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SPECTACULAR INCREASE OF RED-BACKED SHRIKE (*LANIUS COLLURIO*) IN GAUME, SOUTHERN BELGIUM – EVIDENCE FOR NORTHWARD EXPANSION DUE TO STRUCTURAL CLIMATE CHANGE?

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Abstract.

After years of population decline across Europe, the Red-backed Shrike has made a remarkable recovery since the 1980s. In the agricultural area of Gaume (Belgian Lorraine), a significant population growth was recorded despite a continued decline in landscape quality. This shows that larger scale factors also influence the number and distribution of the species. We systematically monitored a breeding population of Red-backed Shrike during 1979-2015 and 2021-2022. Consistent growth was recorded until 1996. From 1999 to 2002, a land re-allotment project was carried out, leading to a significant decline, followed by a stable period until 2015. From 2020 onwards, new population increases were reported, leading to renewed survey efforts that resulted in a new significant and continuous increase in 2021-2023. Variations in climate appear to have played a crucial role in this striking evolution. Annual population numbers during 1980-2008 were compared with variations in climatic factors. Cold springs and wet summer periods appear to have a significant negative impact on breeder recruitment, suggesting that the species' breeding success may benefit from global climate change due to its higher breeding success rate, provided that the habitat is maintained and that its warming does not cause excessive rainfall during a critical period of its reproductive cycle. This paper describes the evolution of the Red-backed Shrike in Southern Belgium (Gaume) over four decades in relation to the evolution in neighboring countries or regions and in function of climate change.

Introduction

The Red-backed Shrike, a widespread breeding species across Europe and extending into Western Siberia between latitudes 40°N and 64°N (reaching 36°N in the southwest), inhabits (semi-)open natural and anthropogenic landscapes where it preys upon large insects and small vertebrates from perches. Predominantly, the population resides in Eastern Europe, with Romania, Poland, Bulgaria, and Russia collectively harboring 75% of the total European population (BirdLife International, 2015). While the species exhibits its highest probabilities of occurrence in Eastern and Southeastern Europe, occurrences diminish towards the North and West. The distribution of the Red-backed Shrike is influenced by climatic constraints, with avoidance of excessively dry and warm conditions in the South and regions of high precipitation and low summer temperatures in the North and Northwest, which can adversely affect reproductive processes (Schaub et al., 2011; Søgaard Jørgensen et al., 2013).

Following a period of population decline across Europe, the Red-backed Shrike has undergone a notable resurgence since the 1980s. Noteworthy expansions have occurred in central Spain, particularly in its southwestern and southeastern regions, as evidenced between EBBA1 (Fornasari, Kurlavicius & Massa In: Hagemeijer & Blair, 1997) and EBBA2 (Nijssen In: Keller et al., 2023), contrasting with prevailing negative trends (Telleria, 2018). Similarly, expansions have been observed in Western Europe, specifically in Western and Northwestern regions including France, Belgium, and the Netherlands. Conversely, losses have been documented in other Mediterranean regions such as Italy (including Sardinia) and Greece, potentially indicating a retreat from coastal areas. In Nordic countries like Norway and Sweden, gains and losses appear to have reached equilibrium (Fig. 1).

In the agricultural landscape of Gaume, situated in Belgian Lorraine, despite ongoing deterioration in landscape quality, a substantial increase in the Red-backed Shrike population has been documented. This phenomenon underscores the impact of broader-scale factors on the species' abundance and distribution. Our study involved systematic monitoring of a breeding population of Red-backed Shrike spanning from 1979 to 2015 and from 2021 to 2022. The recorded growth remained consistent until 1996. However, a notable decline occurred between 1999 and 2002 following a land re-allotment project. Subsequently, a period of stability ensued until 2015, with new population increases noted from 2020 onward. These recent increases prompted renewed survey efforts, revealing a significant and continuous rise in population size from 2021 to 2023. Climate variations have emerged as a key factor influencing this remarkable evolution. Comparative analyses of annual population data from 1980 to 2008 in relation to climatic variables indicate that cold springs and wet summer periods exert a substantial negative impact on breeder recruitment. These findings suggest that the species' reproductive success may be bolstered by global climate change, given its potentially higher breeding success rate, provided habitat preservation is maintained and warming trends do not result in excessive rainfall during critical reproductive periods.

This paper presents an account of the Red-backed Shrike's evolutionary trajectory in Southern Belgium (Gaume) over four decades, contextualized within the

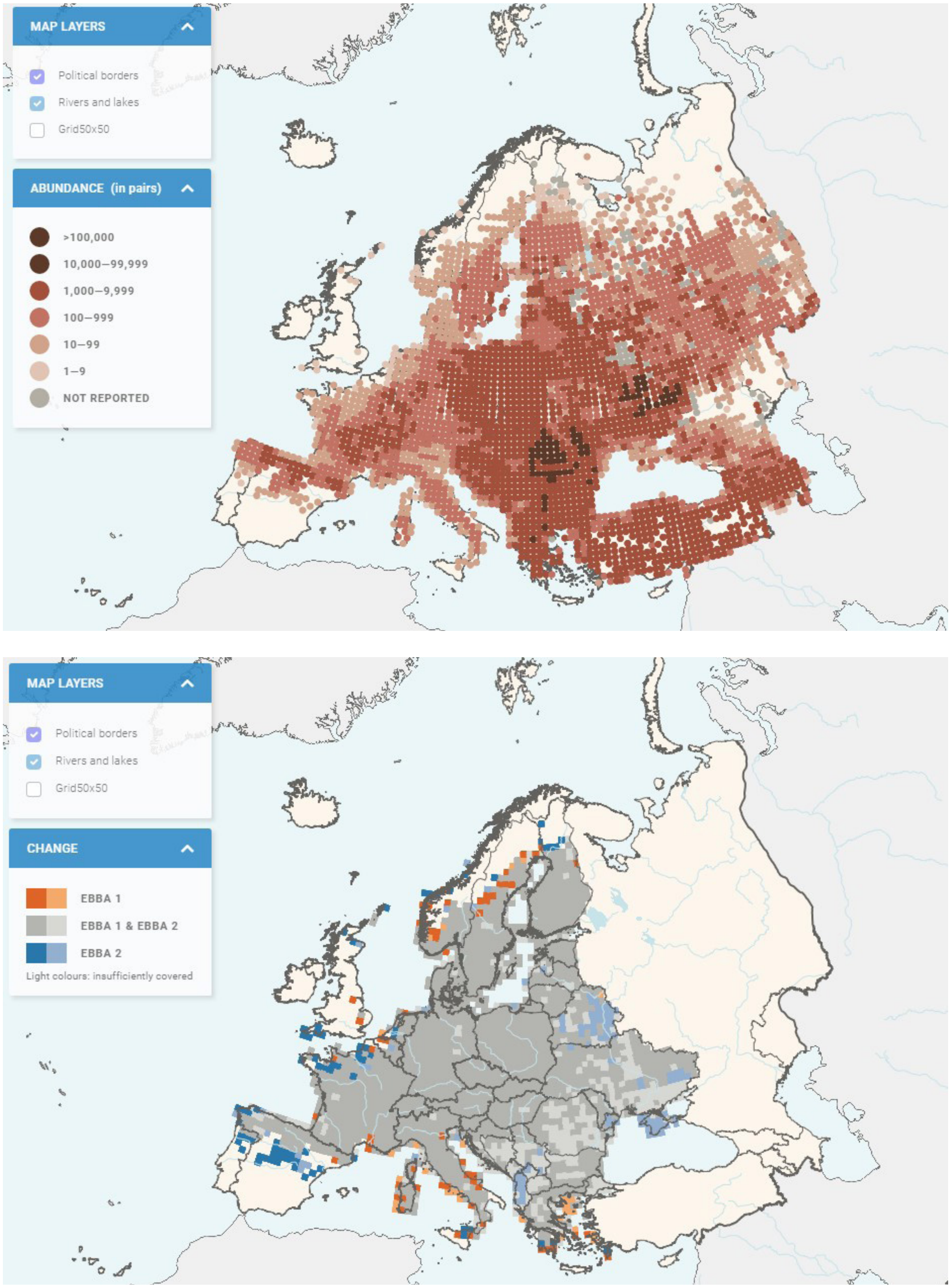

Figure 1. European distribution of Red-backed Shrike in 50 X 50 km grid cells (after Keller et al, 2020). A) Abundance B) Evolution EBBA1 (Hagemeijer & Blair, 1997) versus EBBA2 (Keller et al., 2023).

broader evolutionary patterns observed in neighboring countries or regions and in the context of climate change Figure 1. European distribution of Red-backed Shrike in 50 X 50 km grid cells (after Keller et al, 2020). A) Abundance B) Evolution EBBA1 (Hagemeijer & Blair, 1997) versus EBBA2 (Keller et al., 2023).

Methods

Study area

The study area is situated in Southern Belgium, specifically in the Gaume region (see Figure 2). This region harbors one of Belgium's most significant populations of Red-backed Shrikes, estimated at 750-1150 territories in Belgian Lorraine during the period of 2001-2007 (Titeux et al., 2010). The landscape features a rolling relief and comprises predominantly grasslands, arable land, and forested areas. The grasslands are extensively grazed or utilized as hay fields. Agricultural activities primarily focus on meat production, with a discernible trend towards intensification (Mottiaux, 2003). Notably, the region retains characteristic elements such as calcareous grasslands, thereby augmenting its biodiversity value.

Approximately 51% of the municipality of Rouvroy, encompassing Couvreux, falls within the Natura 2000 designation. Specifically, the site BE34066 – Vallée du Ton & Côté Bajocienne Montquintin – Ruette spans an area of 3056 hectares.

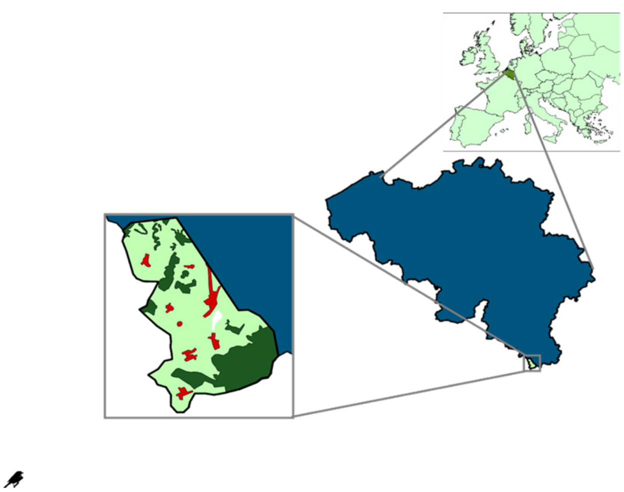

Figure 2. Situation of the study area in S Belgium. The study area covers 5000 hectares of which one third is classified as Natura 2000.

In approximately one-third of the study area, a land re-allotment project was implemented in Couvreux between 1999 and 2002, resulting in a significant alteration of the landscape (Fig. 3). This initiative led to a fundamental increase in the average size of land parcels, accompanied by an 84% reduction in the number of cadastral plots, whereas in non-re-allotted regions, the number of plots remained unchanged (Mottiaux, 2003). However, the land re-allotment program exerted a detrimental impact on landscape structure, scale, and biodiversity, creating less favorable conditions for shrikes. Both the mean and median perimeter lengths experienced notable declines, decreasing from 253 meters to 217 meters and from 195 meters to 149 meters, respectively. Consequently, the total perimeter length decreased by 17%. Additionally, there was an 11% increase in the number of cows, with the average number of cows per farm rising from 65 to 107 (a 64% increase). Notably, while the number of dairy cows

Figure 3. Land re-allotment area with parcel boundaries. Left, the situation before the land consolidation. Right, the situation after the land consolidation with significant increase in average plot size (after Mottiaux (2003).

decreased by 30%, there was a substantial 77% increase in meat cows.

From 1979 to 2015 and again from 2021 to 2023, annual surveys of Red-backed Shrike territories were conducted in Gaume, Southern Belgium, during the last week of June.

To investigate the potential impact of land consolidation on relative population numbers, the number of territories within the consolidation area was compared before, during, and after the consolidation period using proc GLIMMIX in SAS (Schabenberger, 2005).

To assess the influence of climate on annual population fluctuations, Partial Least Squares regression (PLS) modeling was employed. This involved the classification of variables using a latent variable approach, as described by Metzmacher and Van Nieuwenhuyse (2012).

Results

The population numbers of Red-backed Shrikes exhibited a notable upward trend, increasing from 7 territories in 1983 to a peak of 161 territories in 1996 (see Figure 4) (Van Nieuwenhuyse & De Middeleer, 2016, 2017a, 2017b).

Following the land re-allotment, the Red-backed Shrike population experienced a decline, stabilizing at around 90 territories from the early 2000s onwards, gradually rising to 98 territories by 2015.

The average proportion of shrikes within the land consolidation area decreased significantly from 42% to 36% after the land consolidation ($t=2.62$; $p=0.0498$) (Fig. 5; Van Nieuwenhuyse & De Middeleer, 2016).

Annual monitoring resumed in 2021 (n=140), revealing a growing population that reached 236 occupied territories by 2023, representing a 69% increase since 2021. Notably, between 2015 and 2023, the population experienced a remarkable 141% increase. Moreover, there was a 53% increase in population size between 2022 and 2023.

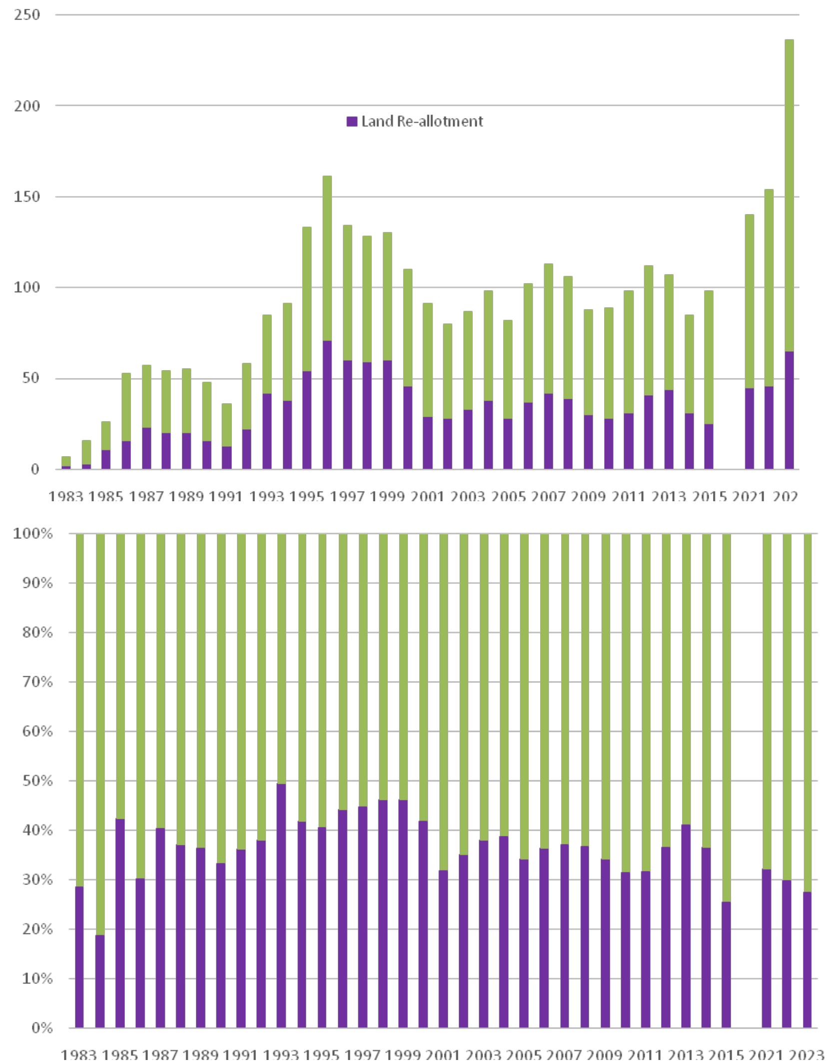

Figure 4. A) Evolution of the population size of Red-backed Shrike *Lanius collurio* in the study area in the Gaume 1983-2015 – 2021-2023. The land re-allotment scheme look place in 1999-2002. B) Evolution of percentage of Red-backed Shrike breeding in re-allotted and non-re-allotted part of research area.

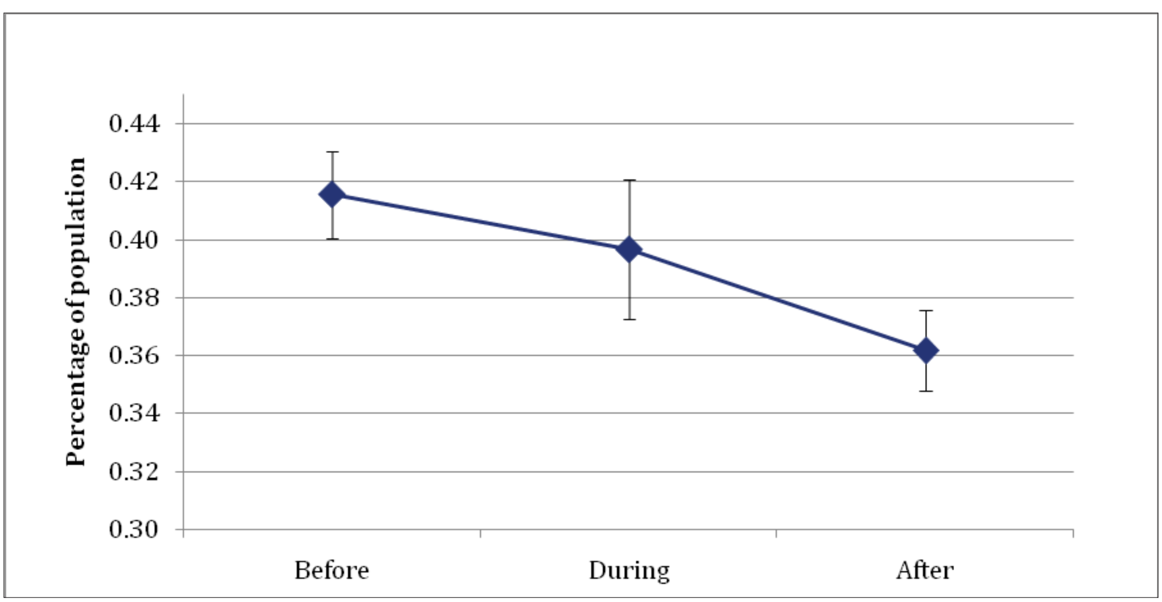

Figure 5. Average proportion of territories within the re-allotted area relative to the total.

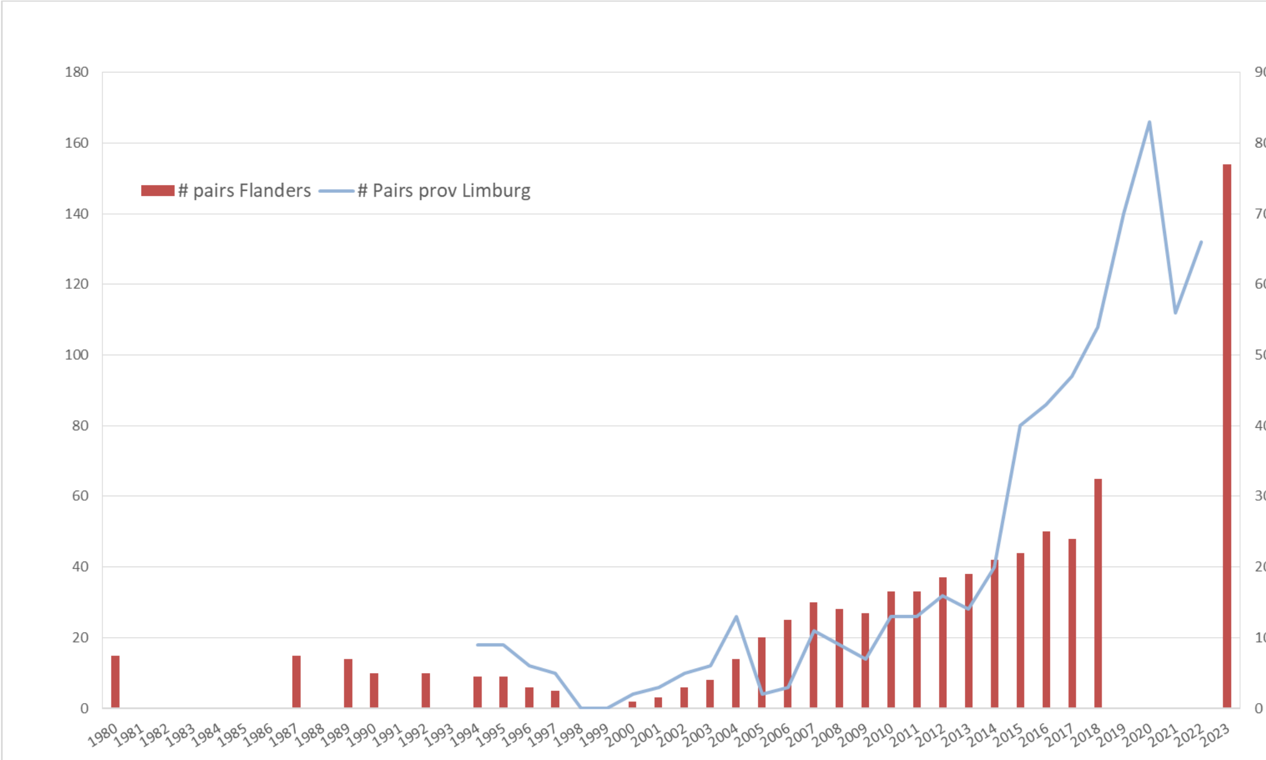

Figure 6. Evolution of Flemish Red-backed Shrike population as number of pairs (1980-2018) and as occupied 1 km² grid cells (2023).

In addition to land consolidation, variations in climate appear to have played a pivotal role in the observed evolutionary changes. To investigate this hypothesis, we conducted a comparative analysis of annual population fluctuations and variations in a series of climatic factors (Metzmacher & Van Nieuwenhuyse, 2012). This study draws from census data collected during the breeding period spanning from 1981 to 2008, utilizing weather data obtained from the nearest weather station to the study population.

Over the period of 1980 to 2008, the mean minimum temperature exhibited a tendency to increase during the April-August period. Additionally, rainfall intensity demonstrated a notable decline during the 1990s, followed by a significant increase in subsequent years. Furthermore, in the last three decades, rainfall intensity for June showed a decreasing trend, while that for August displayed an increasing trend. Notably, the annual variations of these monthly averages were found to be considerable.

Our research highlighted the considerable influence of various parameters associated with minimum temperature and precipitation during the breeding season on breeding population fluctuations. Specifically, cold springs and cool, wet summer periods were identified as factors significantly impacting breeder recruitment rates (Metzmacher & Van Nieuwenhuyse, 2012; Schaub, Jakober & Stauber, 2013). These findings suggest that the breeding success of the Red-backed Shrike could potentially benefit from global climate change, leading to an increased success rate of broods. However, this potential benefit is subject to the preservation of suitable habitat conditions, both in terms of quality and extent. Moreover, it relies on the condition that warming trends do not trigger excessively high rainfall during critical phases of its breeding cycle.

Neighbouring Countries and Regions

Flanders (Griet Nijs, personal communication)

In Flanders, the decline of the Red-backed Shrike traces back to the 1950s. While the Belgian population was estimated at 5,000 breeding pairs in 1950 (Lippens & Wille, 1972), it dwindled to 1,000 pairs by 1972, with only 350 pairs remaining in Flanders. Between 1973 and 1977, the number further decreased to a mere 570 breeding pairs, of which scarcely 110 were located in Flanders. During this period, the primary concentration of distribution was observed in the Kempen region, particularly in North Limburg, with only a few isolated breeding occurrences noted along the coast and in sandy Flanders.

The decline in Flanders accelerated during the 1980s, with the population fluctuating around 15 pairs (Maes et al., 1985). North Limburg, encompassing areas such as Lommel, Lozen, Sint-Huibrechts-Lille, Stamprooierbroek, Sint-Martensheide, and the Zwarte Beek valley, served as the last stronghold for a few years. However, even in these areas, the species continued to decline. By the early 1990s, breeding occurred sporadically outside of Limburg, with the population dwindling further to approximately 10 breeding pairs by 1992 (Vermeersch et al., 2004). In 1994, only nine territories were recorded throughout Flanders, with eight located in Sint-Maartensheide in North Limburg. Ultimately, this last population cluster was abandoned by the end of the 1990s, leading to the Red-backed Shrike being considered extinct in Flanders during the period of 1998-1999. Throughout the

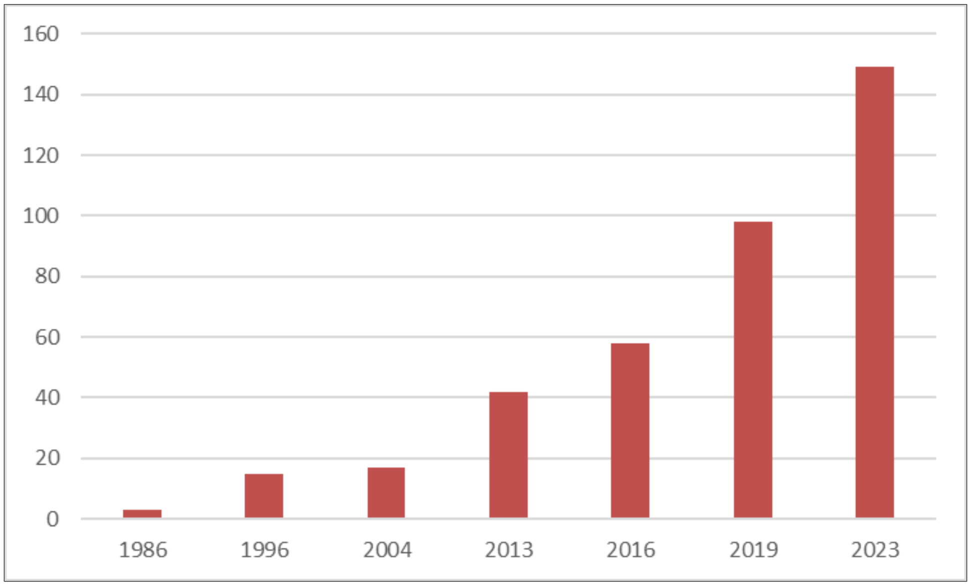

Figure 7. Evolution of breeding pairs in Natura 2000 site BE35027, Eau Blanche, Wallonia, S Belgium.

1990s, isolated breeding occurrences or territories were documented in various locations including the Zwinbosjes in Knokke (1992-1994), Sint-Huibrechts-Lille (1995), the Maatjes in Kalmthout (1996), and the dunes in Knokke (1996) (Vermeersch et al., 2004).

Since 2000, sporadic breeding occurrences have been observed, signaling a resurgence of the species in Flanders. The gradual recovery of the population was initially prominent in Limburg, where the Red-backed Shrike slowly expanded westward. By 2014, an estimated 20 breeding pairs were reported in Limburg.

Following this period, the Red-backed Shrike population experienced a significant resurgence (refer to Figure 6), coinciding with substantial habitat improvements within nature reserves (Nijs, 2020). Red-backed Shrikes are known to prefer diverse, semi-open landscapes characterized by species-rich grasslands with ample structural variation, providing an abundant food supply. Scattered thorny hawthorn, rose, and blackberry shrubs serve as both hunting perches and nesting sites. Consequently, the species thrives in extensively managed landscapes, serving as a vital ecological indicator for the quality of small-scale pastoral regions (van den Burg et al., 2011).

In twelve Flemish nature reserves, site managers implemented adjustments to nature management practices to meet the Red-backed Shrike's ecological requirements (Nijs, 2020). These measures aimed to enhance habitat quality through landscape improvements, with a focus on adjusting mowing management to increase prey availability and accessibility, restoring open landscape characteristics, and expanding potential breeding sites. Additionally, stacking branches to create piles provided additional hunting perches, while promoting the growth of hawthorn, rose, and blackberry shrubs between the branches offered supplementary breeding opportunities for shrikes.

The number of breeding pairs in Limburg increased significantly, reaching 66 breeding pairs by 2022, and their distribution expanded further. For instance, the number of 1 km² grid cells occupied by Red-backed Shrikes increased from 4 in the first decade (2000-2010) to 35 in the subsequent decade (2011-2020). Since 2020, there has been a notable acceleration in area expansion, with 154 grid cells occupied by 2023, and existing core areas are visibly densifying. Notably, the number of territories in core areas such as Sint-Maartensheide and the Voerstreek has increased to approximately 30 and 20-25 breeding pairs, respectively. Rapid increases have also been observed in other core areas, including Schulen (from 1 breeding pair in 2015 to 16 breeding pairs in 2023) and Diest (from 1 breeding pair in 2016 to 11 breeding pairs in 2023). This expansion trend is evident across Flanders, with recolonization observed in the Antwerp Kempen and sporadic breeding occurrences extending further westward, even into the Flemish Ardennes.

Wallonia (Jean-Yves Paquet, personal communication)

Red-backed Shrike monitoring has been conducted in Wallonia, Southern Belgium, specifically within the Natura 2000 site BE35027, which encompasses the Eau Blanche valley between Aublain and Mariembourg. This area, spanning 1300 hectares, is predominantly characterized by grassland habitats. The population of Red-backed Shrikes in this region has undergone significant evolution, increasing from a few pairs in 1985 to 149 territories in 2023, representing a substantial growth compared to the last census conducted in 2019 (see Figure 7).

This nature reserve has undergone continual evolution and improvement, largely attributable to its designation as a Natura 2000 area.

In 1996, the Red-backed Shrike population was low, and three distinct aggregates were observed: one in the southwest, situated within pasture meadows in a narrow section of the valley; another in the north, within a young spruce plantation; and the third in the south, within extensively managed meadows.

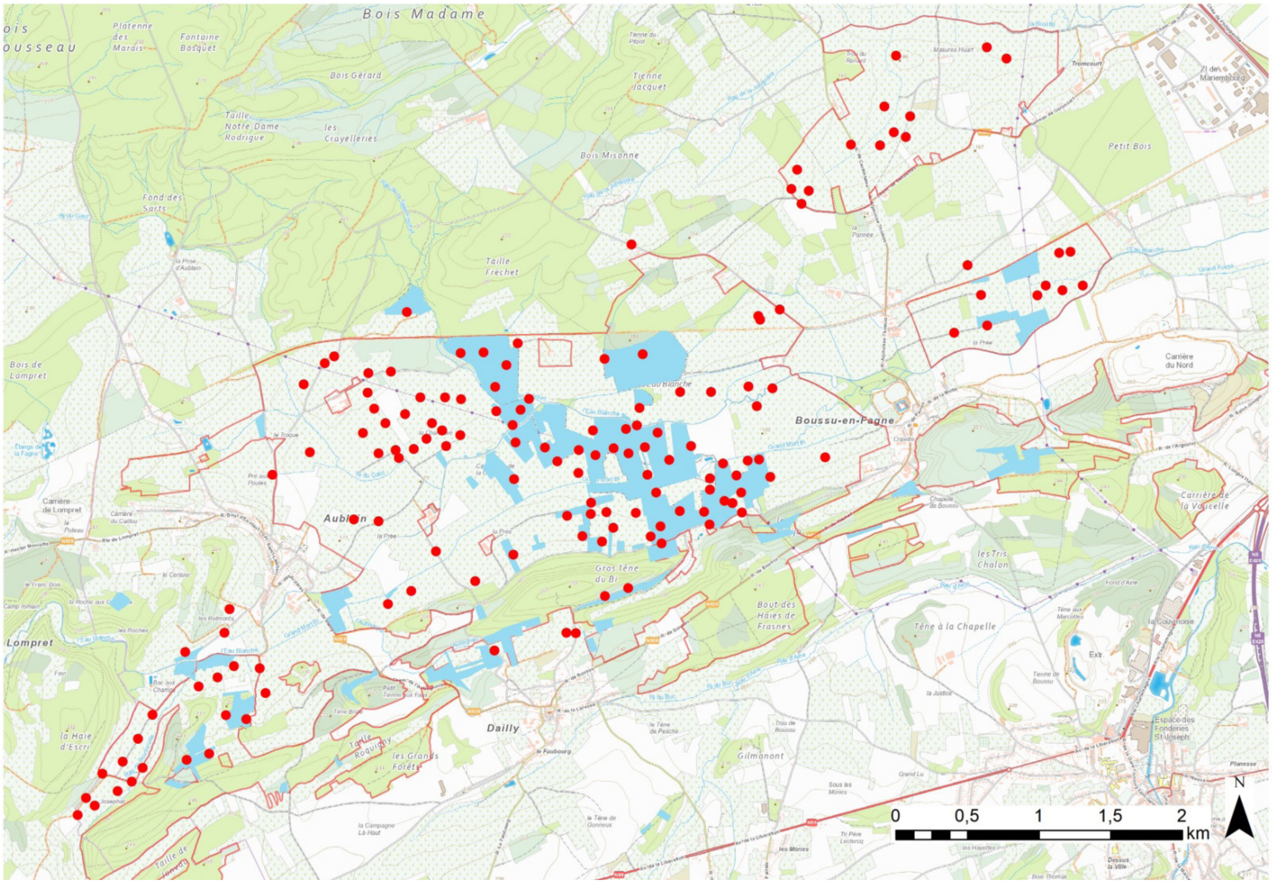

Figure 8. Red-backed Shrike breeding pair distribution in 2023 in Natura 2000 site BE35027, Eau Blanche valley between Aublain and Mariembourg. Existing nature reserve in blue.

By 2013, the nature reserve network had begun to develop, with a focus on the most ecologically significant meadows within the central part of the valley. The young plantation area was no longer favourable, while the central aggregate thrived around the extensively managed meadows and the reserve itself. Additionally, a new aggregate had formed in the east.

In 2023, following the implementation of the LIFE Prairies Bocagères project, a substantial portion of the central area had been preserved, constituting 10% of the entire Natura 2000 site. As a result, the Red-backed Shrike population now breeds throughout the reserve, including within the more intensively used pastures. Furthermore, even the north-eastern extension of the Natura 2000 site is now occupied by the species. It is anticipated that further increases in population are forthcoming (Jean-Yves Paquet, personal communication). Figure 8 illustrates the distribution of Red-backed Shrike pairs in 2023, a species that was virtually absent in the area three decades ago.

The population increase can be attributed in part to the progressive transformation of the landscape, facilitated by appropriate management practices. This transformation is evidenced by the increased length, continuity, and width of hedges, as well as the conversion of a growing number of pastures into haylands. In the case of the Eau Blanche area, it is believed that the nature reserve functions as a population source not solely because of its designation as a nature reserve, but rather due to the specific management practices implemented within these reserves that favor Red-backed Shrikes. These management efforts have created favorable conditions for the species, thereby contributing to its population growth.

Netherlands (Marijn Nijssen, Stichting Bargerveen, 2024)

The Bargerveen Foundation was established in December 1993 by the late Hans Esselink of the University of Groningen, with a primary focus on addressing a fundamental question: how did the population of the Red-backed Shrike in the Bargerveen experience a significant increase from the late 1980s onward, while the species vanished from the rest of the Netherlands? It was observed that the food supply for the species, including lizards, frogs, and large insects such as dragonflies, bumblebees, and grasshoppers, notably increased following rewetting measures that restored gradients in the peatlands, ranging from wet to dry, acidic to buffered, and nutrient-poor to nutrient-rich.

During the 1990s, the Red-backed Shrike population in Bargerveen declined again, primarily due to large-scale management efforts aimed at preventing peatland dehydration, which resulted in temporary habitat loss for the shrikes. At its lowest point just after the turn of the century, there were fewer than 100 breeding pairs in the Netherlands, half of which were in Bargerveen. The species appeared to be on the verge of disappearing from the country. However, from that juncture, the population in Bargerveen stabilized at around 50 breeding pairs, and small populations began to emerge in other areas of Drenthe, particularly in valleys and along the edges of peat bogs where nature restoration and optimization efforts were underway. Gradually, the species expanded further within the province, and there was also a noticeable increase in Limburg. Around 2015, it was estimated that there were approximately 200 breeding pairs in the Netherlands once again.

However, this increase did not occur uniformly. The long drought in the Horn of Africa in 2011 delayed the arrival of Red-backed Shrikes in breeding areas, and both 2011 and 2012 saw significant rainfall during the nesting period, resulting in low breeding success. This illustrated the species' sensitivity to weather extremes and the impact of climate change.

The majority of new settlements and expansions occurred in areas undergoing nature restoration and management, or where traditional landscape structures and farmland quality were restored. Examples include the De Maashorst area in North Brabant, the Fochteloërveen on the border of Friesland and Drenthe, and the arable areas around Muntendam in Groningen. These areas provided increased breeding opportunities and food supply, with slightly nutrient-rich conditions supporting significant insect biomass production while mitigating the acidifying effects of nitrogen deposition.

Since 2019, there has been an explosive increase in the Red-backed Shrike population in the Netherlands, attributed to a sequence of dry springs and summers, coupled with the expansion of suitable habitat through nature restoration and management. Research by Nijssen (2024) indicates higher numbers of fledglings and a greater proportion of first-year birds returning from Africa in subsequent years during this period. Between 2019 and 2023, the Dutch population more than doubled to over 700 breeding pairs.

The species in the Netherlands now appears to be out of the danger zone it faced at the end of the last century, thanks to significant habitat expansion, reducing dependence on a few vulnerable areas. Nature development and restoration, informed by research from the Bargerveen Foundation, have laid a solid foundation for the species' conservation. However, the future trajectory of the population remains uncertain. Continued warm and dry springs and early summers may lead to further population growth, while increased warm and wet weather due to advancing climate change could stabilize or even reverse population gains.

France (Raphaël Bussière, personal communication)

The population of Red-backed Shrikes in France is estimated to range between 100,000 and 200,000 pairs based on studies conducted between 2009 and 2012 (Caupenne et al., 2015; Bussière et al., 2022). The trend in the French population is characterized by fluctuations, as observed during the period from 2001 to 2012 (Caupenne et al., 2015). More recent data from Daviaud et al. (2023) focused on the former Poitou-Charentes region, comprising Charente (16), Charente-Maritime (17), Deux-Sèvres (79), and Vienne (86) departments, where the population ranged between 19,452 and 51,829 pairs, with an average of 29,882 pairs. The national population is classified as "near threatened (NT)" on the red list of threatened bird species in France (Colas et al., 2016), although there have been no updates to this classification since then.

The distribution of the Red-backed Shrike in France spans approximately two-thirds of the country. Significant increases have been noted in Northern France, particularly in Normandy (Deflandre, 2009), Picardy (Robert, 2020), Brittany (Couronné et al., 2017), Ille-et-Vilaine (Couronné et al., 2017), and Maine-et-Loire (Mourgaud and Logeais, 2012), with an extension of its distribution area. Additionally, Raphaël Bussière (personal communication) has monitored a population in Limousin, consisting of 41 to 67 breeding pairs within a 16 km² bocage sector, which has been increasing annually on average by 0.86 [95% CI: 0.21 - 1.52] from 2006 to 2023.

In other regions of France, the trends vary: the population in Haut-Rhin (Upper Doller valley) has remained stable (Ackermann, 2012), while in Haute-Savoie, there has been a slight decrease (Boisier, 2011), and in Alsace, a decline of 7% was observed over a period of 17 years (Muller, 2016).

Spain (Juan Carlos Tellería, personal communication)

In the Iberian Peninsula, the Red-backed Shrike maintains a significant presence across the northern half, primarily associated with the Eurosiberian region. Its distribution spans from the Pyrenees to the Cantabrian mountains, Galicia, Northern Portugal, and the northern part of the Iberian System, where its presence has been longstanding. However, the population of Red-backed Shrikes in Spain has experienced a notable decline over the last three decades, with a decrease of 54%, particularly evident in Northern Spain and Portugal. Nevertheless, this decline should not overshadow recent changes in its distribution area.

Similar to the colonization patterns observed in other species with a distinct Eurosiberian character, such as the Tree Pipit (Anthus trivialis), the Red-backed Shrike has expanded its range from populations in the northern Iberian System towards new favorable areas in the Central and southern Iberian Systems within the Mediterranean region. This expansion into previously unoccupied territories as summer breeding grounds was not observed until the late 20th century.

The primary factors contributing to the retraction of Red-backed Shrike populations in the north are attributed to the loss of optimal habitat and the accelerated decline in insect abundance across much of its range within the Eurosiberian region, including the Iberian Peninsula. These declines are primarily linked to agricultural intensification and land consolidation, as well as the widespread use of pesticides, resulting in the reduction of arthropod populations. Additionally, global-scale factors, such as climate change, may be altering productivity cycles in breeding areas within the Eurosiberian region, potentially driving the species towards mountain ranges, as observed in the

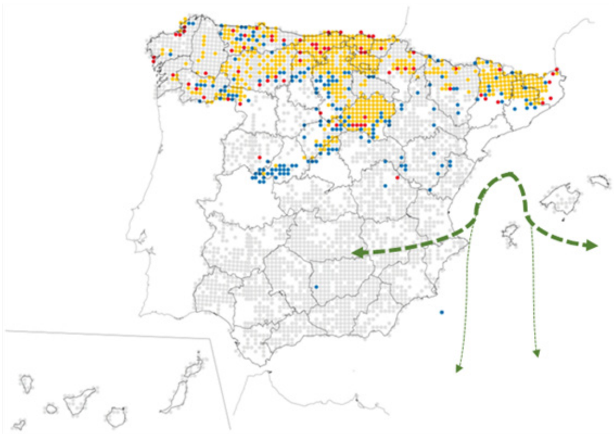

Figure 9. Biogeographic evolution of Red-backed Shrike in Spain during the last decades (Base map from III Atlas of birds during the breeding season in Spain. Moline et al. In SEO/BirdLife, 2022). Blue dots=New occupied grid cell; Yellow=re-occupied grid cell, Red= Abandoned grid cell.

central Iberian Peninsula. However, this trend requires further confirmation in other regions

The primary driver behind the new colonization of Central Iberia by the Red-backed Shrike is a combination of factors, including the favorable status of populations in the Iberian System at the distribution border, coupled with regional dynamics. In this context, the proximity of suitable habitat within approximately 80 kilometers, along with the absence of physical barriers, has facilitated the species' colonization of new territories, which may not necessarily be attributed solely to global warming.

However, climate change does play a role in affecting the retreat of mountain populations to the north of the Iberian Peninsula, particularly in the Spanish Eurosiberian area (Tellería, 2018). Similar to other species associated with mountain habitats, climate change leads to a reduction in habitat suitability and distribution range. Model projections indicate substantial contractions in the species' potential distribution, ranging from 89% to 92% between 2041 and 2070, with a significant decrease in the level of overlap between observed and potential distributions to a range of 6% to 10% during the same period (Araújo et al., 2011). Consequently, the conservation priorities for the Iberian Red-backed Shrike in the coming years should focus on gaining a better understanding of the retraction observed in the north and the expansion observed in Central Iberia.

EU assessments and Member States' data compiled as part of the Habitats Directive - Article 12 reporting process

Recently, detailed distribution and population estimates have been collected by the EU assessments conducted through Member States' data compiled as part of the Habitats Directive - Article 12 reporting process (European Environment Agency, 2021). These assessments covered the EU 27 for the period 2008-2012 and the EU28 for the period 2013-2018. Table 1 confirms countries where population increases have been documented. For instance, Belgium and the Netherlands exhibited both short and long-term increases in population numbers and distribution. Denmark witnessed a short and long-term expansion of distribution, while Finland, France, and Italy saw long-term distribution expansions. Additionally, Romania experienced a short-term population increase, and the Czech Republic observed a long-term increase.

It's worth noting that local positive trends may be obscured by the aggregation of data at the country or regional level. For example, monitoring in Grand Est, Eastern France (Lefranc, 2017) revealed a notable increase in the Villé valley. In 2014, Groscolas (2014, 2015 & 2016) identified 115 occupied territories, which increased to 174 in 2015, representing a 25% rise. Although there was a slight increase compared to 2015 in 2016, the factors believed to account for these variations include breeding success and habitat evolution. Despite the positive trend in the Villé valley, the overall trend in Alsace appears to be declining, as evidenced by a comparison of two surveys conducted 17 years apart (Müller 1998; Müller & Groscolas 2015). In 1998 and 2015, practically the same observers recorded the Red-backed Shrike in the same 30 communities, with numbers decreasing from 311 to 288 couples, indicating a 7% decline, despite 2015 being a favorable year. Similarly, in Alsace, census results as part of the monitoring of biodiversity indicators (SIBA) showed a drop from 209 territories in 2005 to only 169 in 2014, representing a 19% decrease (Müller, 2015). These local findings led to the classification of the species as vulnerable.

Discussion

The evolution in population numbers and distribution of the species can be attributed to several causes, including the impact of large-scale climatic changes on habitat selection and alterations in breeding biology induced by changes in local weather patterns during the breeding season, such as earlier arrivals and breeding, smaller clutch sizes due to adverse weather in May, among others. First, we will discuss the effects of large-scale changes in habitats, followed by an examination of changes in breeding biology parameters.

Shift to the North

On a broad continental scale, the breeding ranges of most bird species are primarily influenced by climate, either directly impacting the birds themselves or indirectly through its effects on habitat development and human land use patterns that favor specific species. By assessing the current climatic conditions within which each species resides in Europe (its 'climatic envelope') and predicting where those conditions may shift in the future, we can gain insights into potential future habitat distributions. Such predictions are valuable for speculation and conservation planning.

According to Huntley et al. (2007), by the end of the century, the breeding ranges of most species are expected to shift towards the north and northeast by approximately 500-1000 km. Models used for these predictions are calibrated with current distribution data and employ various climatic variables such as Mean Temperature of the Coldest Month (MTCO), degree days above 5°C (GDD5) representing overall warmth, and the Annual ratio of actual to potential evapotranspiration (AET/PET) as a measure of available moisture. These models take into account seasonal variations in precipitation supply and evaporative/transpirational demands, reflecting the moisture limitations experienced by organisms.

The Red-backed Shrike primarily breeds in regions where the annual temperature sum exceeds approximately 750 degree days above 5°C, the mean temperature of the coldest month is above approximately -17°C, and seasonal moisture deficit is not severe (AET/PET >= 0.6). It occurs less frequently in regions with lower temperature sums or severe moisture deficits. The upper limit of the coldest month mean temperature varies with temperature sum, ranging from approximately 7°C at 200 degree days to 4°C at 2000 degree days. The model developed by Huntley et al. (2007) demonstrates a very good fit (AUC= 0.982). For the Red-backed Shrike, the extent of its simulated potential future range compared to its present range is R=0.99, and the extent of overlap between its potential future and present distributions is O=0.81.

The model by Huntley et al. (2007) clearly indicates a northern shift in the Red-backed Shrike's range, except for the Iberian Peninsula, where a southern expansion was predicted, initially considered counterintuitive. However, subsequent observations have confirmed this predicted southward expansion, manifesting as colonization of central Iberia, as described by Telleria (2018), alongside a retreat to the north.

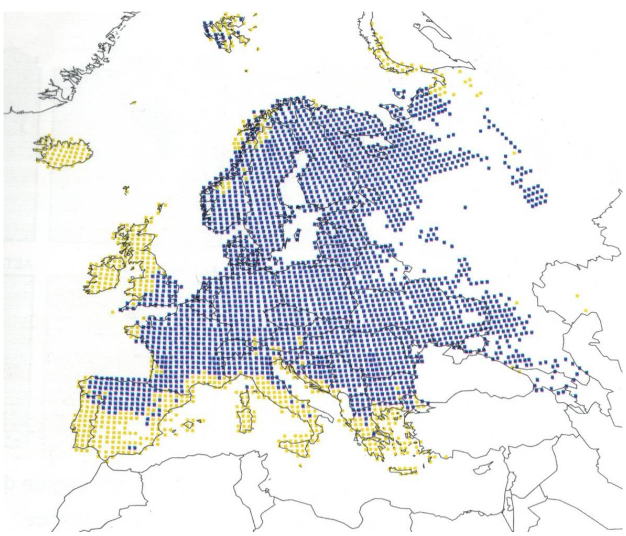

Figure 10. Potential late 21st century-distribution of Red-backed Shrike (after Huntley et al, 2007).

Agri-environmental schemes

Roilo et al. (2024) conducted a study to investigate the relationship between the occurrence probability of Red-backed Shrike in 2019 and the proportion of grassland-based agri-environmental schemes (AES), particularly examining whether this relationship differed between structurally simple and complex landscapes. They incorporated maximum temperature and the sum of mean monthly precipitation between May and July, sourced from the CHELSA Climatologies 1981-2010 V2.1 (Karger et al., 2020). The study compared three agricultural regions: Catalonia (Spain), Mulde River Basin (Germany), and South Morovia (Czech Republic), assessing their response to grassland-based agri-environmental management in relation to the probability of occupation by Red-backed Shrikes.

The effectiveness of AES was found to be higher in structurally simpler landscapes. Grassland, forest, AES, and the amount of small woody features (SHRUBS) were identified as significant positive predictors in all three regions. However, precipitation was only a relevant predictor in the German model, while maximum temperature was significant in the Czech model. The study suggests that the climatic impact on the probability of occupation is limited and may not be optimally modeled using aggregated climate data, especially considering the reliance on Red-backed Shrike data from 2019 alone, without considering the evolution of both dependent and independent variables over time.

Given that AES was not applied in the Gaume region and most of the positive population trends in neighboring regions are observed in managed nature reserves rather than agricultural areas, the authors do not consider AES as a relevant parameter for the current population fluctuations in Western Europe. This suggests that other factors, such as habitat management practices in nature reserves, may play a more significant role in influencing Red-backed Shrike populations in the region.

Changes in Breeding Biology

Metzmacher & Van Nieuwenhuyse (2012) found that a high minimum temperature during a large part of the breeding season is associated with an increase in the numbers of Red-backed Shrikes in the following year. They observed that temperature can influence various parameters of the nesting cycle and success, such as the timing of arrival, start of egg-laying, and brood success. For instance, warmer temperatures can lead to earlier returns and egg-laying, although this may negatively impact the success of the first clutches. However, in some areas, early nesting has been associated with larger clutch sizes, albeit with smaller eggs and lower fledging success.

In contrast, heavy rains have been linked to late returns and negative effects on clutch size, as well as potential abandonment of nests and decreased brood success (Lefranc, 1979, Hušek & Adamik, 2008). Moreover, continuous rain and low temperatures can result in nestling mortality due to cold exposure (Tryjanowski et al., 2000) and limit foraging trips by adult birds. These adverse weather conditions can also reduce the availability of food resources, leading to decreased breeding success and chick mortality (Müller et al., 2005, Antczak et al., 2009).

The abundance of large insects, such as Carabidae, is lower in drier environments, potentially affecting reproductive success. However, there may be a rainfall threshold below which reproductive success is penalized, highlighting the importance of habitats with sufficient moisture for breeding sites.

Overall, the links between local climate and annual fluctuations in Red-backed Shrike populations support the climatic hypothesis (Diehl & Myrcha, 1973), suggesting that a warming climate may have a beneficial effect on populations, provided it does not lead to excesses or deficits of rain (Avery & Krebs, 1984, Lehmann & Sommersberg, 1980). However, other factors such as habitat quality, land-use changes, and conditions in African stopover and wintering areas also play significant roles in population fluctuations

Heavy rains seem to determine the late returns of the Red-backed Shrike, such as those recorded in 2003 and 2005 in Marche-en-Famenne (van der Elst & Vieuxtemps, 2007). The state of the North Atlantic Oscillation (NAO), in February and March, on the other hand, does not seem to affect the chronology of the return (Hubálek, 2004). Showers or continuous rain can also soak the nests. When they contain nestlings, these nests are often abandoned, but replacement clutches are very common in the Red-backed Shrike (Lefranc, 1979; Antczak et al., 2009).

Heavy rains negatively influence clutch size in some females (Antczak et al., 2009). Furthermore, these bad weather conditions could cause a decrease in protein reserves in females. A fall in these reserves undoubtedly creates a stressful situation with an increased release of corticosterone. Via various mechanisms, this hormone can, for example, reduce the secretion of gonadotropin-releasing hormone (GnRH), at the level of the hypothalamus and, at that of the pituitary gland, the release of gonadotropins LH (luteinizing hormone) and FSH (folliculin) to ultimately inhibit the maturation of ovarian follicles (Sapolsky et al., 2000). In addition, these weather conditions can still affect the life expectancy of adults because, even under normal conditions, the reproduction has a cost.

The rainfall and the number of rainy days in May and June can also limit the brood success as was the case in northern Italy (Fornasari & Massa, 2000), in E Poland (Goławski, 2006) and locally in the Czech Republic (Hušek & Adamik, 2008). In the Swiss Alps between 1988 and 1992, on the other hand, Müller et al. (2005) did not detect any effect of climatic conditions on the reproductive performance of the species, but these conditions were perhaps not very rigorous during this study. Continuous rain, accompanied by low temperatures, can cause the death of nestlings due to cold, the birds no longer mobilizing their reserves quickly enough (Lefranc, 1979). Such conditions can also increase the length of trips linked to the foraging and reduce breeding success by limiting the accessibility or abundance of food resources (Hornman et al., 1998). It even happens that very large storms decimate certain populations of prey, like voles (Nesvadbova, 1992). Hence, climatic conditions of the breeding season in one year can affect the recruitment of breeders during the subsequent reproduction period (Olsson, 1995). Chick mortality would constitute the most negative effect on the viability of Red-backed Shrike populations (Takács et al., 2004).

The abundance of large insects such as *Carabidae*, for example, is lower in drier environments (Williams et al., 2008). If the abundance of rain limits reproductive success of the species, there could also be a rainfall threshold below which this success is penalized. It is undoubtedly no coincidence that the species prefers, as a breeding site, habitats with a certain degree of humidity (Titeux et al., 2007). The species is also less common in regions where moisture deficit is severe (Huntley et al., 2007). Overall, the links between local climate and annual fluctuations in Red-backed Shrike population numbers support the climatic hypothesis (Lefranc, 1979) and its variant, that of tap-hypothesis of Saether et al., 2004). These links also suggest that warming climate can have a beneficial effect on its populations, provided that it does not lead to excesses or deficits of rain. It could also encourage the extension towards the northern part of its range, as suggested by the simulation of its potential distribution future (Huntley et al., 2007). But, if climatic factors can influence the phenology and the reproductive success of the Red-backed Shrike, other variables such as the quality of habitat are likely to also modulate the size of its numbers and their geographical distribution.

Reasons for the population fluctuations might also be conditions in African stopover and wintering areas (Schaub et al, 2011, Tøttrup et al, 2011) and land-use changes, abandonment as well as intensification on the breeding grounds (Brambilla et al, 2010). The expected intensification of agricultural land use in E Europe countries will probably lead to loss and fragmentation of habitat and decline of food availability for this species of small-scale landscapes as happened in W Europe in the 20th century and possibly lead to a significant population decline in the future.

Land-use changes, including abandonment and intensification of agricultural practices, particularly in Eastern Europe, may lead to habitat loss, fragmentation, and decline in food availability, potentially resulting in a significant population decline in the future. Therefore, understanding the complex interplay between climate, habitat, and land-use changes is crucial for effective conservation management of Red-backed Shrike populations.

Immigration or local recruitment versus sources and sinks

The data collection focusing solely on population numbers without considering other demographic parameters such as breeding success, mortality, immigration, or emigration makes it challenging to determine the drivers behind population increases. The observed 53% increase in population numbers between 2022 and 2023 suggests that immigration may be a significant factor contributing to population growth, especially considering the lack of detailed breeding biology data in agricultural research areas.

Research by Schaub, Jakober & Stauber (2013) analyzed the dynamics of a Red-backed Shrike population in Germany over 36 years and found that immigration played a crucial role in preventing a strong decline in population size. Without immigration, the population would have decreased considerably, highlighting the importance of immigration for maintaining population numbers. Furthermore, they found that immigration was the primary driver for the number of females, while local recruitment played a key role in the number of males.

To better understand the relative importance of different demographic parameters and the colonization processes of newly occupied habitats, there is a need for research comparing breeding performance between habitats in agricultural areas and nature reserves. This research, similar to that conducted by Bloche et al. (2023), could elucidate whether population increases are driven by local recruitment, immigration, or a combination of both, in conjunction with habitat quality.

Understanding colonization processes and identifying source and sink habitats can inform conservation management strategies in nature reserves and agricultural areas. Implementing shrike-specific management practices in habitats with high potential for colonization could attract and support colonizing birds, potentially mitigating population declines in sink areas. Promising results from shrike-specific management experiments in Belgium and the Netherlands suggest that targeted management efforts within nature reserves and agricultural habitats could benefit Red-backed Shrike populations and facilitate their colonization towards the north (Nijssen, 2024, Nijs, 2020).

Conclusion

The spectacular population increases observed in the agricultural area of Gaume, despite negative landscape evolution due to intensification and land-reallotment schemes, align with the predicted northward shift of Red-backed Shrikes as indicated by climatic evolutionary models. This counterintuitive trend suggests that local climatic influences may be playing a significant role in driving population dynamics.

Interestingly, the impact of grassland agri-environmental schemes (AES) does not seem to have any effect on the Red-backed Shrike population in the Gaume region, nor in neighboring areas where similar population increases were primarily observed in nature reserves with shrike-specific management rather than agricultural areas. This discrepancy suggests that other factors, such as habitat quality and management practices specific to nature reserves, may be more influential in driving population growth in these regions.

The observation of population increases in agricultural areas despite landscape degradation highlights the complexity of species responses to environmental changes and underscores the importance of considering multiple factors, including climate, habitat quality, and management practices, in conservation planning and management efforts. Further research into the specific mechanisms driving population increases in both agricultural and nature reserve habitats could provide valuable insights for effective conservation strategies tailored to different landscapes and ecosystems.

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