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Prey composition modulates exposure risk to anticoagulant rodenticides in a sentinel predator, the barn owl

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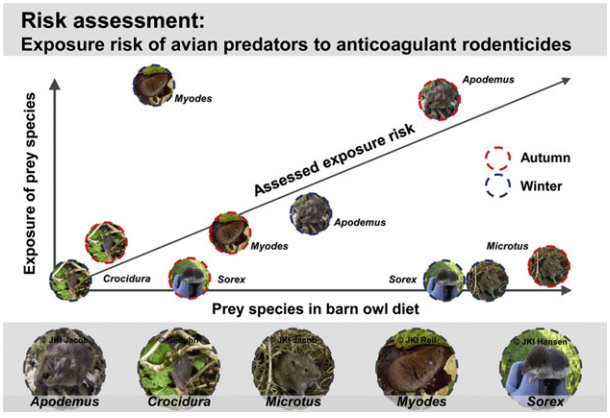
HIGHLIGHTS

- Anticoagulant rodenticide exposure in small mammals drives exposure risk of barn owls.
- Exposure risk of barn owls depends on seasonal variation in prey composition.
- Exposure risk of barn owls is highest in autumn due to contaminated prey.
- Transfer of brodifacoum to barn owls is most likely via *Apodemus*.
- Residues of the 2nd generation anticoagulant rodenticides are common in barn owls.

GRAPHICAL ABSTRACT



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ABSTRACT

Worldwide, small rodents are main prey items for many mammalian and avian predators. Some rodent species have pest potential and are managed with anticoagulant rodenticides (ARs). ARs are consumed by target and non-target small mammals and can lead to secondary exposure of predators. The development of appropriate risk mitigation strategies is important and requires detailed knowledge of AR residue pathways. From July 2011 to October 2013 we collected 2397 regurgitated barn owl (*Tyto alba*) pellets to analyze diet composition of owls on livestock farms in western Germany. 256 of them were fresh pellets that were collected during brodifacoum baiting. Fresh pellets and 742 liver samples of small mammals that were trapped during baiting in the same area were analyzed for residues of ARs. We calculated exposure risk of barn owls to ARs by comparing seasonal diet composition of owls with AR residue patterns in prey species. Risk was highest in autumn, when barn owls increasingly preyed on *Apodemus* that regularly showed AR residues, sometimes at high concentrations. The major prey species (*Microtus* spp.) that was consumed most frequently in summer had less potential to contribute to secondary poisoning of owls. There was no effect of AR application on prey composition. We rarely detected ARs in pellets (2 of 256 samples) but 13% of 38 prey individuals in barn owl nests were AR positive and substantiated the expected pathway. AR residues were present in 55% of 11 barn owl carcasses. Fluctuation

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in non-target small mammal abundance and differences in AR residue exposure patterns in prey species drives exposure risk for barn owls and probably other predators of small mammals. Exposure risk could be minimized through spatial and temporal adaption of AR applications (avoiding long baiting and non-target hot spots at farms) and through selective bait access for target animals.

1. Introduction

Anticoagulant rodenticides (ARs) are used to control commensal pest rodents (Buckle and Smith, 2015), but they can cause non-target exposure and poisoning. Avian predators regularly carry AR residues in many regions of the world (e.g. UK: (Walker et al., 2010) France: (Lambert et al., 2007); Spain: (López-Perea et al., 2015); USA: (Murray, 2011); New-Zealand: (Eason et al., 2002)). AR poisoning has been confirmed or was highly suspected in several avian predator species (Murray, 2011; Hughes et al., 2013; Coeurdassier et al., 2014). Therefore, appropriate risk mitigation strategies are important for non-target species conservation. However, little is known about the details of the exposure pathway and factors that modulate exposure. Such knowledge is important for risk assessment and the development of appropriate risk mitigation strategies.

The barn owl is a suitable model species for risk assessment of ARs because they use farm buildings (De Bruin, 1994) where ARs are regularly applied. Barn owls are increasingly exposed to ARs (Newton et al., 1997; Walker et al., 2010) and numbers are declining in the long-term in Germany (Bundesamt für Naturschutz, 2009). AR bait use in Germany requires covered application (Umweltbundesamt, 2014) to minimize primary poisoning of non-targets. Secondary poisoning can occur via target and non-target small mammals of rodent control programs.

Main target species of biocidal AR application are *Rattus norvegicus* and *Mus musculus*. The latter rarely occurs in barn owls diet in Germany (Görner, 1979; Langenbach, 1982), Great Britain (Glue, 1967; Love et al., 2000), Italy (Bose and Guidali, 2001) and the United States (Smith et al., 1972) but can be common in barn owl diet in south-eastern Europe (Goutner and Alivizatos, 2003; Bontzorlos et al., 2005). Similarly, *R. norvegicus* rarely occurs in barn owl prey (Smith et al., 1972; Görner, 1979; Langenbach, 1982; De Bruin, 1994; Love et al., 2000; Bose and Guidali, 2001; Goutner and Alivizatos, 2003), except for local situations, where rats are hunted in considerable amounts (Bontzorlos et al., 2005; Obuch and Benda, 2009). It seems that high AR exposure of barn owls (Walker et al., 2010; López-Perea et al., 2015) is at least partly be driven by AR residues in non-target small mammals. Non-target small mammals are a considerable source of AR exposure because AR residues in non-target small mammals have been reported in the UK (Brakes and Smith, 2005; Tosh et al., 2012), Canada (Elliott et al., 2014) and Germany (Geduhn et al., 2014). Secondary exposure of predators via non-target species was discussed by Tosh et al. (2011) for red foxes in Great Britain and Ireland. However, quantitative data are scarce.

The composition of barn owl diet and differences in AR exposure among small mammal species may drive the risk of AR exposure in predators. In addition, exposure risk could vary because of seasonal differences in prey abundance and seasonal variation in the use of ARs for rodent management (Shore et al., 2003). Huson and Rennison (1981) found increasing rat infestations on agricultural premises in England from late summer to winter. They suggest that rats occur on farms when food availability decreases after harvest and found farmers controlling rats mainly in winter. This enhances risk of AR-exposure of predators during this period.

For developing optimal risk mitigation strategies, detailed information about exposure pathways from bait to predators is required. Therefore, we considered a) species composition of barn owl diet (targets/non-targets) from a period of 28 months and b) combined this and exposure patterns of non-target small mammals (based on Geduhn et al. (2014)) to estimate exposure risk for barn owls. We additionally analyzed the influence of c) seasonal variation in barn owl diet. Secondly, the expected exposure pathway was assessed. We screened d) pellets of barn owls and e) prey caught by barn owls and carcasses of barn owls for AR residues.

2. Material and methods

2.1. Samples and study area

The risk assessment for barn owl exposure to ARs was based on the AR residues in small mammals that were trapped during baiting campaigns at livestock farms in the Münsterland region (52°N, 8°E) in western Germany and the diet composition of barn owls in the same area. The expected exposure pathway was monitored by the analysis of AR residues in barn owl pellets and liver samples from prey individuals that were hunted by the owls at the same farms.

The study area where the barn owl pellets and small mammals were originated from is a mosaic of farmland (about 60%) interspersed by small forest sections (about 15%). Nesting boxes for barn owls were available at all 9 investigated livestock farms. We used brodifacoum (BR) bait (Ratron® Brodifacoum Flocken 0.05 g/kg BR, frunol delicia® GmbH) to control *R. norvegicus* in October/November at 6 (2011) and 9 farms (2012) and in February/March at 7 (2012) and 8 farms (2013). Baiting campaigns lasted three weeks following label instructions. Further farm details and anticoagulant rodenticide use is described in Geduhn et al. (2014).

From July 2011 until October 2013 we collected barn owl regurgitated pellets from rest and nesting sites at livestock farms once a month (monitoring pellets n = 2141) and every third day during baiting campaigns (fresh pellets n = 256). The barn owl diet was assessed by both, monitoring and fresh pellets and fresh pellets were analyzed for residues of ARs. During and one week after the baiting campaigns we trapped 742 small mammals on farms up to 100 m away from bait points (Geduhn et al., 2014). Furthermore, we collected prey carcasses (n = 38 small mammals) from barn owl nest boxes, which were checked every third day during the baiting campaign in February/March 2012. Whole liver samples of all small mammals were analyzed for AR residues.

In addition, barn owl carcasses at regional scale (three German federal states: North Rhine-Westphalia, Lower Saxony and Baden-Wuerttemberg) were analyzed for AR residues. 11 liver samples were obtained from a veterinarian practitioner, two veterinary institutes and by us. Barn owls were found dead or were euthanized shortly after admission of moribund individuals to a veterinarian.

2.2. Barn owl diet analysis

After initially removing all barn owl pellets present, we collected monitoring pellets once a month (sampling occasion) and dried them for at least three hours at 100 °C. We soaked pellets in tap water, disintegrated them with a strong jet of water and collected all solid components on a mesh. Solids were placed in a plastic bowl and a finer jet of water was used to separate bones and teeth from hair. Hair was decanted and bones and teeth were collected and dried at 60 °C. We identified prey species by cranium and teeth characteristics (Jenrich et al., 2010) and recorded the minimum number of prey individuals by counting upper and lower jaws. Mean body weight of prey