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RESEARCH ARTICLE

# Changes in land-cover within high nature value farmlands inside and outside Natura 2000 sites in Europe: A preliminary assessment

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**Abstract** Low-intensity agriculture is important for the conservation of many European habitats and species. However, biodiverse farmlands—also referred to as high nature value (HNV) farmlands—are threatened by years of agricultural intensification and land abandonment. Considering the ongoing changes in land-cover—evident throughout Europe—it is important to assess how land transformation is affecting HNV farmlands. Here, we evaluate land-cover changes within HNV farmlands during 2006–2018. We find that HNV farmlands inside Natura 2000 sites are less likely than those outside to be converted to artificial surfaces and more likely to maintain mosaic farming. However, land transformation patterns vary between member states, suggesting that different processes are driving the land-cover changes within each state. We recommend that member states support HNV farmers by making a more effective use of the Common Agricultural Policy (CAP) and that the EU prioritizes the protection of HNV farmlands during its next CAP reform post-2020.

**Keywords** Biodiverse farmlands · Common Agricultural Policy · European Union · Landscape change · Low-intensity agriculture · Natura 2000

## INTRODUCTION

European landscapes have been shaped by centuries of anthropogenic activities, especially farming (Pe'er et al. 2014). Currently, farmlands cover approximately half of Europe's land area (Stoate et al. 2009; Lomba et al. 2015). While large-scale, intensive agriculture is known to have negative effects on biodiversity (Henle et al. 2008; Stoate et al. 2009; Lomba et al. 2017), many European habitats and species depend on low-intensity agriculture for their persistence (Plieninger and Bieling 2013; Aue et al. 2014; Lomba et al. 2014; Pe'er et al. 2014). For instance, Halada et al. (2011) report that 63 of the 231 habitats of European importance—listed in the European Union's Habitats Directive (92/43/EEC)—depend either fully or partially on low-intensity agriculture. Moreover, other studies have shown that numerous species of flora and fauna, e.g., farmland birds (Donald et al. 2006; Reif and Vermouzek 2019), also rely on low-intensity agriculture (Donald et al. 2006; Stoate et al. 2009; Morelli 2018).

The realization that low-intensity farming can be beneficial to the conservation of European habitats and species has led in the early 1990s to the development of the term "high nature value (HNV) farmlands" (Baldock et al. 1994; Andersen et al. 2003). HNV farmlands are defined as "areas in Europe where agriculture is a major (usually the dominant) land use and where that agriculture supports, or is associated with, either a high species and habitat diversity or the presence of species of European conservation concern, or both" (Andersen et al. 2003; Lomba et al. 2014). There are three types of HNV farmlands: (1) low-intensity farmlands with high proportion of natural cover; (2) low-intensity farmlands with natural structural elements, which are beneficial to biodiversity (e.g., dry-stone walls and hedgerows); (3) farmlands that support rare species or high percentages of European and global species (Andersen et al. 2003; Schwaiger et al. 2012; Campedelli et al. 2018).

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However, despite the acknowledged conservation importance of HNV farmlands, they are still highly threatened (Plieninger and Bieling 2013), primarily by two processes: (1) the abandonment of agricultural land, and (2) the expansion of intensive agriculture (e.g., through the increased use of agrochemicals and machinery and through the removal of non-productive landscape features, such as hedgerows) (Stoate et al. 2009; Pe'er et al. 2014; Strohbach et al. 2015). Both processes have been attributed, at least partly, to the European Union's Common Agricultural Policy (CAP), which was initiated in 1962 (Stoate et al. 2009) with the aim of increasing agricultural productivity and providing financial stability to farmers (Beaufoy and Marsden 2014; Reif and Vermouzek 2019). CAP consists of two pillars; the first pillar concerns mostly the direct payments made to the farmers in the form of income support (Pe'er et al. 2019), while the second pillar concerns the EU's Rural Development Programme (RDP). According to many experts, CAP has been encouraging the intensification of agriculture because the majority of the funds were allocated—through the direct payments scheme—to farmers practicing large-scale, high-intensity farming (Marković et al. 2012; Navarro and López-Bao 2019). Consequently, smaller and less productive farms were either abandoned or intensified, often with detrimental effects on the environment (Pe'er et al. 2014). Recognizing this problem, the EU has reformed CAP repeatedly (Matthews 2013; Pe'er et al. 2017) in an effort to encourage more sustainable agricultural practices (Pe'er et al. 2019). Currently, in order for the framers to be eligible for CAP support they must comply with basic environmental and health standards (enforced under the cross-compliance scheme). In addition, during the latest CAP reform in 2013, the European Commission introduced three "greening measures"—under pillar 1—that aim at supporting: (1) crop diversification, (2) existing permanent grasslands, and (3) ecological focus areas in arable lands (Pe'er et al. 2017). These greening measures, which are mandatory for the member states (although their application is flexible), require that 30% of each member state's income support budget is linked to those three targets. Moreover, farmlands located in low-productivity areas facing natural or other specific constraints (ANCs)—i.e., many of the areas in which HNV farmlands are found (Gouriveau et al. 2019; Lomba et al. 2020)—are eligible for an additional support of up to 5% of the national budget (although the implementation of this measure is voluntary). Additionally, the agri-environment-climate measures (AECMs) —under pillar 2—are designed to compensate farmers for income forgone due to eco-friendly agricultural practices. Yet, despite these positive reforms (Gouriveau et al. 2019), low-intensity farmlands in Europe continue to be lost (Lomba et al. 2015), jeopardizing the EU's conservation efforts (Keenleyside et al. 2014; Ribeiro et al. 2014).

Attempts to mitigate the loss have been also hindered by insufficient information regarding the changes in land-cover within HNV farmlands (Keenleyside et al. 2014). Although EU member states are required to monitor changes within HNV farmlands—as described in the Common Monitoring and Evaluation Framework of the rural development policy of CAP (Strohbach et al. 2015; Lomba et al. 2017; Mäkeläinen et al. 2019)—currently, there is no commonly accepted or uniformly applied method to implement this requirement (Lomba et al. 2017; Mäkeläinen et al. 2019). Consequently—while multiple studies reiterate that European HNV farmlands are being lost (Keenleyside et al. 2014)—basic information regarding these losses is still lacking. For instance, it is still unclear: (1) how much HNV farmland is being lost across the EU, (2) which processes are mostly driving the loss (i.e., intensification vs. abandonment), and (3) whether the patterns vary across member states. Moreover, although Europe is home to the largest network of protected areas—known as Natura 2000 (Zisenis 2017; Müller et al. 2018)—no study has yet explored the role of Natura 2000 sites in safeguarding HNV farmlands. The Natura 2000 network, designated under the Habitats and the Birds Directives (92/43/EEC and 2009/147/EC, respectively), represents the EU's most important conservation strategy for protecting its habitats and species (European Environment Agency 2019), including the many that depend on agriculture (Halada et al. 2011). Currently, the network includes more than 27 800 sites and it covers approximately 18% of the EU's terrestrial area (European Environment Agency 2019). While each member state is responsible for designating and managing its own sites, member states must also comply with the requirements delineated in the articles of the two directives (e.g., regarding enforcement and monitoring). Although previous research has documented that landscapes within Natura 2000 sites tend to undergo less transformation (Kallimanis et al. 2015; Hermoso et al. 2018), more than 20% of the land within Natura 2000 sites has been affected during the last two decades by changes in land-cover, many of which were due to processes related to naturalization and anthropization (Hermoso et al. 2018). Consequently, the role of the Natura 2000 network in protecting HNV farmlands remains unclear. These fundamental knowledge gaps limit our understanding regarding how European HNV farmlands are being affected by land transformation and how to best protect them.

The gaps persist because of the lack of a comprehensive dataset documenting the extent and the distribution of HNV farmlands across Europe. The development of such dataset has been hindered by several challenges (Keenleyside et al. 2014; Strohbach et al. 2015) and it remains an active research topic (Lomba et al. 2017). Researchers have proposed a range of mapping approaches, which mostly involve the integration of high-resolution land-cover data and data on biodiversity and agriculture (Lomba et al. 2014, 2015, 2017; Zomeni et al. 2018; Maskell et al. 2019). Although several of the proposed methods appear promising (Lomba et al. 2014, 2017), currently the produced maps cover only small parts of Europe (Lomba et al. 2014; Campedelli et al. 2018; Zomeni et al. 2018; Maskell et al. 2019). Yet, some of the most pressing questions regarding HNV farmlands—such as those outlined above—need to be answered at the European level. At that level there is principally only one related dataset, made available by the European Environment Agency (Paracchini et al. 2008; Schwaiger et al. 2012). It is based on data such as the CORINE Land Cover map (a pan-European land-cover map; Copernicus Land Monitoring Service, 2018), the distribution of biodiversity and indicator species within Europe, and farming statistics (Strohbach et al. 2015), and is essentially an estimate of the spatial distribution of HVN farmlands within Europe (but not necessarily their true extent; Paracchini et al. 2008; Schwaiger et al. 2012).

Considering the importance of HNV farmlands (Martino and Muenzel 2018), the immediate threats they face (Plieninger and Bieling 2013; Keenleyside et al. 2014; Strohbach et al. 2015; Ribeiro et al. 2018), and the lack of basic information regarding their loss at the EU level, it is important that we use the best available data to assess how changes in land-cover—prevalent throughout Europe (Feranec et al. 2010; Kallimanis et al. 2015; Hermoso et al. 2018)—affect the conservation of HNV farmlands. This is a timely topic to study because currently the European Commission is in the process of discussing and negotiating the next reform of the Common Agricultural Policy post-2020 (Navarro and López-Bao 2019); hence, our findings could make a useful contribution to that process. Here, we use the map by Schwaiger et al. (2012) to answer—even if it is at preliminary level—some of the unexplored key questions regarding the HNV farmlands within Europe. In particular, we answer the following four questions: (1) What percentage of HNV farmlands within the EU has undergone changes in land-cover during the recent years? (2) Do patterns in land-cover change within HNV farmlands vary across the EU member states? (3) Are HNV farmlands within Natura 2000 sites in the EU less likely to undergo changes in land-cover? (4) Are there differences in the types of land-cover change occurring in HNV farmlands inside vs. outside Natura 2000 sites?

## MATERIALS AND METHODS

### Data on HNV farmlands

We first downloaded the map on the distribution of HNV farmlands within Europe, made available by the European Environment Agency (2015). The map was first prepared by Andersen et al. (2003) and was later enhanced by Paracchini et al. (2008) who added more data and improved the methodology. In 2012, Schwaiger et al. expanded the map to cover more countries and to incorporate the most up to date information. The methods used to prepare the map—described in detail in the reports above—can be summarized as follows: first, researchers used the CORINE Land Cover (CLC) map to locate all agricultural land within Europe. The CLC map is a European wide project, through which land-cover across 39 European countries is mapped every 6 years (Copernicus Land Monitoring Service 2018). CLC distinguishes between 44 land-cover classes (Copernicus Land Monitoring Service 2018; Table S1). The most recent version of the HNV farmlands map is based on the CLC map of 2006, which Schwaiger et al. (2012) used to locate agricultural classes, plus other classes relevant to HNV farmlands, such as “natural grasslands” and “peat bogs”. Then, using the most recent spatial information on the distribution of biodiversity within Europe—particularly the information from the Natura 2000 database, the Important Bird Areas, the Prime Butterfly Areas, and when available and necessary the National Biodiversity datasets—Schwaiger et al. (2012) estimated the potential spatial distribution of HVN farmlands within Europe at a resolution of 1 $km^2$, which is also the resolution of our analysis (Fig. 1).

It must be clarified here that there are limitations associated with the specific map (Paracchini et al. 2008; Schwaiger et al. 2012; Lomba et al. 2014). Although the resolution of the CLC map is 100 m, its smallest mapping unit is 25 ha (Copernicus Land Monitoring Service 2018) making it difficult to capture effectively smaller HNV farmlands that are interspersed within other land-cover types. Likewise, smaller landscape features, such as drystone walls and hedgerows, which are important attributes of HNV farmlands—especially Type II HNV farmlands—are also difficult to capture. Hence, as Schwaiger et al. (2012) explain the map should be mainly considered a reflection of the large parcels of Type I and Type III HNV farmlands across Europe (and to a lesser degree of Type II). Moreover, some of the information used to develop the map was available for some areas but not others; for instance, priority habitats within the EU—listed in the Habitats Directive—are only mapped within the Natura 2000 sites. Finally, some of CLC land-cover classes do not distinguish between varying levels of anthropogenic intensification,

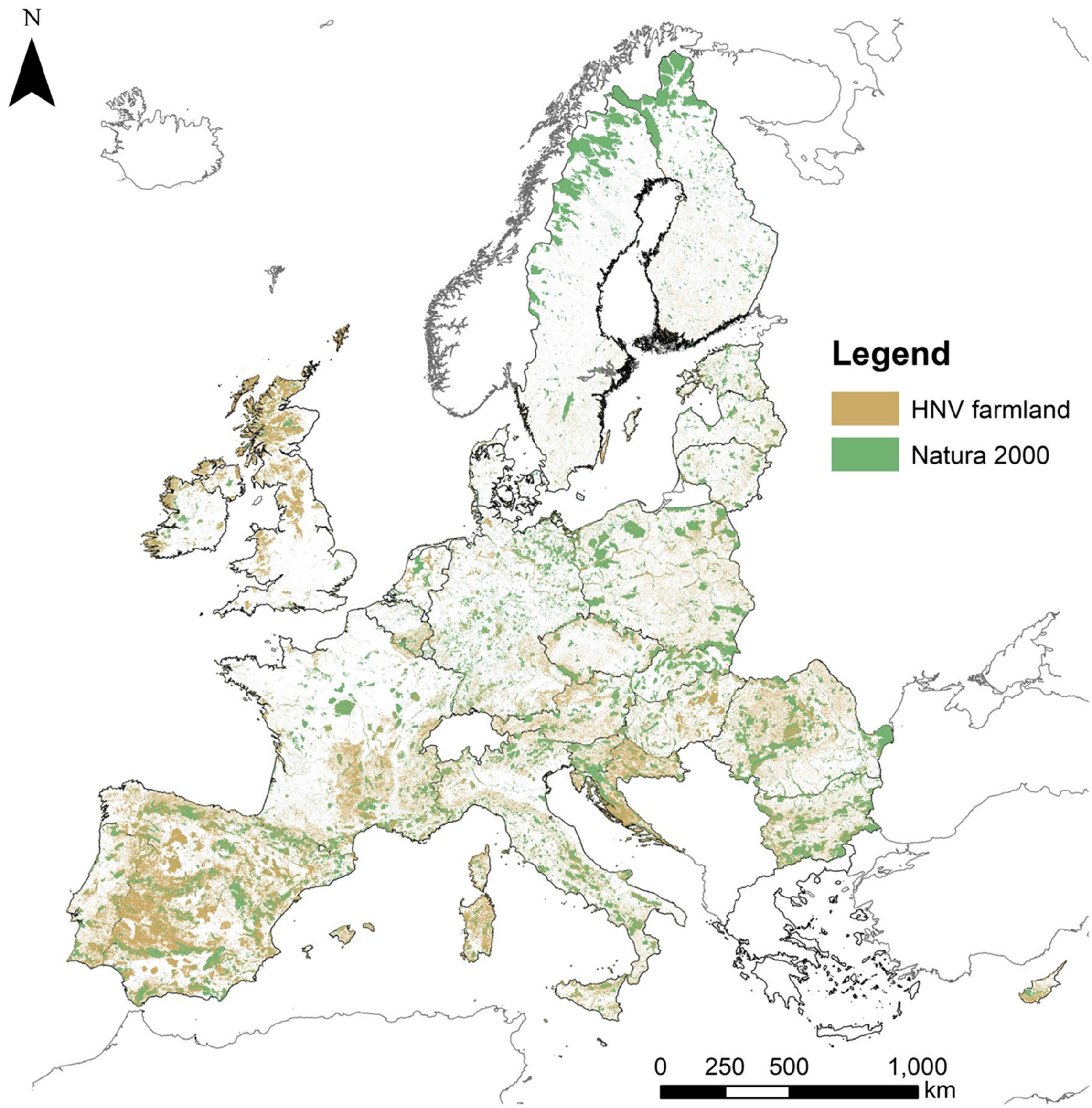


**Fig. 1** The distribution of HNV farmlands—inside and outside the Natura 2000 network—within the 27 EU member states included in the analysis

which can be important for the classification of HNV farmlands (Paracchini et al. 2008; Schwaiger et al. 2012). Therefore, although the map is not suitable for small-scale analyses (Schwaiger et al. 2012; Lomba et al. 2014; Strohbach et al. 2015), it is useful for deciphering important patterns at the European level (Schwaiger et al. 2012).

### Measuring the land-cover change patterns within HNV farmlands

In addition to each new CORINE Land Cover map released every 6 years, the EEA also releases maps that depict the interim land-cover change. The minimum mapping unit for these CLC change maps is 5 ha. The two most recent maps (Copernicus Land Monitoring Service 2018) depict the changes in land-cover across Europe since 2006, i.e., the year on which the map of the HNV farmlands is based. Specifically, the two CLC change maps depict the changes in land-cover during 2006–2012 and 2012–2018 (Copernicus Land Monitoring Service 2018). Hence, we quantified land transformation within HNV farmlands in each EU member state using these two maps. We excluded Greece from the analysis because the corresponding data on HNV farmlands were incomplete, showing only the northern regions of the country (Schwaiger et al. 2012; European Environment Agency 2015). For each of the remaining member states ($n$ = 27), we recorded (a) the total area (in $km^2$) of HNV farmlands transformed between 2006–2012 and 2012–2018, (b) the original CLC class at the beginning of each time period, (c) the transformed CLC class at the end of the period, and (d) whether the transformation occurred within a Natura 2000 site or outside (Fig. 2). Moreover, since it is possible that any differences found may be due not to the protection status but rather the fact that protected areas tend to be situated non-randomly in regions less suitable for other human uses (Joppa and Pfaff 2011), we also recorded whether the land transformation occurred outside Natura 2000 sites but within a buffer of 5 km around each site (Fig. 2; Hermoso et al. 2018). The rationale being that areas adjacent to Natura 2000 sites (i.e., $\leq$ 5 km) hold many of the same characteristics in terms of isolation and landscape composition (Hermoso et al. 2018) but lack the protection status and therefore can be potentially used as a control. To identify the boundaries of each Natura 2000 site, we used the most recent version of the Natura 2000 database (European Environment Agency 2018). We decided not exclude any sites based on their year of establishment for the following two reasons: (a) only a small proportion of the sites were established after 2006 and 2012 (< 10% and 5%, respectively), and (b) Natura 2000 sites are oftentimes protected at the national level long before they are officially listed as Natura 2000 sites, a process that can be sometimes lengthy.

To evaluate the extent of land transformation, we followed the method of Hermoso et al. (2018) and grouped the CLC classes into the following nine categories: (1) artificial surfaces, (2) arable land, (3) pastures, (4) mosaic farming, (5) standing forest, (6) natural grassland, heathland, shrubs, (7) transitional woodland and shrubs, (8) open areas, and (9) water (Table S1 lists all CLC classes assigned to each category). The last category—although not included in the classification scheme of Hermoso et al. (2018)—was added because our dataset included areas converted from/to wetlands and other water bodies (e.g., peat bogs). For each member state, we first measured the extent of land transformed between 2006–2012 and 2012–2018, and then created a transition matrix (Pontius et al. 2004) for each of the two time periods, showing how much area was converted from one land-cover category to another (Pontius et al. 2004; Hermoso et al. 2018). For each of the nine land-cover categories, we calculated the net increase or decrease during each period examined (Hermoso et al. 2018), by subtracting from the area that each land-cover category occupied at the end of the period the area that it occupied at the beginning. A positive number indicated a net increase in total area, while a negative number a decrease. Since the total land area of each member state varies, we converted the areas transformed within each state into percentages to make land-cover changes comparable.

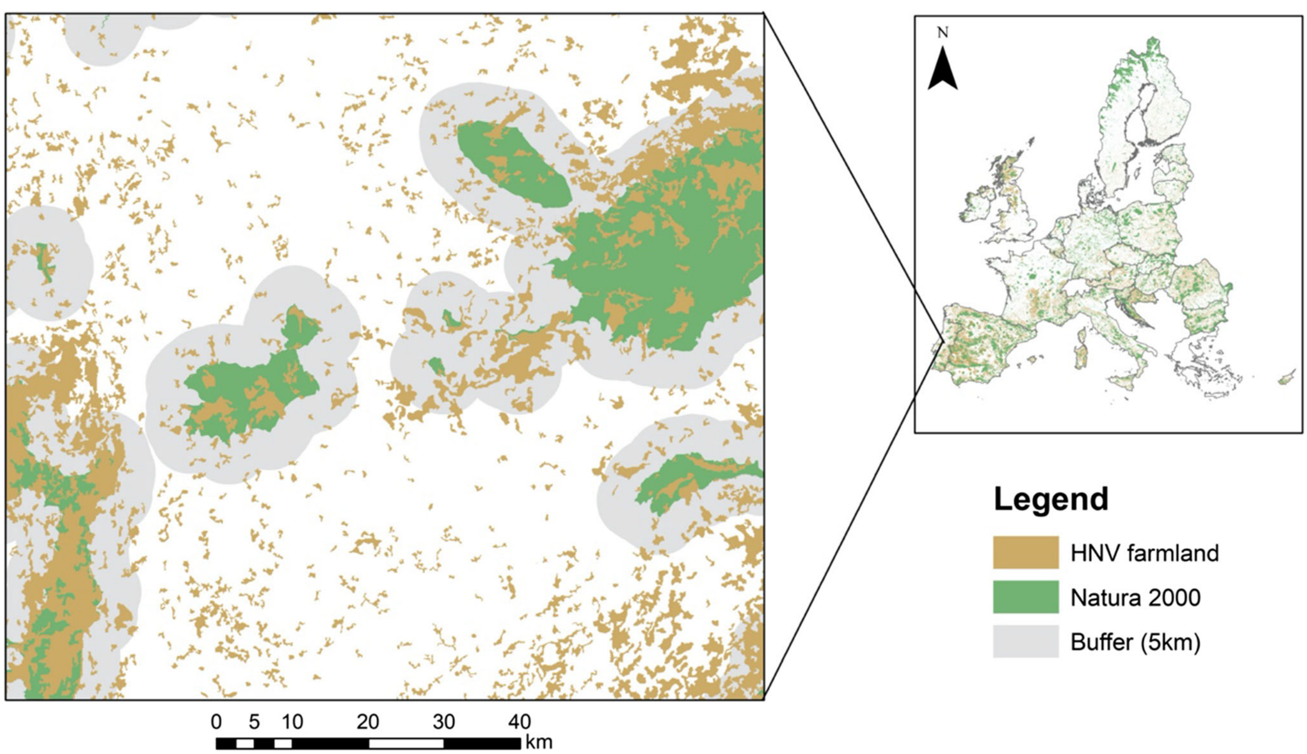


**Fig. 2** An example of the sampling design used to measure land-cover changes within HNV farmlands inside, outside, and within a 5 km buffer of Natura 2000 sites

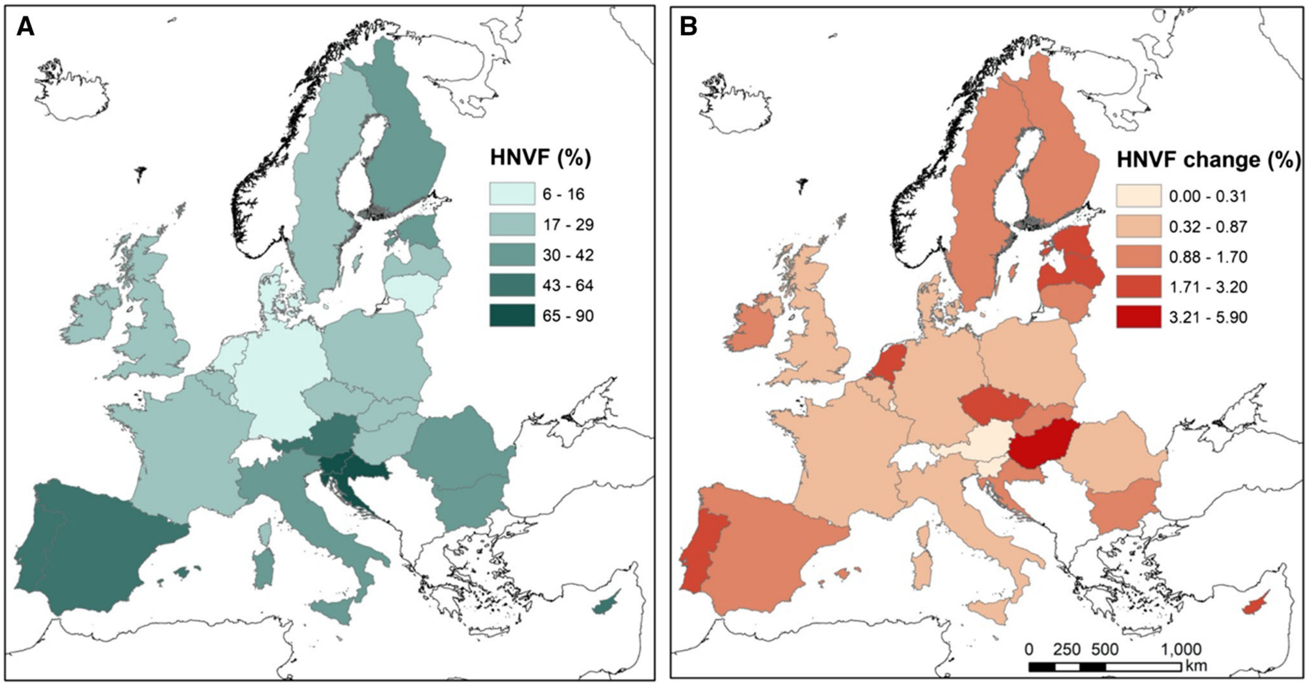


**Fig. 3** Map showing the percentage of HNV farmland within each member state relatively to its total agricultural land (A) and the total percentage of HNV farmland transformed during 2006–2018 (B)

### Statistical analyses

We first assessed whether the patterns in land transformation varied between the two periods examined by running a Mantel's correlation test using the transition matrices at the EU level (Table S2). We then assessed whether HNV farmlands inside protected areas underwent lower rates of transformation compared to (a) areas outside, and (b) areas within the 5 km buffer. To achieve this, we measured the total percentage of HNV farmland transformed within each member state and each type of area (i.e., Natura 2000 sites, outside, and buffer) and compared those percentages using paired t-tests. We repeated the process for each of the nine land-cover categories and the two time periods separately. When running the t-tests, we made multiple comparisons (i.e., inside vs. outside, inside vs. buffer, and buffer vs. outside) and therefore we adjusted p-values using the Bonferroni correction. Each time our sample size equaled the number of the member states ($n = 27$). Lastly, to assess whether HNV farmlands within Natura 2000 sites were more likely to be converted than the remaining land within the sites, we compared the corresponding percentages, for each time period separately, also using paired t-tests. All spatial analyses were conducted using ArcMap (version 10.2) and statistical analyses using the R statistical software (R Core Team 2018). In Table S2, we provide a step-by-step workflow of the analytical approach followed.

## RESULTS

The percentage of HVN farmland relative to the total agricultural area varied markedly among member states (Fig. 3A), ranging from 6% in Denmark and Malta (Table 1) to 90% in Croatia (mean = 33%, sd = 21%). In absolute numbers, Spain had the largest area of HNV farmlands (188 177 km$^2$), followed by France (80 134 km$^2$) and Italy (61 693 km$^2$). The percentage of HVN farmland within Natura 2000 sites also varied (Table 1), ranging from 2% in Finland to 100% in Malta (mean = 35%, sd = 21%). There was also variation in the percentage of farmland transformed within each member state (Fig. 3B), but the patterns were consistent across the two time periods (Table 1). Malta, for example, had none of its area within HNV farmlands transformed between 2006–2012 and 2006–2018 (Table 1). Hungary, by contrast, experienced the highest rates of transformation among all member states, during both time periods (Table 1). In total, 5.9% of Hungary's HNV farmland was transformed during the twelve-year period examined (Fig. 3). The corresponding mean value for all 27 member states was 1.4% (sd = 1.2%).

**Table 1** Total area of high nature value farmlands (HNVF), within each member state, along with the percentage it corresponds relative to each member state's total agricultural land. Also shown, the percentages of HNVF in Natura 2000 sites and HNVF transformed between the years 2006–2012 and 2012–2018

| EU member state | Total HNVF (km$^2$) | Total HNVF (%) | HNVF in Natura 2000 (%) | HNVF transformed 2006–2012 (%) | HNVF transformed 2012–2018 (%) | HNVF transformed total (%) |
|---|---|---|---|---|---|---|
| AT | 21 407 | 64 | 14 | 0.09 | 0.12 | 0.21 |
| BE | 4351 | 24 | 21 | 0.26 | 0.25 | 0.47 |
| BG | 25 776 | 38 | 44 | 0.41 | 0.87 | 1.26 |
| CY | 3431 | 55 | 16 | 1.08 | 1.40 | 2.04 |
| CZ | 11 904 | 26 | 23 | 1.71 | 0.73 | 2.41 |
| DE | 32 513 | 15 | 33 | 0.53 | 0.14 | 0.66 |
| DK | 1896 | 6 | 76 | 0.39 | 0.08 | 0.46 |
| EE | 5308 | 33 | 28 | 1.44 | 1.12 | 2.47 |
| ES | 188 177 | 56 | 35 | 0.80 | 0.57 | 1.32 |
| FI | 12 690 | 42 | 2 | 0.75 | 0.61 | 1.31 |
| FR | 80 134 | 23 | 28 | 0.30 | 0.28 | 0.55 |
| HR | 29 492 | 90 | 34 | 0.57 | 1.18 | 1.66 |
| HU | 19 352 | 29 | 53 | 3.89 | 2.27 | 5.90 |
| IE | 11 503 | 20 | 46 | 0.46 | 1.34 | 1.70 |
| IT | 61 693 | 34 | 27 | 0.29 | 0.51 | 0.72 |
| LT | 6405 | 16 | 21 | 0.72 | 0.69 | 1.39 |
| LU | 137 | 10 | 78 | 0.15 | 0.18 | 0.31 |
| LV | 5694 | 20 | 29 | 0.73 | 1.37 | 2.09 |
| MT | 10 | 6 | 100 | 0.00 | 0.00 | 0.00 |
| NL | 3905 | 15 | 37 | 1.31 | 0.70 | 1.94 |
| PL | 44 885 | 23 | 29 | 0.50 | 0.43 | 0.87 |
| PT | 28 524 | 58 | 34 | 1.30 | 2.11 | 3.20 |
| RO | 52 211 | 36 | 27 | 0.18 | 0.49 | 0.67 |
| SE | 11 661 | 27 | 10 | 0.63 | 0.57 | 1.18 |
| SI | 5703 | 76 | 31 | 0.02 | 0.11 | 0.13 |
| SK | 4798 | 20 | 38 | 0.61 | 0.71 | 1.29 |
| UK | 53 667 | 28 | 29 | 0.22 | 0.34 | 0.53 |

*AT* Austria, *BE* Belgium, *BG* Bulgaria, *CY* Cyprus, *CZ* Czech Republic, *DE* Germany, *DK* Denmark, *EE* Estonia, *ES* Spain, *FI* Finland, *FR* France, *HR* Croatia, *HU* Hungary, *IE* Ireland, *IT* Italy, *LT* Lithuania, *LU* Luxembourg, *LV* Latvia, *MT* Malta, *NL* Netherlands, *PL* Poland, *PT* Portugal, *RO* Romania, *SE* Sweden, *SI* Slovenia, *SK* Slovakia, *UK* United Kingdom

### Land-cover change patterns within HNV farmlands across the EU

At the EU level, much of the transformation within HNV farmlands during 2006–2012 was to artificial surfaces, which increased in area by 721 km$^2$ (Tables 2 and 3), followed by transformation to standing forests (628 km$^2$; Table 3). Artificial surfaces essentially represent built-up areas and infrastructure, such as road and rail networks (Copernicus Land Monitoring Service 2018). Pastures and natural grasslands, heath lands and shrubs saw the largest declines in area (− 684 km$^2$ and − 539 km$^2$, respectively; Table 3). These two land-cover categories also saw the largest declines in area during 2012–2018 (− 576 km$^2$ and − 756 km$^2$, respectively; Table 3). However, during this period most of the transformation within HNV farmlands was to arable land (534 km$^2$) and open areas (513 km$^2$). Open areas represent non-vegetated or sparsely vegetated areas, including bare rocks, burnt areas, beaches and dunes, and areas covered with perpetual snow and ice (Copernicus Land Monitoring Service 2018). Artificial surfaces and forests also increased during 2012–2018 (358 km$^2$ and 289 km$^2$, respectively; Table 3), as they did in 2006–2012. Overall, land transformation patterns (Table 2) were—for the most part—consistent across the two time periods, as indicated by the Mantel test and the large correlation value between the two transition matrices (r = 0.98, $p$ value $< 0.001$).

**Table 2** Transition matrices used in the analyses, showing land-cover change (in $km^2$), at the EU level, during the years 2006–2012 and 2012–2018

| | Land-cover in 2012 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ARA | ARTF | FOR | GRSH | MOS | OPEN | PAS | TRW | WATER |
| Land-cover in 2006 | | | | | | | | | |
| ARA | 358 | 165 | 4 | 12 | 130 | 1 | 223 | 85 | 26 |
| ARTF | 2 | 72 | 0 | 5 | 0 | 0 | 9 | 2 | 4 |
| FOR | 12 | 15 | 0 | 7 | 1 | 18 | 2 | 211 | 3 |
| GRSH | 82 | 165 | 10 | 37 | 25 | 241 | 16 | 152 | 37 |
| MOS | 63 | 137 | 8 | 16 | 11 | 3 | 4 | 106 | 18 |
| OPEN | 0 | 1 | 0 | 125 | 0 | 8 | 3 | 35 | 2 |
| PAS | 468 | 229 | 1 | 18 | 22 | 1 | 0 | 160 | 52 |
| TRW | 19 | 21 | 872 | 5 | 6 | 47 | 9 | 0 | 8 |
| WATER | 0 | 12 | 0 | 0 | 2 | 0 | 3 | 23 | 10 |

| | Land-cover in 2018 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ARA | ARTF | FOR | GRSH | MOS | OPEN | PAS | TRW | WATER |
| Land-cover in 2012 | | | | | | | | | |
| ARA | 501 | 67 | 4 | 22 | 11 | 2 | 82 | 41 | 18 |
| ARTF | 7 | 119 | 0 | 6 | 1 | 1 | 26 | 2 | 12 |
| FOR | 24 | 9 | 0 | 3 | 4 | 33 | 4 | 407 | 1 |
| GRSH | 146 | 94 | 16 | 62 | 13 | 470 | 47 | 130 | 11 |
| MOS | 53 | 56 | 8 | 2 | 5 | 13 | 7 | 56 | 15 |
| OPEN | 3 | 1 | 2 | 118 | 0 | 8 | 0 | 39 | 3 |
| PAS | 499 | 135 | 7 | 6 | 15 | 1 | 0 | 72 | 31 |
| TRW | 40 | 17 | 737 | 14 | 7 | 109 | 17 | 0 | 7 |
| ARA | 9 | 34 | 0 | 0 | 1 | 51 | 7 | 7 | 10 |

*ARA* arable land, *ARTF* artificial surfaces, *FOR* standing forest, *GRSH* natural grassland, heathland, shrubs, *MOS* mosaic farming, *OPEN* open areas, *PAS* pastures, *TRW* transitional woodland and shrubs, *WATER* wetlands and waterbodies

## Land-cover change patterns in HNV farmlands within the member states

At the member state level, the percentage of HNV farmlands converted from one land-category to another varied substantially (Tables S3 and S4). In Slovenia, for example, most of the land within HNV farmlands was transformed from mosaic farming to artificial surfaces. In Italy, however, most of the land was transformed from natural grasslands, heath lands and shrubs to artificial surfaces and open areas. In Latvia, by contrast, very little land within HNV farmlands was converted to artificial surfaces; most of the land was transformed from pastures and mosaic forests to transitional woodlands and arable land. The land transformation patterns within the member states were highly consistent across the two time periods (Tables S2 and S4).

On average, HNV farmlands comprised 28% of the land within Natura 2000 sites (sd = 16%). HNV farmlands within Natura 2000 sites were less likely to be transformed

**Table 3** Total area occupied by each land-cover category in 2006, along with the net change between the years 2006–2012 and 2012–2018

| Land-cover category | Total area in 2006 ($km^2$) | Percentage of total HNV farmland in 2006 | Net change 2006–2012 ($km^2$) | Net change 2012–2018 ($km^2$) |
|---|---|---|---|---|
| ARA | 90 395 | 12.4 | 0 | 534 |
| ARTF | 6733 | 0.9 | 721 | 358 |
| FOR | 26 998 | 3.7 | 628 | 289 |
| GRSH | 176 883 | 24.3 | − 539 | − 756 |
| MOS | 208 107 | 28.6 | − 169 | − 158 |
| OPEN | 5439 | 0.7 | 145 | 513 |
| PAS | 149 205 | 20.5 | − 684 | − 576 |
| TRW | 26 733 | 3.7 | − 212 | − 193 |
| WATER | 36 732 | 5.1 | 110 | − 10 |

*ARA* arable land, *ARTF* artificial surfaces, *FOR* standing forest, *GRSH* natural grassland, heathland, shrubs, *MOS* mosaic farming, *OPEN* open areas, *PAS* pastures, *TRW* transitional woodland and shrubs, *WATER* wetlands and waterbodies compared to the rest of the land within the sites ($t_{2006–2012}$ (26) = − 2.69, $p = 0.012$; $t_{2012–2018}$ (26) = − 2.87, $p = 0.008$). Moreover, HNV farmlands within Natura 2000 sites experienced a slightly lower percentage of land transformation on average when compared to HNV farmlands outside (0.57% vs. 0.67% in 2006–2012 and 0.58% vs. 0.66% in 2012–2018). The difference, though, was only statistically significant for the first time period ($t_{2006–2012}$ (26) = − 2.25, $p = 0.033$). However, despite the similarities in the levels of land transformation within HNV farmlands inside and outside Natura 2000 sites, there were important differences in terms of the types of land transformation, which were consistent across both two time periods. HNV farmlands inside Natura 2000 sites were less likely to be converted to artificial surfaces ($t_{2006–2012}$ (26) = 4.99, $p < 0.001$; $t_{2012–2018}$ (26) = 3.48, $p = 0.005$) and more likely to maintain mosaic farming ($t_{2006–2012}$ (26) = − 2.72, $p = 0.034$; $t_{2012–2018}$ (26) = − 3.76, $p = 0.003$). The same patterns were found when farmlands within Natura 2000 sites were compared to those within the 5 km buffer outside of Natura 2000 sites. Farmlands within the buffer were more likely than farmlands in Natura 2000 to be converted into artificial surfaces ($t_{2006–2012}$ (26) = 5.19, $p < 0.001$; $t_{2012–2018}$ (26) = 3.30, $p = 0.008$) and more likely to lose their mosaic farming ($t_{2006–2012}$ (26) = − 2.68, $p = 0.038$; $t_{2012–2018}$ (26) = − 3.56, $p = 0.004$). There was no statistically significant difference between the farmlands outside Natura 2000 sites and the farmlands within the 5 km buffer. There were also no statistically significant differences between any of the other comparisons we made, for any of the other seven land-cover categories (i.e., inside vs. outside, inside vs. buffer, and buffer vs. outside). The only exception was between HNV farmlands within Natura 2000 sites vs. farmlands within the buffer that were transformed to open areas. Farmlands within Natura 2000 sites were less likely to be transformed to open areas; however, this comparison was only statistically significant for the second time period ($t_{2012–2018}$ (26) = − 2.77, $p = 0.031$).

## DISCUSSION

### The role of Natura 2000 sites in protecting HNV farmlands

Our results show that the percentage of land transformed within HNV farmlands in Natura 2000 sites was slightly lower than of those outside; however, the difference was only statistically significant for one of the two periods examined. Hermoso et al. (2018) found that landscapes within Natura 2000 sites are generally more stable; our results and the results of Lomba et al. (2020)—who assessed the changes within HNV farmlands inside and outside Natura 2000 sites in a region in Portugal—suggest that this may not apply to the same extent to HNV farmlands. However, HNV farmlands within Natura 2000 sites may indeed benefit from the protection status, since they are less likely to be converted into artificial surfaces—a pattern also observed by Kallimanis et al. (2015)—and more likely to maintain their mosaic farming, even when compared to adjacent areas (i.e., ≤ 5 km away). By contrast, all other land transformations were equally prevalent in all HNV farmlands (i.e., both inside and outside Natura 2000 sites), and this pattern explains why countries such as Ireland and Belgium, which had relatively large proportions of HNV farmlands within Natura 2000 sites, also had relatively large percentages of land-cover changes within HNV farmlands (Table 1).

### Land-cover change patterns within HNV farmlands across the EU

Overall, the transformation of transitional woodland and shrubs into standing forests was the most extensive transformation in HNV farmlands across the EU, during both time periods (Table 2), suggesting that abandonment of agricultural land is indeed a widespread issue for HNV farmlands (Gouriveau et al. 2019). Succession processes leading to naturalization are usually a positive change. However, in the case of HNV farmlands, high rates of afforestation, due to land abandonment, can impact biodiversity negatively (Doxa et al. 2012)—particularly species that depend on agricultural landscapes (Halada et al. 2011; Morelli 2018)—and especially when afforestation is combined with losses of other important land-cover categories (Keenleyside et al. 2014). For instance, the extent of pastures within HNV farmlands was also reduced during both time periods, with the majority of the converted pastures transformed into arable land (68% and 87% in 2006–2012 and 2012–2018, respectively). According to Feranec et al. (2010), such transformations indicate agricultural intensification. Most of the remaining of the converted pastures were transformed to artificial surfaces. Natural grasslands, heath lands and shrubs—another important land-cover category for biodiversity—were also reduced (Table 2). They were mainly converted to (1) open areas, i.e., non-vegetated or sparsely vegetated areas (45% and 62% in 2006–2012 and 2012–2018, respectively); (2) artificial surfaces (30% and 12%); and (3) transitional woodland and shrubs (28% and 17%), which according to the patterns we report in this study, could soon transform into forest. It is worth noting here that the overall net increase of artificial surfaces within HNV farmlands was also considerable (Tables 1 and 2). Although much of it could be due to transformation of abandoned agricultural land, it is possible that some of it was due to urban encroachment and expansion of human settlements into functioning HNV farmlands, a possibility that has received much less attention in the literature and based on our results is worth exploring further.

### Land-cover change patterns in HNV farmlands within the member states

The land transformation patterns varied considerably between the member states, both in terms of the total area of land transformed (Table 1), as well as the area transformed into each of the land-cover categories (Tables S2 and S4). For instance, in Hungary—the member state with the highest percentage of transformation (5.9%)—land was mostly converted from transitional woodlands and shrubs to forests. Very little of Hungary's land within HNV farmlands was converted to artificial surfaces and almost all of its mosaic farming remained intact. In Austria, by contrast, where only 0.21% of the farmlands underwent transformation, most of it was to artificial surfaces and some to transitional woodlands. It is clear that the variation in land transformation patterns between the member states reflects different drivers of land-cover change and consequently require different strategies to address them (Reif and Vermouzek 2019). This finding is not surprising, since land transformation patterns, in general, are driven by country-specific factors, such as economic development level, emphasis on different economic sectors, and time of accession to the EU (Kallimanis et al. 2015). Reif and Vermouzek (2019), who studied the agricultural production within the Czech Republic before and after its accession in the EU in 2004, concluded that agriculture has intensified significantly following accession, mainly because of CAP. Indeed, our analysis shows that much of the increase in arable land within HNV farmlands—between the years 2006 and 2018—has happened mainly in the member states that joined the EU around that time, e.g., in the Czech Republic and in Latvia (which joined in 2004) and in Bulgaria (which joined in 2007) (Tables S2 and S3).

Although the overall percentage of HNV farmlands experiencing land transformation, within each member state, may appear small (e.g., mean = 1.4%), it must be noted that the available CLC change maps only include areas larger than 5 ha (Copernicus Land Monitoring Service 2018). Smaller areas that are also likely to be important for biodiversity, especially for sensitive species, are not captured. Consequently, our results are only a conservative estimate of the real processes on the ground. Also, our analysis covers a relatively short period of time, i.e., 12 years, for which data are available. Hermoso et al. (2018), who looked at land-cover changes across the entire EU, over a period of 20 years, have found that the total percentage of area transformed inside Natura 2000 sites could be as high as 20% and 50% outside (although much of it was due to changes in forested areas rather than agricultural land). It will be interesting to explore further the trends regarding HNV farmlands when the next CLC change maps are released. Nevertheless, the comparisons made here, based on the two periods currently available, suggest that the land transformation patterns within HNV farmlands are consistent over time.

### Actions to be taken to protect HNV farmlands

Considering our findings, we suggest that, wherever possible, member states take the necessary actions to incorporate their most biodiverse HNV farmlands into Natura 2000 sites—assuming that the farmlands are not negatively impacted by any land-use restrictions associated with the management of those Natura 2000 sites. Currently, the majority of the HNV farmlands within the European Union are located outside Natura 2000 sites (mean = 65%, sd = 21%); incorporating HNV farmlands within protected areas is likely to help prevent further human encroachment (e.g., conversion to artificial surfaces) and agricultural intensification. That said, we acknowledge that implementing such measures can be difficult (Psaralexi et al. 2017) because they are often hindered by the conflicting interests of the stakeholders. Moreover, considering that Natura 2000 sites cover already on average about a fifth of the member states' land (European Environment Agency 2019), we recognize that the majority of the HNV farmlands within Europe will remain outside protected areas. Consequently, it is imperative that members states make better use of the available CAP measures, such as those associated with the areas facing natural or other specific constraints (ANCs) and the agri-environment-climate measures (AECMs), in pillars 1 and 2 respectively, to encourage and support farmers in maintaining HNV farmlands (Gouriveau et al. 2019).

Although the measures associated with ANCs do not specifically target HNV farmlands, many of HNV farmlands are located in such areas (Gouriveau et al. 2019) and thus these voluntary payments could be used by member states to support HNV farming (Keenleyside et al. 2014). Similarly, the agri-environment-climate measures—which are part of the EU's Rural Development Policy (RDP)—could be also used to compensate at least to some extent farmers for losses associated with the retainment of non-productive landscape features, such as buffer strips (Pe'er et al. 2019), which are nonetheless beneficial to biodiversity. That said, it must be noted that the funds available for the second pillar of CAP, and specifically the AECMs, are substantially lower to the funds available for the first pillar (Pe'er et al. 2019), which absorbs approximately three-quarters of the total budget. Hence, as other experts have mentioned, to properly support HNV farming, it is crucial that the full gamut of the available tools in both pillars are used (Keenleyside et al. 2014; Pe'er et al. 2019). Following the latest CAP reforms, the first pillar now includes "greening measures", which aim to promote sustainable agriculture; they require member states to spend 30% of their monetary allocations to payments associated with specific environmental measures (Massot 2019). In particular, the greening measures encourage the diversification of crops, the maintenance of existing grasslands, and the maintenance of "ecological focus areas" in arable farmlands (Massot 2019). Member states should take advantage of these measures, to redirect some of the CAP payments to farmers who engage in HNV farming (Keenleyside et al. 2014). To achieve this, however, member states must place a higher emphasis on the conservation importance of HNV farmlands and must eliminate the bureaucratic hurdles preventing HNV farmers from receiving adequate support (Keenleyside et al. 2014; Gouriveau et al. 2019). For example, Keenleyside et al. (2014) explain that in some cases member states tend to interpret CAP legislation (and the corresponding guidance from the European Commission) in an overly restrictive manner, and consequently large parcels of HNV farmlands are ineligible for CAP funding.

Any positive actions from the individual member states, alone, are unlikely to provide a comprehensive solution to the loss of HNV farmlands within the EU. In conjunction with the member states' efforts, the EU must take advantage of the current discussions and negotiations regarding the next CAP reform post-2020 to improve the policy further by integrating better its agricultural and conservation goals (European Commission 2011; Navarro and López-Bao 2018; Pe'er et al. 2019)—including the conservation of HNV farmlands (Navarro and López-Bao 2018; Pe'er et al. 2019). For instance, currently, key European habitats—which are listed in the Annex I of the Habitats Directive (92/43/EEC) and depend on livestock grazing for their persistence (Halada et al. 2011)—are not eligible for CAP support because they are not considered agricultural land (Keenleyside et al. 2014). However, this creates a conflict between the EU's Common Agricultural Policy and Biodiversity Strategy. In their recent policy paper, Gouriveau et al. (2019) explain that the proposed CAP reforms for post-2020 appear to be placing greater emphasis on minimizing the impacts of intensive agriculture rather than on supporting the existing HNV farmlands, which cover on average more than 30% of the EU's agricultural land (Table 1)—and are essential to the conservation of its biodiversity. To address this shortcoming, Gouriveau et al. (2019) propose a series of rectifying measures, which other researchers have highlighted also (Navarro and López-Bao 2018), such as (a) the adjustment of the direct payments in pillar 1—in order to reduce the bias that favors intensive farmlands, e.g., due to the criteria set based on the farmland size—and (b) the increase of the budget available for pillar 2 (Gouriveau et al. 2019), which currently represents less than one-third of the total CAP budget.

Some caveats to consider when interpreting the results of our study. The analysis represents mainly a preliminary assessment, which must be repeated as more detailed maps of HNV farmlands within Europe become available (Keenleyside et al. 2014). Although the map used for the analysis is based on a substantial amount of data (Paracchini et al. 2008; Schwaiger et al. 2012), uncertainties remain due to the limitations mentioned in the previous sections. For example, information was not consistently available for all areas (Schwaiger et al. 2012). Moreover, the map is based on only a few indicator taxa, e.g., birds (Schwaiger et al. 2012), which traditionally have received more attention (Campedelli et al. 2018; Maskell et al. 2019). This latter issue, though, is not specific to the particular map, but rather a widespread pattern (Mammides 2019), which unfortunately will affect most of the future mapping efforts. In any case, as more data become available, the map of HNV farmlands within Europe must be updated to improve its accuracy and utility (Keenleyside et al. 2014). Simultaneously, additional regional maps could be developed (Benedetti 2017; Lomba et al. 2017; Zomeni et al. 2018), which could be used to improve the implementation of CAP and the conservation of HNV farmlands (Lomba et al. 2017; Zomeni et al. 2018). Attention must be paid, though, to standardize the methods used to create these smaller-scale maps. Understandably, at this preliminary and experimental stage, the employed methods vary, making the available maps incompatible and hence unsuitable for assessing patterns at larger scales.

## CONCLUSIONS

A growing body of literature suggests that HNV farmlands in Europe are under threat (Lomba et al. 2015; Zomeni et al. 2018; Lomba et al. 2020). Our results confirm that European HNV farmlands are being lost to multiple process, which tend to vary across member states. Although HNV farmlands inside and outside Natura 2000 sites are equally likely to be transformed, it appears that HNV farmlands within Natura 2000 sites are less likely to be converted to artificial areas and more likely to maintain mosaic farming, two patterns important for conserving biodiversity. Therefore, member states should consider including their most biodiverse farmlands within their network of protected areas. Moreover, member states should make a more effective use of the measures available through the Common Agricultural Policy (Matthews 2013; Pe'er et al. 2017), in order to provide farmers with stronger incentives to protect HNV farmlands (Keenleyside et al. 2014). At the same time, the EU must take advantage of the current opportunity to reform the Common Agricultural Policy post-2020 (Navarro and López-Bao 2018; Pe'er et al. 2019) to ensure that the farmers who engage in HNV farming receive sufficient support (Gouriveau et al. 2019). The EU has missed its 2020 target to halt biodiversity loss (Mammides 2019) and it is unlikely that it will achieve its next target without effectively addressing the threats to HNV farmlands, which are essential to the conservation of many of the EU's habitats and species (Baldock et al. 1993; Keenleyside et al. 2014; Ribeiro et al. 2018; Pe'er et al. 2019).

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