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Impact of *Microtus arvalis* and *Lepus europaeus* on apple trees by trunk bark gnawing

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Abstract: A unique evaluation of the apple tree trunk bark damage caused by common vole and European hare was presented. Damage was found in an apple orchard under organic farming, in Central Moravia (Czech Republic), at 700 m a.s.l. There were two cultivated apple cultivars Red Spring and Melodie/Angold. Damage occurred in winter with the snow cover lasting from December to February. In total 1 012 trees and 95.7% of trees were damaged. The cv. Red Spring was damaged more than cv. Melodie/Angold. Almost 90% of the dead trees were killed by common voles. While hares damaged both cultivars equally, voles damaged the cv. Red Spring to a significantly greater extent ($P = 0.04$). The study confirms the need of further research on the development of methodologies for orchard protection from damage caused by small mammals.

Keywords: Common vole; European hare; *Malus* × *domestica*; orchards; tree damage

Fruit tree damage by herbivorous species of small mammals such as rodents (Rodentia) and hares (Lagomorpha) is a debated issue in many European and North American countries (Byers 1984; Sullivan & Hogue 1987; Jacob & Tkadlec 2010; Jacob *et al.* 2014). These species damage tree trunks by bark gnawing and rodents also by gnawing the root system. The majority of injuries are caused in winter when there is a lack of food sources, or the quality of food is low (Homolka 1983; Pehrson 1983; Chapuis 1990; Hansson 2002; Reichlin *et al.* 2016). Among rodents the most important pests in the temperate zone of the northern hemisphere are various voles (*Microtus* spp., *Arvicola* spp.). Vole species locally periodically increase their numbers (Sullivan & Hogue 1987; Merwin *et al.* 1999; Miñarro *et al.* 2012; Bertolino *et al.* 2015; Miñarro *et al.* 2017; Somoano *et al.* 2017). Among European Lagomorphs, the bark of a higher number of trees can be severely damaged by European hare (*Lepus europaeus* Pallas 1778), sometimes Mountain hare (*L. timidus* Linnaeus, 1758) or European rabbit (*Oryctolagus cuniculus,* Linnaeus 1758) (Thompson & Armour 1952; Pehrson 1983; Chapuis 1990; Reichlin *et al.* 2016).

Important producers of various fruits in the countries of Western and Southern Europe pay great attention to the damage of fruit trees, especially by voles (Walther *et al.* 2008; Bertolino *et al.* 2015; Miñarro *et al.* 2017; Somoano *et al.* 2017). The more severe the damage to the tree bark, the greater the negative effect on fertility and life expectancy of the tree. When a large amount of bark is removed and/or the conducting tissue is interrupted completely around the tree trunk (girdling), almost every tree dies. However, there has been neither systematic research nor monitoring of damage caused by rodents (or other mammals) to trees in orchards in the Czech Republic. Although the losses can reach several million euros per year (Czech News Agency 2006), there are only old studies, mostly from the second half of the 20th century (Grulich 1959, 1960;

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Nesvadbová 1988), which no longer correspond to the current situation of fruit tree growing in the European Union. There are no specific methodologies or recommendations for minimising damage caused by mammals in orchards. Basically, nothing is known about the extent of damage caused by different species of mammals. Therefore, even short-term studies that specify the extent of fruit tree damage by various mammals in relation to environmental conditions are highly valued. This paper evaluates the influence of hare and voles in an apple orchard and it is a unique study in the Czech Republic.

MATERIAL AND METHODS

In April 2017, we evaluated massive damage to apple trees in an orchard by bark gnawing of voles and hares. Damaged plantation is located at 700 m a.s.l. near the village of Pavlov (Jihlava district, Central Moravia, Czech Republic; 49.4507458N, 15.9138408E). The age of the plantation was 3 years. The orchard size was about 620 × 35 m and it was surrounded by a 2–5 m wide strip of low trees, shrubs and grasses. Behind this vegetation was arable land with wheat and barley. As the orchard was under an organic farming regime, it was not protected against rodents. Damage occurred at the end of the winter season 2016/2017. The snow cover lasted from the end of December to the beginning of February, and its depth was between 10 and 50 cm (because of the snowdrift). Straw, hay, horse manure and mulch were applied in the orchard as fertilization. Regular mowing of vegetation took place in the orchard. The vegetation was left in place.

In total 1 012 apple trees of two varieties (*Malus* × *domestica,* Borkh 1803) were evaluated; 506 individuals of cv. Melodie/Angold with branching crown habit, and 506 individuals of cv. Red Spring with columnar crown habit. The orchard was damaged by common vole (*Microtus arvalis* Pallas 1779) and European hare. The occurrence of damage and its cause were noted for each tree. The origin of damage was determined by the size and nature of scratches on tree trunks (Figures 1and 2).

The extent of tree damage was divided into two categories: partial damage (the bark was not completely removed around the tree trunk) and fatal damage (the tree was girdled). Some trees were damaged only by hares, others only by voles, and a large number of trees was damaged by both. A detailed survey was carried

Figure 1. The origin of damage was determined by the size and nature of scratches on tree trunks (hare damage – upper part of the trunk; vole damage – base of the trunk)

(**A**)

(**B**)

Figure 2. Example of damage on cvs (**A**) Red Spring and (**B**) Melodie/Angold

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out in a sample of 335 trees to distinguish whether the decisive damage was caused by hares or voles.

The influence of herbivorous species and apple tree varieties on the degree of partial and fatal damage of fruit trees was studied with the help of generalised linear models (GLM) with binomial error distribution and logit link function. The binomial error distribution was chosen because the dependent variable (bark damage) was expressed as a proportion of the total number of the trees.

To test the dependence between the dependent variable (the level of partial damage and fatal damage) and explanatory variables (fruit tree variety and animal species), *F*-statistics were used in the analysis of deviance (ANOVEV). The individual differences in fatal damage caused by hares, voles and both herbivorous species were tested by the multiple comparison analysis for GLM models. The "multcomp" library for multidimensional comparisons and the "glht" function from the R statistical software (Hothorn *et al.* 2008) were used. The data were analysed in the R environment (R Core Development Team 2016).

RESULTS

An overview of the basic results is in Figure 3. In total, 137 out of 335 trees (40.9%) were killed by voles and/or hares. Fatal damage to trees was mostly caused by common voles (P < 0.001) and by combined gnawing by both species (P < 0.001); the lowest number of fatally damaged trees was caused only by hare (Figure 4). Voles caused fatal damage to 122 out of 335 trees (30%), compared to 15 out of 335 trees (about 4.5%) fatally damaged by hares. The rate of death in the two cultivars did not differ significantly. The hare did not prefer any of the two cultivars (4.2% cv. Melodie/Angold and 4.7% cv. Red Spring, P > 0.05). Common voles preferred the cv. Red Spring to cv. Melodie/Angold (P = 0.04); they fatally damaged 73 trees out of 170 trees cv. Red Spring (43%), whereas only 49 out of 165 trees cv. Melodie/Angold (30%) (for details see Figure 5).

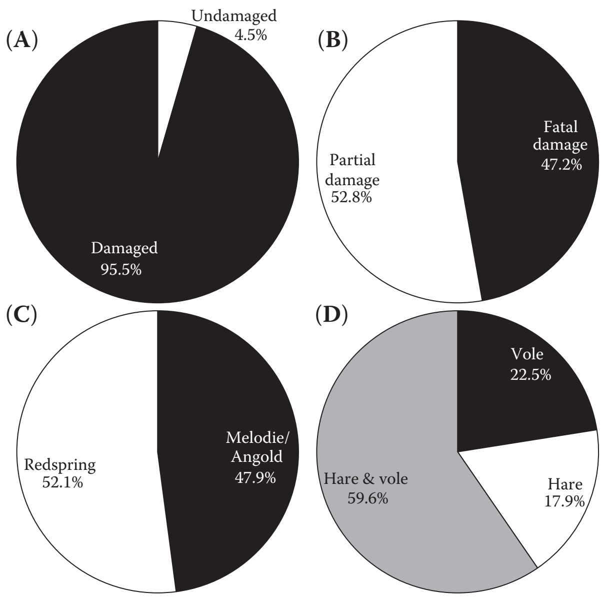

Figure 3. Pie charts showing the proportions of (**A**) undamaged and damaged trees, (**B**) fatally damaged and partially damaged trees, (**C**) damaged tree cultivars, and (**D**) damaged trees by hares, voles, and combined damage by both species

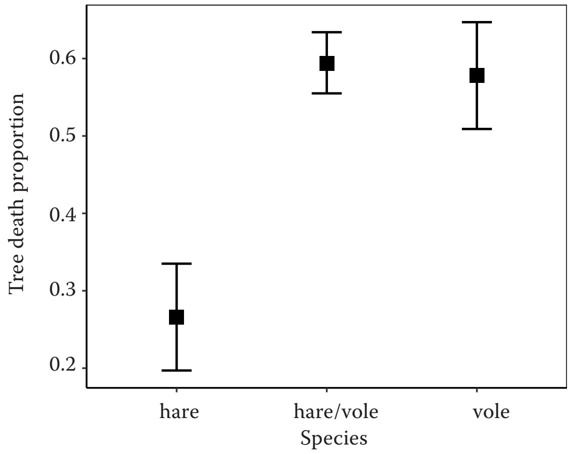

Figure 4. The proportion of fatal damage by hares, voles and combined damage by both species (significantly higher mortality was caused by voles and by combined damage; the error bars represent 95% confidence interval)

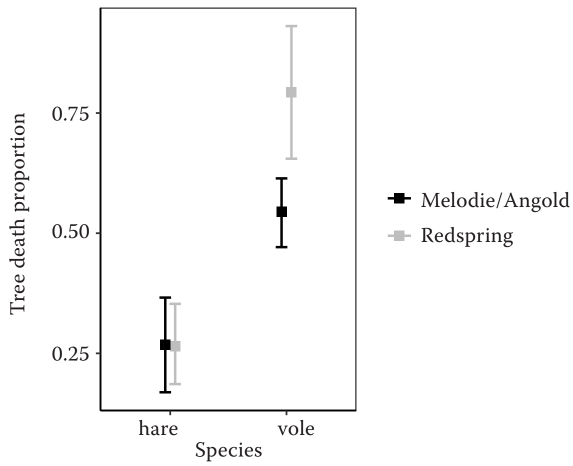

Figure 5. The proportion of fatal damage caused to the cultivars by hares and voles (the error bars represent 95% confidence interval)

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DISCUSSION

Both hares and voles caused extensive damage to apple trees in the orchard. Fatal damage was, however, much more often caused by voles. An important finding is that voles prefer different varieties of apple trees. Why voles preferred the cv. Red Spring to cv. Melodie/Angold is not known yet. We anticipate a difference in the bark composition. Different preferences of bark are known in birch (*Betula* spp.) of various origins (Rousi 1988). The bark composition can also be influenced by cultivation in the fruit tree nursery and in the orchard, and by many external factors (e.g. soil composition, fertilization, sum and distribution of precipitation and irrigation, temperature and sunshine during the year). Foresters have noticed that some artificially grown seedlings from forest nurseries are more attractive to voles than saplings from natural regeneration (Bergeron 1996). In forest plantations, greater damage to autumn plantings compared to spring plantings was observed (Virjamo *et al.* 2013). The cv. Red Spring suffered more extensive gnawing of branches because they grow closer to the ground (Figure 2 in comparison with Figure 3). As no data on preferences of voles to different cultivats of apple trees (or other fruit trees) are available, further research is needed.

Although hares did not usually kill the trees directly, the damage still has a negative impact on the growth and development of the trees and fruit yield. Removing large quantities of bark causes susceptibility to bacterial, viral, and fungal infections that can attack the tree at the wounds; fruit trees are particularly sensitive to these infections (Walther *et al.* 2008; Jacob *et al.* 2014). That is why in these cases growers replace all damaged trees in orchards, i.e. both the killed and partly damaged ones (owner of the orchard, pers. comm.). While the damage of trees by hares in orchards can be prevented by appropriate fencing or using repellents (Thompson & Armour 1952; Nesvadbová 1988), the reduction of damage by voles is considerably more complicated (see below).

The main cause of damage in the orchard was the combination of several environmental factors (Miñarro *et al.* 2012; Bertolino *et al.* 2015); winter with the long-lasting snow cover (Byers 1984; Heroldová *et al.* 2012) and high autumn density of common voles (in 2016 about 6 000 active holes per hectare; Tkadlec E., pers. comm.). Even though the orchard was fenced, the fence could not prevent the voles penetrating to the orchard, and the high snow cover made the trespass possible for hares as well. The grassland around the trees was ideal for the survival of voles.

As far as the orchard cultivation in organic farming is concerned, proper agrotechnical interventions and proper management of the herb layer are important. Such interventions can significantly affect the abundance and distribution of voles in agrocoenosis (Merwin *et al.* 1999; Jacob & Hempel 2003; Jacob 2008). In intensive production orchards, the herb layer is suppressed either by mowing or by herbicides or by mulching (e.g. using wood chips). Therefore, these orchards are unattractive to voles (Sullivan & Hogue 1987). However, in the organic farming system, the vegetation cover remains preserved and often provides both adequate shelter and rich food resource that allow voles to survive on the site (Brown 1999). The character of the biotope near orchards is also important. An example of this is the line of unmowed vegetation in the surroundings of intensively managed orchards. Unmowed vegetation lines can help eliminate tree damage since voles prefer such vegetation to the intensively managed orchards with poor or missing undergrowth, which are unsuitable habitats for voles (Sullivan & Sullivan 2009). On the other hand, orchards represent large agrocoenosis with simple habitat structure and limited vegetation cover and it can be assumed that the size of the linear vegetation strips is not sufficient for the high numbers of voles who may then cause significant damage to orchards (Bertolino *et al.* 2015).

The occurrence of voles can also be influenced by the species composition of herbal layer which is sometimes used in ecologically managed (organic) orchards as living mulch (Wiman *et al.* 2009). To promote living mulch, species producing a large amount of organic matter and thus improving the soil quality are grown. However, the same species also support the presence of voles on the site. Therefore, it is appropriate to use low-growth competitive weeds that can fix nitrogen and may have a repellent effect on rodents to prevent tree damage. An example may be sweet-scented bedstraw (*Galium odoratum*), which demonstrably reduced the presence of voles more than other herbs, in North America (Wiman *et al.* 2009; Sullivan *et al.* 2018). However, this species is an exception. Further research is needed to test and verify the repellent effect of other herbs (Wiman *et al.* 2009).

At present, integrated or biological protection against rodents is often used in orchards as a counterpart to the intensive use of rodenticides (Jacob *et al.* 2014). This requires a specific approach to target

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pests that depends on the production system in orchards (Byers 1984; White *et al.* 1997). It is necessary to rely on good knowledge of habitat preferences and of the influence of environmental variables on individual species, as well as on knowledge of the impact of agrotechnical practices on the occurrence and size of populations of individual vole species (Bertolino *et al.* 2015). This knowhow, which is almost absent in Czech conditions, has further local specifics. Therefore, there is an urgent need of more intensive research in this field resulting in methodological recommendations for fruit growers. Organic orchards grown in the ecological regime and using integrated protection against rodents need it in particular.

CONCLUSION

Massive damage to apple trees in the orchard was caused by common voles and European hares. Damage by the hare was extensive but it was not as fatal to so many individuals as vole damage. The annual shoots of columnar apple trees of the cv. Red Spring were often gnawed down to the trunk. Some of the new apple trees were gnawed so much that the crown was left bare. In both other cultivars (cvs Melodie and Angold) with an extensive habit, the lower branches were also damaged but not to such an extent. Trunks of the cv. Red Spring were more heavily damaged by both voles and hares. This cultivar also suffered more extensive gnawing of branches because they grow closer to the ground. Fatal damage (girdling) was almost 90% due to the vole.

Prevention should be the main protection of orchards from damage by mammals. For example, factors such as density of the vole population in the area in autumn (State Phytosanitary Administration and its recommendations) should be observed. The population of the common vole is already stabilized in late autumn. At that time, it is appropriate to apply recommended procedures, such as the use of suitable pesticides. To prevent greater damage, autumn grassland treatment should be permitted even in organic farming. The study confirms the significance of the observed mammalian species as fruit tree pests and the need for research and application of results in the form of recommendations and methods of protecting orchards from damage by small mammals.

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