasshoppers. But this concerns mainly larger insects, such as grasshoppers (e.g. *Chorthippus albomarginatus, Chorthippus parallelus*), whose physiological traits prevents rapid heat transfer from the body and reduce high body temperature (Willot 1997). Additionally, when vegetation is shortened, sound producing by male crickets can be better heard in farther distance (Wiley & Richards 1978), which is important in communication between crickets in population. Bock et al. (2006), similar to our findings, demonstrated positive effect of grazing on orthopterans. Grazing has a positive effect not only on small animals like insects but also on birds, as a result of creation of a habitat structure optimum for them, reducing pressure of small predators on nests (Mazurek 2002, Mazurek 2003, Metera et al. 2010). However, in case of small mammals, it was shown that meadow management such as grazing in general reduce mammal species richness (Bejcek & Stastny 1996, Schmidt & Olsen 2003).

It is important to note that in our current study only 41 squares sites in grazed areas (compare to 286 non-grazed areas) were investigated. It was due to the fact that areas with grazing animals were more difficult to investigate. Many meadows owners did not allow entries into their private properties, or entrance on some areas became dangerous due to the risk of getting attacked by the animals.

We have also found that burrow density ranged from 0 to 21 per square meter. This diversity is likely due to the fact that the habitat was not homogenous in terms of vegetation and soil. Moreover, we have revealed that both juvenile and adult crickets preferred resident burrow with south-facing entrance. This finding could be related to highest insolation and hence highest temperature, which is preferred by crickets (Remmert 1985), compared to others geographical directions. In this scenario, in order to get warm individuals stay in a safe arena in front of the burrows and do not expose themselves far from burrow entrance to prevent potential attack by predators. This way, in case a predator attacks, crickets will be very close to the entrance of their burrows and could quickly hide in a safe refuge.

We have also confirmed our hypothesis that adult crickets have larger arenas than their juvenile counterparts. This difference is most likely explained by the fact that with the ongoing vegetation season, the arenas in front of the burrows enlarge due to continuous fretting the plants, farther away from the burrow entrance. Adult insects had more time to make bigger arenas and had bigger and stronger mandibles, which make fretting more easily for them. Another explanation could be related to the size of arena surface, which correlate with the mating season. Environmental conditions, like vegetation and its density, can affect the sound transmission and detection (Endler 1992, Forrest 1994), which are crucial for successful matings. Therefore, the burrow location and size of the arena seem to be very important in inter-individual communication in population. As one of the reproductive strategies used by adult males is to attract females by their calling songs in front of the burrow (French & Cade 1987, French & Cade 1989, Cade a& Salzar Cade 1991), it is crucial for males to be heard. The distance over which acoustic signals can carry information depends on the amplitude and structure of the sound at the source, by the receiver's detective mechanism and characteristics of the medium and its boundaries (Forrest 1994). In heterogeneous environments, sound deriving from source to receiver is a signal in the form of scattered sound, and is highly degraded (Forrest 1994). Thus, sound producing by males is less damped when the arena is larger, because grass and herbaceous plants, which can disrupt sound radiation, are removed. In such conditions females which are more distant from males are able to hear and find their mates on the population area. However, being the owner of big arena is not always good for crickets. Among grass and plants cover population area, bare ground is much more visible for predators, such as birds. In the study area the grey great shrike *Lanius excubitor* which have great predatory pressure on crickets were found in maximum densities (Tryjanowski & Hromada 2005).

Size, weight and age, are positively correlated with strength, aggressiveness, dominance, mate signaling and mating success in crickets (Simmons 1988, Simmons 1994, Brown et al. 1996). It is also well known that adult crickets of the species *Gryllus campestris* and *Anurogryllus muticus* change burrows over the season and thus dominate the arenas repeatedly (How-Jing & Loher 1996, Ritz & Köchler 2007). Young individuals are smaller and lighter compared to adults (Bertram 2000, Bateman et al. 2001), and it was found that dominance is related to size (Dixon & Cade 1986, Simmons 1994). Moreover, young males avoid competition and do not have experience in fights. Thus, another explanation why adult crickets have bigger arenas than juveniles ones is that individuals who underwent their last moult earlier, which have smaller and thus worse arenas, rout out juvenile ones from their burrows with better arenas, and occupy them.

In summary, our results indicate significant relationship between livestock grazing and population structure of crickets. Animals, such as horses and cows, shorten the grass and plants, mush the turf and this actions positively affect the field crickets' population density. Shortening of the vegetation by animals results in the improvement in environmental conditions on the ground, which is important for insect living there. Weakened plants may also be more available as food for crickets and other herbivorous insect. Thus, we speculate that the usage of traditional grazing may have a positive impact on biodiversity of meadows and may be an important factor in protecting populations of field cricket in farmland areas.

Acknowledgements. We would like to thank Peter Mikula, Drs Martin Hromada, Zofia Sajkowska and Marcin Antczak for help in the field studies and to Dr. Piotr Zuniak for his effort with ORIANA software.

References

Abràmoff, M.D., Magalhäes, P.J., Ram, S.J. (2004): Image processing with Image J. Biophotonics International 7: 36-43.

Alcoc, J. (1994): Postinsemination association between males and females in insects: the mate-guarding hypothesis. Annual Review of Entomology 39: 1-21.

Alexander, R.D., Meral, G.H. (1967): Seasonal and daily chirping cycles in the northern spring and fall field crickets, *Gryllus veletis* and *Gryllys pennsylvanicus*. The Ohio Journal of Science 67: 200-209.

Antczak, M., Hromada, M., Grzybek, J., Tryjanowski, P. (2004): Breeding biology of the great grey shrike *Lanius excubitor* in W Poland. Acta Ornithologica 39: 9-14.

Batáry, P., Báldi, A., Szél, G., Podlussány, A., Rozner, I., Erdős, S. (2007): Responses of grassland specialist and generalist beetles to management and landscape complexity. Diversity and Distributions 2: 196–202.

Bateman, P.W., Gilson, L.N., Ferguson, J.W.H. (2001): Male size and sequential mate preference in the cricket *Gryllus bimaculatus*. Animal Behaviour 61: 631-637.

Bejcek, V., Stastny, K. (1996): Small terrestrial mammal communities of wet meadows (Trebon, S-Bohemia). Proceeding of the I European Congress of Mammalogy, Museu Bocage, Lisboa.

Bennet-Clark, H.C. (1970): The mechanism and efficiency of sound production in mole crickets. Annals of the Entomological Society of America 72: 596-598.

Bertram, S. (2000): The influence of age and size on temporal mate signaling behaviour. Animal Behaviour 60: 333-339.

Bock, C.E., Jones, Z.F., Bock, J.H. (2006): Grasshopper Abundance in an Arizona Rangeland Undergoing Exurban Development. Rangeland Ecology & Management 6: 640-647.

Branson, D.H., Haferkamp, M.A. (2014): Insect herbivory and vertebrate grazing impact food limitation and grasshopper populations during a severe outbreak. Ecological Entomology 3: 371–381.

Braschler, B., Marini, L., Thommen, G.H., Baur, B. (2009): Effects of small-scale grassland fragmentation and frequent mowing on population density and species diversity of orthopterans: a long-term study. Ecological Entomology 3: 321–329.

Bretman, A., Rodriguez-Muñoz, R., Walling, C., Slate, J., Tregenza, T. (2011): Fine-scale population structure, inbreeding risk and avoidance in a wild insect population. Molecular Ecology 20: 3045-3055.

Brockmann, H.J. (1979): Nest-site selection in the great golden digger wasp, *Sphex ichneumoneus* L. (sphecidae). Ecological Entomology 4: 211-224.

Brown, W.D., Wideman, J., Andrad,e M.C.B., Mason, A.C., Gwynne, D.T. (1996): Female Choice for an Indicator of Male Size in the Song of the Black-Horned Tree Cricket, Oecanthus nigricornis (Orthoptera: Gryllidae: Oecanthinae). Evolution 50: 2400-2411.

Budrys, E., Pakalniskis, S. (2007): The Orthoptera (Insecta) of Lithuania. Acta Zoologica Lithuania 17: 105–115.

Cade, W.H., Salzar Cade, E. (1991): Male mating success, calling and searching behaviour at high and low densities in the field cricket, *Gryllus integer*. Animal Behaviour 43: 49-56.

Decleer, K., Devriese, H., Hofmans, K., Lock, K., Barenbrug, B., Maes, D. (2000): Voorlopige atlas en ''rode lijst'' van de sprinkhanen en krekels van Belgie (Insecta, Orthoptera). Werkgroep Saltabel i.s.m. I.N. en K.B.I.N. Rapport Instituut voor Natuurbehoud. 10. Brussel.

Dixon, K.A., Cade, W.H. (1986): Some factors influencing male-male aggression in the field cricket Gryllus integer (time of day, age, weight and sexual maturity). Animal Behaviour 34: 340-346.

Dumont, B., Farruggia, A., Gartel, J.P., Bachelard, P., Boitier, Frain, M. (2009): How does grazing intensity influence the diversity of plants and insects in a species-rich upland grassland on basalt soils? Grass and Forage Science 64: 92-105.

Ekner, A., Majlath, I., Majlathova, V., Hromada, M., Bona, M., Antczak, M. (2008): Densities and Morphology of Two Co-existing Lizard Species (Lacerta agilis and Zootoca vivipara) in Extensively Used Farmland in Poland. Folia Biologica 56: 165-171.

Endler, J.A. (1992): Signals, signal condition, and the direction of evolution. The American Naturalist 139: 125-153.

Endo, C. (2007): The underground life of the oriental mole cricket: An analysis of burrow morphology. Journal of Zoology 274: 414-420.

Endo, C. (2008): An analysis of the horizontal burrow morphology of the oriental mole cricket (Gryllotalpa orientalis) and the distribution pattern of surface vegetation. Canadian Journal of Zoology 86: 1299-1306.

Etienne, M. (2005): Menagment of grazing animals for environmental quality. Options Méditerranéennes 67: 225-235.

Ewig, A.W. (1989): Arthropod Bioacoustics: Neurobiology and Behaviour: Ithaca, Cornell University Press.

Forrest, T.G. (1994): From sender to receiver: propagation and environmental effects on acoustic signals. American Zoologist 34: 644-654.

French, B.W., Cade, W.H. (1987): The timing of calling, movement and mating in the field crickets *Gryllus veletis*, *G. pennsylvanicus*, and *G. integer*. Behavioral Ecology and Sociobiology 21: 157-162.

French, B.W., Cade, W.H. (1989): Sexual Selection at Varying Population Densities in Male Field Crickets, Gryllus veletis and *G. pennsylvanicus*. Journal of Insect Behavior 2: 105-121.

Gardiner, T., Hassall, M. (2009): Does microclimate affect grasshopper population after cutting of hay in improved grassland? Journal of Insect Conservation 13: 97-102.

Gardiner, T., Hill, J. (2006): Mortality of Orthoptera caused by mechanical mowing of grassland. British Journal of Entomology and Natural History 19: 38-40.

Głacowiński, Z., Nowacki, J. (2004): Polska czerwona księga zwierząt, Bezkręgowce, Tom II, Instytut Ochrony Przyrody PAN w Krakowie i Akademia Rolnicza im. A. Cieszkowskiego w Poznaniu.

Grime, J.P., Jeffrey, D.W. (1965): Seedling Establishment in Vertical Gradients of Sunlight. Journal of Ecology 53: 621-642.

Hack, M.A. (1997): Assesment strategies in the contest of male crickets, *Acheta domesticus* L. Animal Behaviour 53: 733-747.

Hahn, S., Lorch, D. (2005): Besiedlungsmuster und Fruhjahrs-Phanologie einer Population der Feldgrille *Gryllus campestris* L. im westlichen Wiener Wald. Verhandlungen der Zoologisch-Botanischen Gesellschaft in Österlich 142: 1-8.

Hochkirch, A., Witzenberger, K.A., Teerling, A., Niemeyer, F. (2007): Translocation of an endangered insect species, the field cricket (*Gryllus campestris* Linnaeus, 1758) in northern Germany. Biodiversity and Conservation 12: 3597-3607.

Holmquist, J.G., Schmidt-Gengenbach, J., Haultain, S.A. (2010): Does Long-term Grazing by Pack Stock in Subalpine Wet Meadows Result in Lasting Effects on Arthropod Assemblages? Wetlands 30: 252-262.

Holzer, B., Jacot, A., Brinkof, M.W.G. (2003): Condition-dependent signaling affects male sexual attractiveness in field crickets, *Gryllus campestris*. Behavioral Ecology 14: 353-359.

Honegger, H.W. (1981): Three different diel rhythms of the calling song in the cricket, *Gryllus campestris*, and their control mechanism. Physiological entomology 6: 289-296.

How-Jing, L., Loher, W. (1996): Influance of Age and Environmental Factors on Burrow-Making Behaviour of the Short-Tailed Cricket, *Anurogryllus muticus* (De Geer) (Orthoptera: Gryllidae). Journal of Insect Behaviour 9: 819-834.

Huber, F., Moore, T.E., Loher, W. (1989): Cricket Behavior and Neurobiology. Cornell University Press.

Ingrisch, S., Köhler, G. (1997): Rote Liste der Geradflügler (Orthoptera s. l.) In: Binot M., Bless R., Boye P., Gruttke H., Pretscher P., (eds), Rote Liste gef ährdeter Tiere Deutschlands.

Jacot, A., Scheuber, H., Kurtz, J., Brinkhof, M.W.G. (2005): Juvenile immune status affects the expression of a sexually selected trait in field crickets. Journal of Evolutionary Biology 4: 1060-1068.

Jerrentrup, J.S., Wrage-Mönnig, N., Röver1and, K.U., Isselstein, J. (2014): Grazing intensity affects insect diversity via sward structure and heterogeneity in a long-term experiment. Journal of Applied Ecology (on-first): DOI: 10.1111/1365-2664.12244.

Kleukers, R., Nieukerken, E.V., Odé, B., Willemse, L., Wingerden, W.V. (1997): De Sprinkhanen en Krekels van Nederland (Orthoptera). Nederlandse Fauna I. KNNV Uitgeverij & EISNederland.

Köchler, G., Reinghardt, K. (1992): Beitrag zur Kenntnis der Feldgrille (Gryllus campestris L.) in Thuringen. Articulata 7: 63-76.

Kostarakos, K., Hennig, M.R., Römer, H. (2009): Two matched filters and the evolution of mating signals in four species of cricket. Frontiers in Zoology 6: 22.

Kovach, W.L. (2009): Oriana – Circular Statistics for Windows, ver. 3, Kovach Computing Services, Pentraeth.

Lobhart, T. (1999): How polarization-sensitive interneurones of crickets see the polarization pattern of the sky: A field study with an optoelectronic model neurone. Journal of Experimental Biology 7: 757-770.

Mazurek, Ł. (2002): Wpływ wypasu bydła oraz presji drapieżników na liczebnośc i sukces lęgowy ptaków wodnobłotnych gniazdujących na powierzchni "Brzostowo" w 2002r. WWF.

Mazurek, Ł. (2003): Wpływ wypasu bydła oraz presji drapieżników na liczebnośc i sukces lęgowy ptaków wodnobłotnych gniazdujących na powierzchni "Brzostowo" w 2003r. WWF.

Metera, E., Sakowski, T., Słoniewski, K., Romanowicz, B. (2010): Grazing as a tool to maintain biodiversity of grassland – a review Grazing as a tool to maintain biodiversity of grassland – a review. Animal Science Papers and Reports 28: 315-334.

Mikheyev, A.S., Tschinkel, W.R. (2004): Nest architecture of the ant Formica pallidefulva: Structure, costs and rules of excavation. Insectes Sociaux 51: 30-36.

Packer, L., Knerer, G. (1986): An analysisis of variation in the nest architecture of Halicatusligatus in Ontario. Insects Sociaux 33: 190-205.

Pearce-Kelly, P., Jones, R., Clarke, C., Atkin, P., Cunningham, A.A. (1998): The captive rearing of threatened Orthoptera: a comparison of the conservation potential and practical considerations of two species' breeding programmes at the Zoological Society of London. Journal of Insect Conservation 2: 201–210.

Proess, R., Meyer, M. (2003): Rote Liste der Heuschrecken Luxemburgs. Bulletin de la Société des Naturalistes Luxembourgeois 104: 57–66.

Rada, S., Mazalová, M., Šipoš, J., Kuras, T. (2014): Impacts of moving, grazing and edge effect on orthoptera of submontane grasslands: perspectives for biodiversity protection. Polish Journal of Ecology 62: 123–138.

Remmert, H. (1985): Crickets in Sunshine. Oecologia 68: 29-33.

Rillich, J., Buhl, E., Schildberger, K., Stevenson, P.A. (2009): Female crickets are driven to fight by the male courting and calling songs. Animal Behaviour 3: 737-742.

Ritz, M.S., Köchler, G. (2007): Male behaviour over the season in a wild population of the field cricket *Gryllus campestris* L. Ecological Entomology 32: 384-392.

Rodriguez-Muñoz, R., Bretman, A., Walling, C., Slate, J., Tregenza, T. (2010): Natural and sexual selection in a wild insect population. Science 328: 1269-1272.

Rost, R., Honegger, H.W. (1987): The timing of premating and mating behaviour in a field population of the cricket *Gryllus campestris* L. Behavioral Ecology and Sociobiology 21: 279-289.

Sakaluk, S.K. (1991): Post-copulatory mate guarding in decorated crickets. Animal Behaviour 41: 207-216.

Scheuber, H., Jacot, A., Brinkhof, M.W.G. (2003): Condition dependence of a multicomponent sexual signal in the field cricket *Gryllus campestris*. Animal Behaviour 65: 721-727.

Schmidt, N.M., Olsen, H. (2003): The response of small mammal communities to cattle grazing on a coastal meadow. Polish Journal of Ecology 51: 79-84.

Simmons, L.W. (1988): Male size, mating potential and lifetime reproductive success in the field cricket, *Gryllus bimaculatus* (De Geer). Animal Behaviour 36: 372-379.

Simmons, L.W. (1994): Correlates of male quality in the field cricket, *Gryllus campestris* L.: age, size, and symmetry determine pairing success in field populations. Behavioral Ecology 6: 376-381.

Stevens, M., Caswell Stoddard M., Higham, J.P. (2009): Studying Primate Colour: Towards Visual System-dependent Methods. International Journal of Primatology 30: 893-917.

Sutherland, W.J. (1996): Ecological census techniques: a handbook, Cambridge University Press.

Tryjanowski, P., Hromada, M. (2005): Do males of great grey shrike, *Lanius excubitor*, trade food for extrapair copulations? Animal Behaviour 3: 529-533.

Tschinkel, W.R. (1987): Seasonal life history and nest architecture of a winter-active ant, Prenolepis impairs. Insectes Sociaux 34: 143-164.

Tschinkel, W.R. (2004): The nest architecture of the Florida harvester ant, *Pogonomyrmex badius*. Journal of Insect Science 4: 21.

Turcek, F.J. (1967): Ecological studies of the field cricket G*ryllus campestris* L. Biologia 22: 808-816.

Wiley, R.H., Richards, D.G. (1978): Physical constraints on acoustic communication in the atmosphere: Implications for the evolution of animal vocalizations. Behavioural Ecology and Sociobiology 3: 69-94.

Willot, S.J. (1997): Thermoregulation in four species of British grasshoppers (Orthoptera: Acrididae). Functional Ecology 11: 705-713.

Witzenberger, K.A., Hochkirch, A. (2008): Genetic consequences of animal translocations: A case study using the field cricket, *Gryllus campestris* L., Biological Conservation 12: 3059–3068.

Zippeus, H.M. (1946): Die Paarungsbiologie einger Orthopteren-Arten. Zeitschrift für Tierpsychologie 6: 372-390.

Zuk, M. (2010): Dance like no one is watching, sing like no one is listening? Science 5983: 1237-1238.