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Simulation to aid in interpreting biological relevance and setting of population-level protection goals for risk assessment of pesticides

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ABSTRACT

Specific protection goals (SPGs) comprise an explicit expression of the environmental components that need protection and the maximum impacts that can be tolerated. SPGs are set by risk managers and are typically based on protecting populations or functions. However, the measurable endpoints available to risk managers, at least for vertebrates, are typically laboratory tests. We demonstrate, using the example of eggshell thinning in skylarks, how simulation can be used to place laboratory endpoints in context of population-level effects as an aid to setting the SPGs. We develop explanatory scenarios investigating the impact of different assumptions of eggshell thinning on skylark population size, density and distribution in 10 Danish landscapes, chosen to represent the range of typical Danish agricultural conditions. Landscape and timing of application of the pesticide were found to be the most critical factors to consider in the impact assessment. Consequently, a regulatory scenario of monoculture spring barley with an early spray treatment eliciting the eggshell thinning effect was applied using concentrations eliciting effects of zero to 100% in steps of 5%. Setting the SPGs requires balancing scientific, social and political realities. However, the provision of clear and detailed options such as those from comprehensive simulation results can inform the decision process by improving transparency and by putting the more abstract testing data into the context of real-world impacts.

1. Introduction

In environmental risk assessment for pesticides, the protection goal is normally based on protecting populations. Sometimes it is based on individuals, for instance for all vertebrates, or on a function (e.g. nitrification) or on behaviour (e.g. for bees and vertebrates). In all cases the risk assessment starts with standard ecotoxicological tests like in the Avian Reproductive Test (OECD 206). In this test, a number of endpoints have to be assessed. These include, egg production rate, percentage of cracked eggs, viability, hatchability, number of 14-day old survivors, and eggshell thickness. The hazard assessment is based on a NOEC, i.e. the highest concentration tested in which the values for the observed effect are not significant different from the control. In principle, all of these endpoints are assumed relevant when populations are the protection goal. However, although an endpoint is statistically significantly *different* from the control it may not be biologically *relevant*. In order to determine the biological relevance of an effect, it should be considered whether the effect could lead to a functional deficit later on in the study. For example, if the weight of birds at nest leaving is lowered by the effect of a pesticide it may or may not lead to differential survival after nest-leaving. If not, then the effect may not be biologically relevant. However if there is a carry-over of effects into the number of survivors or their subsequent reproductive fitness, then it can be considered a biologically relevant effect.

In the case of eggshell thinning, it is believed that the biological relevant percentage of eggshell thinning starts at 18% reduction in eggshell thickness (Blus, 2003; EFSA, 2009). This is because this is the point at which it is assumed that eggs start to crack. To relate this effect between laboratory and model we need to know the dose at which this effect occurs (the benchmark dose, BMD). The BMD equivalent to 18% effect can be calculated with an appropriate method (see for instance EFSA Scientific Committee, 2017). This BMD can be considered as the “NOEC” for cracked eggs. A “NOEC” for cracked eggs is, based on the precautionary principle, a good starting point for the risk assessment, but probably not the value at

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which a population will start to show signs of decreased ability to survive. Indeed, the point at which a population-level effect is detectable may be quite different from the level at which the effect on the population is considered unacceptable.

The point at which an effect is unacceptable is often referred to as a specific protection goal (SPG). This is typically expressed as a proportional reduction in a service and is often assessed as a change in population size of a focal species. The focal species being a species which is used to represent a realistic worst-case, and is therefore protective of other species. For birds in EU regulatory risk assessment, the focal species is often the skylark (Aagaard, 2014; Dietzen et al., 2014; Aae et al., 2015). This is a small ground nesting passerine species typically breeding in fields during the time of pesticide application. It is therefore considered to be highly exposed. The skylark *Alauda arvensis* is one of the farmland bird species for which population declines have been most severe throughout most of Western Europe (Fuller et al., 1996; Siriwardena et al., 1998; Chamberlain and Crick, 1999) and is the subject of a EU management plan (European_Communities, 2007). Being one of the few farmland birds to nest and feed almost exclusively in open fields and field margins, the skylark is one of the farmland bird species most likely to be vulnerable to pesticides. A number of studies have attempted to identify the causes of decline in the skylark. They have demonstrated a negative influence on skylark reproduction of tall, dense and fast-growing autumn-sown cereals, a simplification of crop rotation leading to a decrease in crop diversity and structure (Odderskaer et al., 1997; Wilson et al., 1997; Wakeham-Dawson et al., 1998; Chamberlain et al., 1999), silage cutting and trampling on grass fields (Wakeham-Dawson et al., 1998), and loss in winter stubble fields (Donald et al., 2001a). Whilst these drivers are not directly related to pesticides they do create a situation where the skylark population is potentially more ecologically vulnerable to further stressors.

This short article demonstrates how complex systems models of focal species could be used to measure endpoints corresponding to thresholds set by SPGs, using eggshell thinning in skylarks as an example. The idea is to demonstrate the concept only, it is not to present a detailed or exhaustive list of scenario results, nor is it to define any actual values for endpoints or SPGs, which would require dialogue with risk managers. The scenarios developed below all describe different assumptions regarding the effects of eggshell thinning and the exposure of skylark populations to a stressor causing this. One issue particularly highlighted is the uncertainty about the way in which egg loss may be distributed between clutches of exposed females, and this is addressed using alternate scenarios. Initially, we look at a situation of 100% egg loss and constant global exposure to provide the most extreme case possible against which more realistic scenarios can be judged. We then go on to refine our assumptions to investigate the dynamics of the response of the skylark population to toxic effect, application rates, scale of use and timing of application.

2. Methods

2.1. Skylark model overview

The study is based on the use of the ALMaSS skylark model, which is an agent-based simulation model within the open source Animal Landscape and Man Simulation System (https://gitlab.com/ChrisTopping/ALMaSS_all). This model has been used in pesticide risk assessment for some time (Topping and Odderskaer, 2004; Topping, 2005; Topping et al., 2005). The most recent model version and its testing is described in (Topping et al., 2013), and full documentation for the skylark model can be found in Topping (2011). However, a very short overview of the model is presented here to aid readability.

The individual model skylarks are categorised as being members of five life-stages. clutch, nestlings, pre-fledglings, males, and females. The main drivers of the skylark model are the topography and habitat quality of the landscape elements being modelled, farming activities (crop choice, physical disturbance), crop growth, and weather. Available insect food biomass is determined by vegetation structure in each landscape element and type (i.e. locally for each patch), see (Topping, 2012), and by its availability in terms of physical accessibility to the birds during foraging. Foraging in from a home range containing the territory. Insect biomass resources are updated daily in the model and are affected by vegetation growth processes and also by human management (e.g. insecticides or herbicides). During the breeding period, defined here as incubation and care of young up to 30 days old, the model considers the energetic balance of the adults, the food requirements for maintenance, requirements of young, and the weather constraints both as a limit to foraging success and as increased energetic costs for cold weather. The initiation of breeding depends upon firstly finding a suitable territory, and secondly, upon vegetation structure being suitable for nesting. Breeding success depends on the habitat being able to fulfil the energetic requirements of the birds during the breeding period and the survival of eggs and nestling. This is determined by food resource quantity and availability, and is a function of management, weather and skylark behaviour. Birds may also be disturbed during nesting e.g. by farming activities, but this is rare during the breeding season.

The model has been extensively tested and is capable of reproducing a full range of real world skylark population and individual behaviours. These include the mean and variation around time to hatch and nest leaving, densities of skylarks per farm, and within season phenology under different field conditions (Topping et al., 2013).

2.2. Model landscapes used for simulation

Ten model landscapes were selected to be used in the simulation runs Fig. 1. These were designed to represent the range of agriculture present in Denmark, and also to represent a range of landscapes from very intensive agriculture to extensive agriculture with

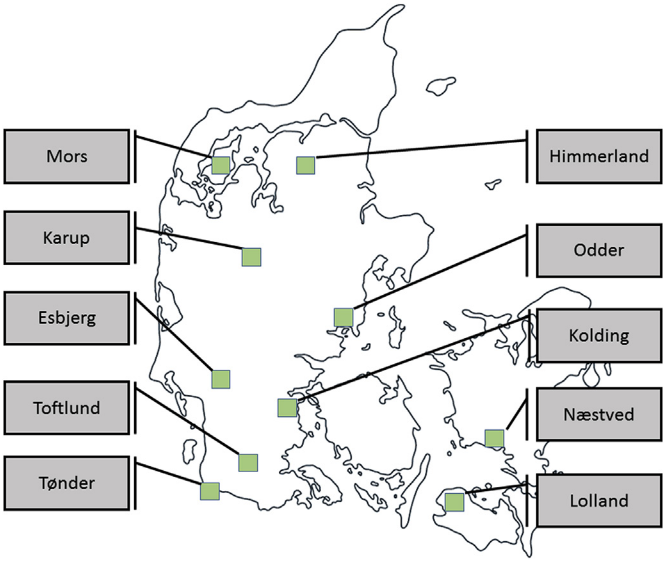

Fig. 1. The location of each of the 10 Danish landscapes used for simulation.