The effects of farming intensification on an iconic grassland bird species, or why mountain refuges no longer work for farmland biodiversity

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Abstract

Agricultural intensification is threatening ecosystems and causing the collapse of farmland birds. Biodiversity-rich, semi-natural grasslands dramatically decreased in recent decades and were either intensified, replaced by more remunerative crops or abandoned. We investigated the factors driving habitat selection by corncrake *Crex crex*, a flagship species for grassland conservation, in Trentino (Italy, European Alps), considering topography, public payments through Rural Development Programme (RDP), agro-botanic grassland types and farming intensification, during 2010-2018.
Topographical variables were the most important predictors, but a synthetic model combining different predictors was even more supported. Elevation (negatively) and solar radiation (positively) affected occurrence; untargeted subsidies for grassland mowing had a negative effect, whereas specific subsidies for the management of Natura 2000 grasslands had a positive effect. Stocking density (livestock units/ha), taken as a direct measure of intensification, had a negative impact on occurrence. Corncrakes preferred unfertilized grasslands, then species-rich grasslands with little fertilization; mountainside and, especially, valley-floor grasslands were under-selected.
Corncrake has progressively disappeared from Trentino's valley-floors, 'shifting' to mountain areas, but the effects of topography remind it is a lowland species pushed towards uplands by farming intensification, which is now affecting also the 'mountain refugia'. Grassland types are selected by the species according to a gradient from unmanaged to heavily managed; subsidized mowing and livestock units/ha, a proxy for the amount of fertilizers and timing/frequency of mowing, had negative impacts.
The conservation of the Alpine corncrake population and associated biodiversity critically depends on the maintenance of low-intensity farming on a relevant portion of cultivated grasslands. The reduction of fertilization, the adaptation of mowing regimes (to avoid early mowing, close subsequent cuts and homogeneous cutting over large areas), and the broader adoption of biodiversity-targeted payment schemes are urgently required. Grasslands at relatively moderate

elevation and sun-exposed are particularly important: lowering management intensity there is crucial for conservation.

Keywords

conservation; *Crex crex;* habitat selection; Rural Development Programme; topography

1. Introduction

Agricultural intensification is one of the main threats to biodiversity and ecosystems in current decades. Among the several impacts that farming intensification has on wild species, its link with the collapse of farmland birds is particularly renown and highly concerning (Gamero et al., 2017). The dramatic decline of many bird populations has been attributed to the changes occurred in agricultural practices and landscapes (Donald et al., 2001). In Europe, the Common Agricultural Policy (CAP), which involves the largest share of the EU total budget, has promoted intensification in most accessible and economically profitable lands, whereas it has indirectly encouraged abandonment in the less remunerative areas over the last 50 years, with huge impacts on biodiversity (Bignal, 1998; Renwick et al., 2013). Such unsustainable outcomes of the CAP has led to progressive policy changes, with e.g. the introduction of agri-environmental schemes (AESs; or, more recently, agri-environment-climate payments, AEC), or with direct payments conditioned to the implementation of greening measures by farmers (Pe'er et al., 2014). AESs include both broad-scoped measures, such as habitat restoration or amelioration, and specifically-targeted options, aimed at e.g. promoting the occurrence of a given species tied to specific farmed habitats (Kleijn and Sutherland, 2003). On the other side, the largest share of CAP subsidies are unlikely to be ecologically relevant, do not take into account the needs of farmland biodiversity, and may strongly reduce the potential suitability of farmed areas for several species (Pe'er et al., 2014).

Those general considerations fully apply to European grasslands. Grasslands are a semi-natural habitats, largely created and maintained by agriculture, which perfectly represent the unfortunate (at least from an environmental point of view) trajectories of recent farming. They have dramatically decreased in recent decades (e.g. -11.8% between 1993 and 2011 in the countries joining the EU in 2004; Pe'er et al., 2014), being replaced by more remunerative crops, or abandoned in areas where conversion was not feasible (Assandri et al., 2019; Brambilla et al., 2010; Laiolo et al., 2004); the remaining grasslands have been subject to a strong intensification and mechanization of farming practices (Humbert et al., 2016), with a dramatic reduction of their value in terms of biodiversity and ecosystem services. This is critical for biodiversity conservation in Europe, where a large amount of wild species depend more or less strictly on agricultural land (e.g. around half of European birds; Tucker and Evans, 1997), because grasslands are the most valuable agricultural habitat in several areas and, in absolute terms, semi-natural grasslands are among the biodiversity-richest habitats in Europe (Veen et al., 2009). Specific subsidies and measures for grassland conservation have been introduced, including a greening measure in the last revision of CAP targeted at maintaining permanent grassland. However, this greening measure allowed a further 5% decrease of grassland extent by 2020 and included a commitment to preserve the overall extent of grassland, but did not define the exact location of grassland parcels (resulting in potential relocation with ploughing and reseeding) and did not consider the different values of different grassland types, thus lacking in environmental prescriptions and leaving the door open to further intensification and degradation (Assandri et al., 2019; Dicks et al., 2014; Pe’er et al., 2014). Therefore, measures and subsidies included in the current CAP are not sufficient for the conservation of low intensity, biodiversity-rich, grasslands.

Corncrake *Crex crex* (Aves: Rallidae) is a flagship species for grassland conservation, of particular conservation concern and listed in the Annex I of the Birds Directive (2009/147/CE). During the breeding season (mostly May-August) it inhabits grassland habitats of different types throughout temperate Eurasia, being generally rather scarce. After a general dramatic decline and range contraction in the past two centuries, this iconic grassland species have shown some local or national recoveries in the last three decades, thanks to conservation interventions or to the positive effect, even if ephemeral, of agricultural abandonment (Keiss, 2003). The historic collapse of the species, which is still ongoing in many areas such as Italy (Pedrini et al., 2016), had been mostly related to agricultural intensification, which implies early and mechanized mowing, high levels of fertilization and other changes in agricultural practices (Broyer, 1987; Keiss, 2003; Moga et al., 2010). Corncrake is believed to have originally inhabited floodplain and lowland grassland, often in relatively wet or even flooded contexts; then, such habitats dramatically declined in Europe because of drainage and land reclamation and the species mostly shifted to mown grassland (Koffijberg and Schaffer, 2006), even if a preference for wet and often unmanaged grassland can be still observed in some areas (Berg and Gustafson, 2007; Berg and Hiron, 2012). Several studies highlighted the effect of mowing on the species, especially through a decrease of survival and breeding success (e.g. Bellebaum et al., 2016; Broyer, 2003; Green et al., 1997b, 1997a; Tyler et al., 1998), but also via the creation of suitable habitats (Arbeiter et al., 2018), especially in eutrophic contexts (Arbeiter et al., 2017a), or when mowing is performed in alternate years (Berg and Gustafson, 2007).

Targeted AESs have been proposed for the species, mostly including delayed mowing (no cut before August) and/or corncrake-friendly mowing, such as outwards moving or conservation of unmown strips (Bellebaum and Koffijberg, 2018). AESs somewhere led to population recovery, such as in Scotland, where targeted AESs had been applied on large extents of suitable habitat and over a long period (O'Brien et al., 2006), but they are in general considered to be largely insufficient to significantly benefit the European corncrake population (Bellebaum and Koffijberg, 2018).

In Italy, corncrakes are mostly found in grassland mown for hay-making (hay-meadows; Pedrini et al., 2016). Within our study region (Trento province, NE Italy, see below), they originally occupied floodplains, marshes, wetlands and meadows in valley floors, and secondarily other grasslands (Pedrini et al., 2002), then predominantly shifted to mid-elevation grasslands because of habitat destruction or degradation in the valley floors (Pedrini et al., 2005 and Fig. 1; see also Alba et al., 2020). It is possible that the species' scarcity on mountainsides in the past was due not only to climate and topography, but also to widespread grazing, leading to unsuitable grassland structure over many areas at mid-elevation. Widespread mechanization of mowing, also favoured by broad-scoped, non-targeted AESs (Brambilla and Pedrini, 2013), as well as grassland conversion and intensification (Assandri et al., 2019), are likely to be the current main obstacles to corncrake conservation in the area (Pedrini et al., 2012). With this work, we investigated factors driving habitat selection by corncrakes in mid-elevation grasslands in an Alpine area. More specifically, we considered the effect of topography, AEC and other payment schemes comprised in the local Rural

Development Programme (RDP), of agro-botanic grassland typology and of farming intensification on corncrake occurrence probability, providing an unprecedented evaluation of the concomitant effects of such different drivers of farmland bird ecology on a species of high conservation concern. We started from the following predictions, based on the general knowledge on corncrake ecology, applied to the species in this Alpine area:

i) originally being “a lowland species”, also within the study region, in the mid-elevation belt they currently inhabit in this region corncrakes should prefer milder environments and microhabitats, being thus favoured by lower elevation and higher solar radiation, and flatter areas, being negatively conditioned by slope;

ii) corncrakes should select ‘wetter’ grassland types, because they typically occupy (when available) floodplains and wet grassland, and even marshes and wetlands;

iii) corncrakes could be impacted by RDP measures, with negative effects by those measures promoting widespread, non-targeted mowing, which just focus on mowing and do not consider the ecological needs of grassland species, in terms of management prescriptions at the relevant temporal and spatial scales. Instead, corncrakes could be positively affected by AEC payments encouraging delayed and/or targeted mowing. They could also be favoured by organic farming, which could result in higher invertebrate preys, thanks to the expected lower toxicity of treatments, and in lower management intensity;

iv) given that corncrakes are negatively affected by farming intensification (because of higher inputs, species-poor vegetation and early and more frequent mechanized mowing), occurrence probability should be negatively associated to proxies for intensification.

2. Materials and Methods

2.1 Study area and fieldwork

Our study was carried out between 2010 and 2018 in the Trento province, north-eastern Italy, in the eastern Alps (45.67–46.51 °N and 10.51–11.96 °E; elevation 65–3764m asl). This is a mountain region, where cultivated grassland in form of hay-meadows and alpine pastures are generally interspersed with woodland, other crops and urban areas, approximately between 250 m and 2000 m (currently, they are mostly above 800 m). Hay-meadows, the most common corncrake habitat, are used and managed by (cow) dairy farms to produce forage to feed cows in stables. Hay-meadows generally occur below 1600 m, and have been undergoing a dramatic decline (from 37.761 to 20.367 ha between 1990 and 2010: Provincia Autonoma di Trento, 2017). Such a decline was matched by a reduction in the number of livestock farms (-53.8% between 2000 and 2010), but such changes were not mirrored by a comparable trend in the number of livestock units, which indeed slightly increased in recent years (+11.8% between 2000 and 2010), resulting in a much higher stocking density (La Notte et al., 2015; Scotton et al., 2012). Several meadows are experiencing an anticipation of the first cut (to increase fodder quality), and a consequent increase of cut frequency (Assandri et al, 2019). Mowing methods also changed in the last decades; the former mosaic fashion of mowing, due to the highly fragmented properties mown at different time by the respective owners, had been replaced by extensive, simultaneous, mowing over wide areas (Brambilla and Pedrini, 2013).

Valleyfloors have been largely altered by human activities: natural (wetland, forest, flooded grasslands) and semi-natural habitats (hay-meadow) have been replaced by intensive crops and urban areas, whereas on mountainsides forest increased in recent decades at the expense of low-intensity pastures and grasslands. Large meadow areas have been converted into intensive crops, such as apple orchards or vineyards (Assandri et al., 2019; Pedrini et al., 2005). See Fig. 1 for a graphical representation of the main landscape changes.

Corncrakes were surveyed on average twice per breeding season (May-July) within six study areas (Fig. 2; overall elevation span 750 – 1450 m asl), which have been intensively surveyed since the end of the last century to monitor the population trend of the species (Pedrini et al., 2012). Each study area (extent between 113.9 and 807.5 ha) was surveyed simultaneously by different teams of observers, who moved during the night (22:00-03:00) across team-specific sectors of the study areas, following paths, tracks and minor roads, listening to singing males and broadcasting male's song every 200-300 m (one minute of playback, followed by three minutes of listening, all repeated twice) if no male was heard. The surveyors carefully recorded on detailed maps or on a GPS device the exact location of all singing males. For further details see previous studies (Brambilla and Pedrini, 2013, and references therein).

2.2 Environmental predictors

We considered three different kinds of predictors, in order to assess habitat selection by corncrakes and test our initial expectations. Topographical predictors were derived from a 10-m resoluton Digital Terrain Model (DTM) of the Trento province, and included elevation, slope and solar radiation; the latter was the global radiation on the 21st June, calculated in GRASS (Neteler et al., 2012), taking into account the shadowing effect of reliefs. Management predictors included stocking density, expressed as adult livestock units (LU) per hectare of meadows, and RDP measures adopted on a given grassland parcel.

LU is an important parameter as it allows a quantification of the relative abundance of effluent produced in stables and that is then spread over the meadows belonging to the farm; according to Italian legislation, one LU corresponds to 83 kg/year of nitrogen equivalent. LU per ha was corrected for the number of animals that spent the summer (calculated as three months) on alpine pastures, according to the following formula:

LU per ha = (total LU – (0.25 * LUalp)) / meadow extent

where LUalp is the number of LU that moved to alpine pastures in summer. LU per ha therefore provided a reliable estimate of the amount of effluents spread as fertilizer over the meadows of a given farm.

RDP measures were grouped into a few groups of relatively homogeneous measures to avoid too many values for this categorical factor. The resulting groups were the following ones: subsidies for mowing, organic farming (all measures promoting introduction or maintenance of organic farming; no prescriptions about mowing period; maximum LU/ha equivalent set to 2), compensation for mountain farming (funds to compensate for lower income related to mountain farming, in relation to farm size, slope steepness and elevation), specific management for Natura 2000 grasslands (consisting in delayed mowing: no cuts between 25 May and 15 July).

Finally, agro-botanic grassland type was also considered on the basis of a four-level classification (La Notte et al., 2015; Scotton et al., 2012):

i) dry or wet, species-rich, grasslands (mapped by means of specific fieldwork) that should not be fertilized (*Nardetalia*, grasslands with *Festuca rubra* and *Agrostis tenuis*, *Bromion erecti*, included patches of xeric *Bromion erecti*), wet mown grassland: *Molinietalia caeruleae*, fens (*Caricetum davallianae* and *Caricion fuscae*);

ii) dry, species-rich, grasslands (mapped by means of specific fieldwork) with little fertilization (transition forms between *Bromion erecti* and *Arrhenatherion*, *Anthoxanto-Brometum erecti* and *Ranunculo bulbosi-Arrhenatheretum*, *Centaureo transalpinae-Trisetetum flavescentis*, transition forms between *Centaureo transalpinae-Trisetetum flavescentis* and *Centaureo carniolicae-Arrhenatheretum elatioris*, *Centaureo transalpinae-Trisetetum flavescentis*, *Centaureo carniolicae-Arrhenateretum elatioris*);

iii) valleyfloor grasslands (easily accessible grassland on plains or slopes <10°, excluding species-rich grassland);

iv) mountainside grasslands (all other grasslands).

Intensification increases from grasslands without any fertilization, to dry grasslands with little fertilization, mountainside and valleyfloor grasslands.

The use of some environmental variables is associated with some uncertainties. In particular, grassland type was defined in 2014, and the adoption of RDP measures was available for the year

2020. This means that some changes could have happened during the time span covered by our study. However, considering that agro-botanic grassland type is the result of the interaction between climate, topography, soil and long- or medium-term management, it is unlikely to have significantly changed during the study period, which is centred around the definition of grassland type. For what concerns RDP measures, they are part of the 2014-2020 programme, and usually adhesion to measures is rather constant across the duration of a given RDP. Therefore, we can start from the assumption that relevant changes in grassland type and RDP payment schemes are unlikely to occur within the considered period, and that the effect of any variation should be negligible for the purpose of our study. Finally, the value of LU per ha, which represents a direct measure of fertilization and a good proxy for management intensity in general, is available as a unique value for each farm and not as parcel-scale value; if an individual farm has more grassland parcels, it could potentially dispose effluents in different proportions over different parcels. However, this is the best indicator available for intensity of meadow management and it is likely to work well over the broad scale, as in our study.

2.3. Statistical analyses

To obtain pseudo-absence points, we followed previously adopted approaches linking selected sites to surrounding ones (Bosco et al., 2019), having the survey area as a grouping factor in our case. We therefore compared the characteristics of corncrake occurrence sites with surrounding, where no records were obtained (pseudo-absence sites, available but not used habitat; Bosco et al., 2019). We scattered random points within the study areas, subject to two constraints: to be at least 20-m apart from a corncrake calling location, and 40-m apart from other random points. For 120 corncrake locations and 2089 random points, all the considered environmental variables were available (for some points, RDP measures and/or grassland type were lacking). When more RDP measures were applied to a single grassland parcel (and hence were associated with a corncrake or random point), one of them was randomly selected for the analyses.

We carried out a two-step GLMM (generalized linear mixed model) procedure. In the first step, we evaluated the relative importance of different types of determinants of habitat selection; in the second step, we identified the single, most relevant drivers of habitat selection in the corncrake population we studied. In GLMMs, we added the study area as a grouping (random) factor, corncrake occurrence as the dependent (binomial) variable and the environmental variables described above as predictors (all continuous variables were centred around mean and scaled by their standard deviation before the analyses). We did not consider year as a factor potentially affecting occurrence probability because i) environmental variables are constant over the study period, or are meant to be considered as average values over it, and ii) considering occurrence and pseudo-absence sites all over the period is less sensitive to potential absence due to low return rates in some specific years, rather than to habitat unsuitability, something not unlikely for a species showing strong inter-annual fluctuations like the corncrake. We used for model building and comparison an information-theoretic approach (Burnham and Anderson, 2002), using AIC (Akaike's information criterion) as a measure of model support. We first compared the AIC value of the most supported model (the one with the lowest AIC) for each single group of predictors (topography, management and grassland type) to evaluate the support for each group (Brambilla et al., 2020). Then, we selected the variables included in the most supported models for each group and build a synthetic model to identify the most relevant drivers of habitat selection in corncrakes (on the basis of the AICc, i.e. AIC corrected for small sample size, as the ratio between sample size and number of predictors dropped below 40). To take into account the uncertainties associated with model selection, the most supported models (ΔAICc < 2) were conditionally averaged after the removal of uninformative parameters (Arnold, 2010). We used the dredge command of the package MuMin (Bartoń, 2020) to compare the AICc of all possible models within a given set, the package glmmTMB (Brooks et al., 2017) to build GLMM models and estimate 95% confidence intervals, and the package visreg (Breheny and Burchett, 2018) to plot variable effects in the software R (R

Development Core Team, 2020). Model validation was carried out on a model including all variables comprised in the average model using the package Dharma (Hartig, 2020).

3. Results

Between the three different groups of predictors, support was maximum for the topographical variables, followed by the management model and the type of grassland (Table 1). However, the synthetic model was more supported than the single-group ones (see Table 2 for the most supported models).

Model averaging on the most supported synthetic models led to a final model including RDP measures, elevation, solar radiation, LU per ha and grassland type (Table 3). The model including all variables comprised within the most supported models was not overdispersed ($P > 0.5$).

Topographical variables were very important: even if slope did not enter the most supported models (even at the single group level), elevation and, secondarily, solar radiation (Fig. 3) affected habitat selection in corncrakes, according to our prediction (negative and positive effect, respectively).

Management variables were also highly relevant. LU per ha had a clearly negative impact on the probability of corncrake occurrence (Fig. 3), matching our expectation. All RDP measures showed a positive effect on corncrake occurrence when compared with the general and untargeted mowing subsidy; as expected, the latter had thus a negative effect, whereas the most positive impact was exerted by specific management measures for Natura 2000 grasslands (Fig. 4), and the latter was the only measure for which the 95% CI of the effect did not encompass zero (Table 3). Finally, grassland type was also supported, but its effect poorly matched our expectation: the order of preference was dry and wet species-rich grassland that should not be fertilized, species-rich grassland with little fertilization, mountainside grassland and valleyfloor grassland (Table 3).

4. Discussion

Farming intensification stands at the very heart of current biodiversity crisis and has been pivotal in driving the collapse of farmland birds throughout Europe from the last three decades of the past century onwards (Donald et al., 2006, 2001; Pain and Pienkowski, 1997). Species-rich, low-intensity management grasslands are a vanishing habitat of utmost importance for biodiversity in Europe (Pe'er et al., 2014). Their widespread disappearance and/or degradation results in bird species tied to grassland-like habitats being in a worse status then other farmland birds in many areas (Brambilla, 2019; Gamero et al., 2017). Intensification of meadow management, resulting in severe impacts on biodiversity (Humbert et al., 2016), at least in the Alpine region, is strongly and circularly associated with intensive livestock farming (Assandri et al., 2019; Scotton et al., 2014). This process of intensification includes high levels of organic fertilization, early and more frequent mowing, species-poor grassland that are dominated by one or a few nitrophilous species and are likely to be ploughed and resown. However, extensive grassland are irreplaceable in terms of biodiversity value, because the degraded or resown meadows can no longer harbour rich biological communities and/or specialized species (Assandri et al., 2019; Humbert et al., 2009; Marini et al., 2008b, 2008a). These low-value (for biodiversity) grasslands, which are often associated to higher risks for the broader environment (Scotton et al., 2014), have the same weight of biodiversity-rich and low-intensity management grassland when calculating the amount of grassland required to access the CAP greening requirement and when designing local RDP measures, this being a major drawback of the recent CAP (Assandri et al., 2019; Pe'er et al., 2014).

Habitat selection by corncrakes in the Italian Alps provided a clear example of the impact of farming intensification on grassland species. Originally a floodplain, lowland species, corncrake disappeared decades ago from valley floors of the Trento province because of drainage, reclamation and conversion of wetlands, marshes and natural grassland, and now mostly occur in areas at higher elevation (Pedrini et al., 2002). The negative effect of elevation and the positive one of solar radiation recall that this is not a mountain species, rather it is an example of those farmland birds that have been progressively pushed towards uplands and mountain regions by farming intensification in lowland areas (Archaux, 2007). Unfortunately, such ‘mountain refugia’ for farmland birds are losing their role because of ongoing intensification (Archaux, 2007; Korner et al., 2018), and the same applies to our corncrake population (Pedrini et al., 2012). In fact, intensification is still degrading its potential habitat: grassland type are selected according to a gradient perfectly matching the management intensity (from unmanaged to heavily managed). LU per ha, a true indicator of management intensity, being correlated with the amount of fertilizers and with timing and frequency of mowing, had a negative effect on occurrence probability. The untargeted RDP measure promoting generalized grassland cutting (mowing subsidy), which had been considered among the causes of the regional decline of the corncrake population (Brambilla and Pedrini, 2013), was the less favourable for the species among all RDP measures, because it did not consider corncrake-friendly management requirements. All these results clearly indicate how intensification lowers habitat suitability for corncrakes, even in mountain and upland areas.

Other corncrake targeted and/or more environmentally oriented AEC payments provided benefits to corncrake, increasing the occurrence probability at a given point. In particular, the most positive effect was by far that of the specific management for Natura 2000 grassland (Fig. 4). This measure included delayed mowing (no mowing between 25 May and 15 July within the elevational belt considered by our study), with positive outcomes for corncrakes and likely other grassland species. This is fully coherent with the positive effects found elsewhere for management (whether based on AESs or not) promoting postponed or alternated mowing, or the preservation of unmanaged strips of adequate width (Arbeiter et al., 2018, 2017b; Berg and Gustafson, 2007; O’Brien et al., 2006), as well as with the positive effect on the short-term of grassland abandonment, which result in suitable (but transitory) unmanaged grassland (Keiss, 2003). Such measures could also promote the availability of invertebrate preys for corncrakes (Arbeiter et al., 2020) and of suitable conditions for other bird species (Broyer et al., 2020). Postponing mowing until the end of July will likely increase the chance of successful breeding by corncrakes. The contrasting effect of AEC payments on corncrake is also consistent with the mixed effect of AESs on biodiversity reported at broader scales (Kleijn et al., 2006; Kleijn and Sutherland, 2003).

Corncrake history and ecology in the Trento alpine area exemplifies the fate of several population of farmland birds in Europe, which have declined and contracted because of agricultural intensification and other environmental modifications, particularly in lowland areas, where grasslands have been converted into other crops or urbanized areas. Such species often found some sort of refuges in mountain areas; unfortunately, such areas have been and are currently impacted by land abandonment and by farming intensification, which was only delayed with respect to lowland areas. Such dynamics have been dramatic for grasslands, which include some of the biodiversity-richest habitats of Europe. Many grasslands have been abandoned in hilly and mountain areas (Brambilla et al., 2017), or converted into other (more remunerative) crops (Assandri et al., 2019), while the remaining ones have underwent intensification of farming practices (Humbert et al., 2016). All those unfavourable changes have led to the decline of many taxonomic groups, and, among birds, particularly impacted on open habitat specialists (Brambilla, 2019).

The conservation of the declining corncrake population of Italian Alps (Pedrini et al., 2016), as well as of a large amount of animal and plant species relying on grasslands in the same region (e.g. Marini et al., 2008a), critically depends on the maintenance of low-intensity farming on a relevant portion of cultivated grasslands. The reduction of fertilization with organic fertilizers or other external inputs, a revision of mowing regimes (to avoid early mowing, close subsequent cuts and homogeneous cutting over wide areas), and a broader adoption of biodiversity-targeted AEC payments are urgently required. In particular, grassland patches at relatively moderate elevation (< 1100 m asl) and with good exposure to to solar radiation (> 8850 $Wh/m^2 * day^{-1}$ on 21st June) are particularly important: they are key sites for corncrakes (especially during the first part of the breeding season, Brambilla and Pedrini, 2011) and are also likely to harbour rich and diverse plant and arthropod communities. Preventing or (at least) reducing fertilization (below 2.5 UBA/ha) and lowering management intensity in these contexts is crucial for conservation (cf. Marini et al., 2008a) and could contribute also to restore the high cultural value and appeal for recreation and tourism of grassland landscapes (Fischer et al., 2008). Promoting ‘traditional’ farming in Trentino, with Alpine breeds, lower stocking rates and a sustainable use of landscape resources, is likely the most efficient way to conserve both grassland species and cultural landscapes, and should be favoured by e.g. strengthening the link between traditional farming and high-value productions (Sturaro et al., 2013). This would also promote the refugia role of mountain grassland for farmland species, especially in the light of climate change; the latter indeed will lead to an increase in the climatic suitability of upland areas for several species (including corncrake), which have been declining because of intensification and habitat alteration in lowland.

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Tables

Table 1. Relative support (according to AIC) for the different groups of predictors considered as potential determinants of corncrake occurrence (most supported models, and the relative AIC values, are shown).

Model	**AIC**
Topography: elevation, solar radiation	851.36
Management: AEC measure, LU per ha	859.54
Grassland type	861.72
Synthetic: grassland type, AEC measure, elevation, LU per ha, solar radiation	846.20

Table 2. Most supported synthetic models (AICc < 2) among all the possible ones. Those in bold represent the models that were selected for the model averaging procedure.

int.	**grassland**	**RDP**	**elevation**	**solar radiation**	**LU per ha**	**df**	**logLik**	**AICc**	**delta**	**weight**
-3.36		**+**	**-0.56**	**0.28**		**7**	**-416.93**	**847.9**	**0**	**0.2**
-3.38		+	-0.55	0.26	-0.17	8	-415.92	847.9	0	0.2
-3.41		**+**	**-0.47**		**-0.19**	**7**	**-417.34**	**848.7**	**0.81**	**0.13**
-3.38		**+**	**-0.48**			**6**	**-418.53**	**849.1**	**1.2**	**0.11**
-1.29	**+**		**-0.61**	**0.29**		**7**	**-417.57**	**849.2**	**1.28**	**0.11**
-1.39	+		-0.61	0.28	-0.16	8	-416.66	849.4	1.47	0.1
-1.98	+	+	-0.62	0.27		10	-414.72	849.5	1.63	0.09
-2.1	+	+	-0.61	0.26	-0.16	11	-413.87	849.9	1.95	0.08

Table 3. Averaged model according to conditional averaging; estimates and relative standard errors (SE) and confidence intervals are estimated by the GLMM modelling procedure followed by conditional averaging of the most supported models, after the exclusion of the uninformative parameters (see text for details).

Full average	**Estimate ± SE**	**95% CI**
intercept	-2.98 ± 1.24	-5.41 – -0.55
AEC measure (baseline: mowing subsidy)		
organic management	0.42 ± 0.38	-0.32 – 1.16
compensation for mountain farming	0.45 ± 0.35	-0.24 – 1.14
Natura 2000 grassland management	2.31 ± 0.77	0.80 – 3.82
elevation	-0.53 ± 0.15	-0.82 – -0.24
solar radiation	0.28 ± 0.16	-0.03 – 0.59
LU per ha	-0.19 ± 0.12	-0.43 – 0.05
grassland type (baseline: grassland that should not be fertilized)		
dry grassland (low fertilization)	-1.51 ± 0.70	-2.88 – -0.14
mountainside grassland	-1.80 ± 0.72	-3.21 – -0.39
valleyfloor grassland	-2.36 ± 0.78	-3.89 – -0.83

Figure captions

(colour figures only in print)

Figure 1. Simplified representation of landscape and farming changes from historical to current time in the study region, with the associated changes in corncrake (shown as black birds) distribution from lowland to mountainsides.

Figure 2. Study area with pictures representing the different survey sites. The upper inset shows the position of Trento province within Italy.

Figure 3. Effect of continuous predictors on corncrake occurrence probability and relative 95% CI according to a GLMM model including all factors comprised within the average model: elevation, livestock unit per ha and cumulative (global) solar radiation (calculated for 21st June). Dashed lines represent the overall occurrence probability of corncrakes over all the points included in the analysis.

Figure 4. The effect (and the relative 95% CI, shown as vertical bars) of the measures included in the Rural Development Programme shown as the relative impact compared to mowing subsidies, according to the conditional averaged model (Table 3). Base occurrence probability (0.5) is shown by the dotted line.