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Population dynamics and future persistence of the clouded Apollo butterfly in southern Scandinavia: The importance of low intensity grazing and creation of habitat patches

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ABSTRACT

We investigated the population dynamics and future persistence of the last remaining Clouded Apollo butterfly metapopulation in southern Scandinavia. Based on three decades of surveys (1984–2015), we modelled colonization-extinction dynamics and local population sizes using habitat patch characteristics and connectivity, while accounting for imperfect detection and uncertainty in the local population sizes. The colonization probability increased with increasing connectivity and the local extinction probability decreased with increasing local population size in accordance with metapopulation theory. The local population size increased with increasing patch area, and was also affected by grazing intensity. Light grazing resulted in larger local populations compared to heavy grazing or no grazing at all. The butterfly population has decreased considerably during the study period and according to projections of future dynamics the estimated extinction risk within the coming 10 years is 17%. However, it is possible to change the negative trends and decrease the extinction risk considerably by conservation actions. By optimizing the grazing pressure in existing patches the extinction risk was reduced to 11% (a reduction with 35% compared to the scenario with no conservation action). If a few new patches are created close to the occupied ones the extinction risk can be reduced further. In conclusion, there is a large risk that the Clouded Apollo butterfly will go extinct from southern Scandinavia within the coming decade. However, conservation measures that are focused to the core area of the current distribution and applied soon can considerably improve the situation for the butterfly.

1. Introduction

Semi-natural grasslands are important for biodiversity in agricultural landscapes (e.g. Duelli and Obrist, 2003). However, the intensified use of agricultural land and abandonment of less productive land in Europe during the last century has led to a major loss and fragmentation of habitat for species associated with these grasslands (Cousins et al., 2015; Krauss et al., 2010; WallisDeVries et al., 2002). For species to persist in the remaining grasslands one important factor is that habitat quality is maintained over time (Öckinger and Smith, 2007). Many grasslands rely on local grazing regimes to remain open, and abandonment leads to succession that may have negative impacts on many grassland specialists (Luoto et al., 2003; Weiss, 1999). On the other hand, too intense grazing may have negative impacts on some species (Kruess and Tscharntke, 2002; McLaughlin and Mineau, 1995). However, for most species we do not know the specific habitat requirements and how e.g. grazing intensity affects the population dynamics, which is essential for efficient conservation.

Grassland butterflies is an example of a relatively well studied group of species that has experienced negative population trends due to the loss and changed management of semi-natural grasslands (e.g. Maes and Van Dyck, 2001; Warren et al., 2001). Although population dynamics and mobility are species-specific most butterflies seem to have a very limited dispersal ability, and their colonization probability therefore often increases with increasing connectivity to surrounding occupied patches (e.g. Hanski, 1994), in accordance with metapopulation theory (Hanski, 1999). The local extinction probability of butterflies is known to decrease with increasing local population sizes, which usually increase with patch area (e.g. Harrison et al., 1988). Therefore, patch area is often used as a rough proxy for the local population size (e.g. Hanski, 1994; Wahlberg et al., 2002) even if many suggest a more resource-based approach (e.g. Dennis et al., 2006; Turlure et al., 2010). Empirical evaluations of the patch size – population size paradigm suggest that observed local extinctions are more effectively predicted as a direct function of local population size than by patch size (Pellet et al.,

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2007). One reason could be that the local population size, and hence the local extinction probability, is also affected by the quality of the habitat (e.g. Thomas et al., 2001). Since habitat quality is difficult to measure and differs between species it has often been neglected and less studied compared with patch area and isolation that are comparably easy to measure. However, habitat quality can contribute more to species persistence than patch area or isolation (Franzén and Nilsson, 2010; Thomas et al., 2001). For the majority of the grassland species, habitat quality may increase when less intensive late grazing is applied on managed semi-natural grasslands (Batáry et al., 2011; Dover et al., 2010; Nilsson et al., 2013) as this increases the amount of flowering plants and the availability of host plants.

Effective conservation management of threatened species depends on our ability to understand and predict their local population dynamics. Projections of future dynamics are an important tool to evaluate population persistence and compare different management scenarios to find efficient conservation strategies (e.g. Beissinger and McCullough, 2002). For reliable projections, predictive models should preferably be based on long term data of local population dynamics and patch characteristics, as short time series may create misleading results that can underestimate extinction threats (Thomas et al., 2002). When comparing the effect of different management scenarios on future population sizes it is important to include model uncertainty, not only caused by stochasticity in the projected dynamics but also in the model parameters (Heard et al., 2013; McGowan et al., 2011). This can be achieved by using the Bayesian modelling framework, which is also very flexible in accounting for e.g. imperfect detection (Royle and Kéry, 2007; Sutherland et al., 2014) and handling missing data (O'Hara et al., 2002). Therefore, the Bayesian framework is very suitable for risk analysis for the management of threatened species and is increasingly used for population viability analysis (e.g. Heard et al., 2013).

The aim of this study was to analyze the colonization-extinction dynamics and local population size of the Clouded Apollo butterfly (*Parnassius mnemosyne*), which is highly specialized species associated with semi-natural grasslands. We do this using a long term data set of a Clouded Apollo metapopulation in southern Sweden over 32 years (1984–2015) and the Bayesian modelling framework. We hypothesized that the colonization probability increases with increasing connectivity to occupied patches and that the local extinction probability decreases with increasing local population size, in accordance with metapopulation theory. Further we hypothesized that the local population size increases with increasing patch area and is related to habitat quality as measured by grazing intensity. We also aimed at evaluating future persistence of the butterfly under different scenarios of management. Specifically, we compare the population size and extinction risk until 2025 when the present conditions remain the same with scenarios of changed grazing regimes and when new patches are created by conservation actions.

2. Material and methods

2.1. Study species

The Clouded Apollo (*Parnassius mnemosyne*) is a Palearctic butterfly that is classified as endangered (EN) in Sweden (Gärdenfors, 2015) and is also threatened elsewhere in Europe (van Swaay and Warren, 1999). The butterfly has non-overlapping generations. It is active in May–June and hibernates as an egg. The species is monophagous on host plants belonging to the genus *Corydalis*. In the study area it is *C. pumila* and *C. intermedia*, which both seem to have rather stable populations in southern Sweden and are therefore classified as least concern (LC) on the Swedish red-list (Gärdenfors, 2015). The Clouded Apollo is a rare inhabitant of flower-rich meadows and semi-natural grasslands, and this type of habitat is dependent on a management of either grazing or mowing. The butterfly has become extinct in many parts of its previous southern Scandinavian distribution range including Denmark (extinct in 1961) and the Swedish province Scania (extinct in 1954) (Franzén and Imby, 2008). In 2015 only three local populations remained of the southern Scandinavian population, situated in the province Blekinge. Isolated populations also exist in Norway and central Sweden but they have been described as other subspecies. The decline of the Clouded Apollo has been attributed to the ceasing of traditional management regimes, grazing and mowing of semi-natural grasslands, and coppiced woodlands (Väisänen and Somerma, 1985). During the last century management of grasslands has drastically changed in southern Sweden and grazing of natural pastures has decreased, leading to gradual transformation of most grasslands into either intensively used agricultural fields or forests (e.g. Cousins et al., 2015). At the same time the few remaining grasslands have been more intensively managed and more intensively grazed by cattle (e.g. Nilsson et al., 2008).

2.2. Study area and patch definitions

The field work was conducted from 1984 until 2015 in the surroundings of Ronneby in Blekinge province in southeast Sweden (long: 15.2780, lat: 56.2170). The major feature of the landscape is a mixed open-forested area with arable fields, semi-natural grasslands, deciduous forests, glades and rocks. In the study-area, all potentially suitable habitat patches (24 in total) were surveyed and mapped in 1984 (Fig. 1). Suitable patches were defined as open grasslands with >0.5 m^2 cover (or >50 shoots, see Välimäki and Itämies, 2003) of the host plant (*Corydalis* spp.) anywhere in the patch, and presence of the major nectar plant *Lychnis viscaria* (>50 flowering individuals). Habitat patches were defined as separate if the borders were situated 150 m apart or more. This slightly more coarse patch separation, compared to other studies (e.g. Välimäki and Itämies, 2003), may result in more 'unsuitable' habitat being included in the patch, the absence of short inter-patch dispersal distances, and lower population densities. On the other hand, it may be more user friendly for practitioners, as our patches most often are well-defined grasslands that are naturally delimited by neighbouring arable fields or forests. By using whole grasslands both larval (host plants) and adult resources (nectar plats) are included, which has been suggested to be important when assessing patch suitability (Fred et al., 2006). However, we did not quantify these resources over time, and could therefore not model them explicitly, but they are indirectly included under the assumption that they increase with increasing patch area.

2.3. Butterfly survey

During the study period we collected data on butterfly occurrences and local population sizes in the 24 patches. However, the quality of the data varied between the years because Capture Mark Release (CMR) studies were not performed each year (Appendix A). For the following 18 years: 1984 to 1987, 1991 and 2003 to 2015 the quality of the data was rather good as most patches were visited at least six times each year with standardized CMR methods used (see below). Especially, species occurrences in these years are rather reliable as several visits reduce the risk of observing false zeros (i.e. that the species was not observed when it in fact occurred in the patch). The butterfly is very easy to observe from long distances (up to 50 m) as it is a large and charismatic species exposing itself on flowers and thus has a presumably high detectability. However, we did not have information about in how many of the visits the species was detected for all patches and years. We therefore used a plug-in estimate of species detection probability in our model. The plug-in estimate was computed from three of the occupied patches that were visited more intensively (at least 9 times per year) during six consecutive years (2004–2009). During this period the species was on average found in 80% of the visits and the detection probability was thus estimated to 0.80 per patch and visit. Hence, already after three visits in one patch the detectability is extremely high (>99%). Even if the detection probability was very high we included it in the