Identification and mapping the high nature value farmland by the comparison of a combined and species approaches in Tuscany, Italy

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Abstract

Low-intensity farming systems play a crucial role in nature conservation by preserving 50% of habitats, flora and fauna occurring in Europe. For this reason the identification, classification and mapping of high nature value farmlands (HNVfs) is becoming an overriding concern. In this study, two different approaches, namely combined approach and species-based approach, were used to spatially identify HNVfs (type 1, 2 and 3) across Tuscany region (Italy). The first approach calculated different indicators (extensive practices indicator, crop diversity indicator, landscape element indicator) at 1×1 km grid cell spatial resolution using pre-existent spatial datasets integrated within a global information system environment. Whilst, the species-based approach relied on a pre-existent regional naturalistic inventory. All indicators and the resulting HNVfs derived from the two approaches were aggregated at municipality level. Despite some difference, the two adopted approaches intercepted spatially the same HNVfs areas, accounting for 35% of the total utilised agricultural area of the region. Just 16% of HNVfs resulted located inside protected areas, thus under current conservation and protection management actions. Finally, HNVfs of the Tuscany region were spatially aggregated in four relevant agro-ecosystems by taking into consideration the cropping systems and the landscape elements' characteristics peculiar in the region.

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Key words: High nature value farmlands, extensive agriculture; farmland habitat; extensive practices indicators; landscape element indicators; species and habitat indicators.

Funding: this study was conducted as part of the research project HNVf, funded by ISPRA, Italy.

Acknowledgements: the authors wish to thank Vanna Forconi for her help in the preparation of the manual *Agricultural Areas of high natural value (HNVf): from identification to management. Manuals and guidelines: 62/2010, Ed. © ISPRA, MLG ISBN 978-88-448-0455-8.*

Conference presentation: SIA XLIII Congress, Pisa, 2014.

Received for publication: 1 April 2015.
Accepted for publication: 13 June 2015.

Italian Journal of Agronomy 2015; 10:676
doi:10.4081/ija.2015.676

Introduction

Approximately 45% of the European Union territory consists of agricultural landscapes (Henle *et al*., 2008), which encompass a set of combination of factors such as soils and orographic conditions, water availability and different intensity levels of farming and farm activities. Such combinations are responsible for the establishment and the existence of an array of ecological conditions and biodiversity (Pain and Pienkowski, 1997).

Over the centuries, the rapid and profound evolution of agriculture has reduced the naturalness of the Europe's primordial environment. Nevertheless, the emergence of both semi-natural habitats and a new diversity of flora and fauna depend upon the presence of farming landscapes (Kristensen, 2003; Beaufoy and Cooper, 2009), whose mosaic-like distribution in the territory provides a high variety of habitats that in turn guarantees a great biodiversity (Cooper *et al*., 2009). Kristensen (2003) argues nearly all our cultural landscapes arose from agricultural practices and 50 % of all species in Europe depend on agricultural habitats.

Since the early 90s, the concept of high nature value farming (HNVfs) has been framed to meet the growing recognition that in Europe the several habitats and species related to farming systems preserve high nature conservation value, which can be protected only by farmers and their farming practices (Cooper *et al*., 2009). Various authors relate to the emergence of the HNV to farming systems *low intensity*, namely systems with low use of agricultural external inputs and thus low yielding (Baldock *et al*., 1993; Beaufoy *et al*., 1994). Andersen and colleagues (2003) argue that the HNV farmlands are those 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. It is widely recognised that low-intensity farming systems play a crucial role in nature conservation by preserving those habitats, flora and fauna that they themselves have contributed to create. Thus, in order to maintain low-intensity farming systems, the identification, classification and mapping of the HNV farmland becomes an overriding concern. Indeed, the HNVf can serve as a model for the management of sustainable land use practices and therefore be a response to the conflict between intensification and biodiversity in agricultural areas (Bignal and McCracken, 2000).

Several authors focused on the identification and mapping of HNVf, using different data types and applying different methodological approaches. A detailed review on the methodological approaches for the identification and mapping the European HNV was done by Lomba and colleagues (2014).

Interesting is the Porter's experience (2008), who identified HNV areas in England by implementing a species-based approach with regard to birds and butterflies occurrences. Similarly, Klimek *et al.* (2014) identified priority areas for the conservation of farmland biodiversity at national level by modelling both the spatial distribution of both plant species (*i.e.*, species-rich farmland) and landscape elements (*e.g.*, hedgerows, ditches and scrubs). At European level, several authors (Pointereau *et al.*, 2007; Samoy *et al.*, 2007; Paracchini *et al.*, 2008) adopted combined approach that foresee the use of different data types such as land cover, farming systems and protected/sensitive areas (Lomba *et al.*, 2014). In order to develop an EU agri-environment indicator on HNV farmland, information on the distribution pattern of HNV farmland retrieved from the land cover data were combined with farm system data that provide information about types and characteristics of farms (EEA, 2004). Moreover, regardless the approach adopted, indicators are defined and calculated to identify the three types of HNVf as defined by Andresen *et al.* (2003), namely: farmland with a high proportion of semi-natural vegetation (type 1); farmland with mosaic of habitats and/or land uses (type 2); farmland supporting rare species of a high proportion of European or World populations (type 3) (Andersen *et al.*, 2003; IEEP, 2007a, 2007b). The objectives of the present study were: i) to present a revised methodology for the identification of the HNVf at regional scale in Tuscany (Italy) comparing two different approaches: combined and species-based approaches; ii) to present and discuss the spatial identification of HNVf (type 1, 2 and 3) resulting from the two approaches; iii) to show agro-ecosystems and habitats identified within those areas of high nature value.

Materials and methods

Scheme of analysis

In this work, two different revised approaches were used to identify HNVf (types 1, 2 and 3) at regional scale, namely a combined approach (Samoy *et al.*, 2007; Paracchini *et al.*, 2008) and a species-based approach (Porter, 2008). For the first approach, three indicators were calculated, namely extensive practices indicators (EPI), crop diversity indicator (CDI) and landscape element indicator (LEI). To this end, information from land cover, landscape elements, regional agriculture statistics were collected and spatially homogenised. Spatial information deriving from regional inventories on species and habitat of conservation interest was used to calculated HNVf according to the species-based approach (Figure 1). For each HNV areas resulting from

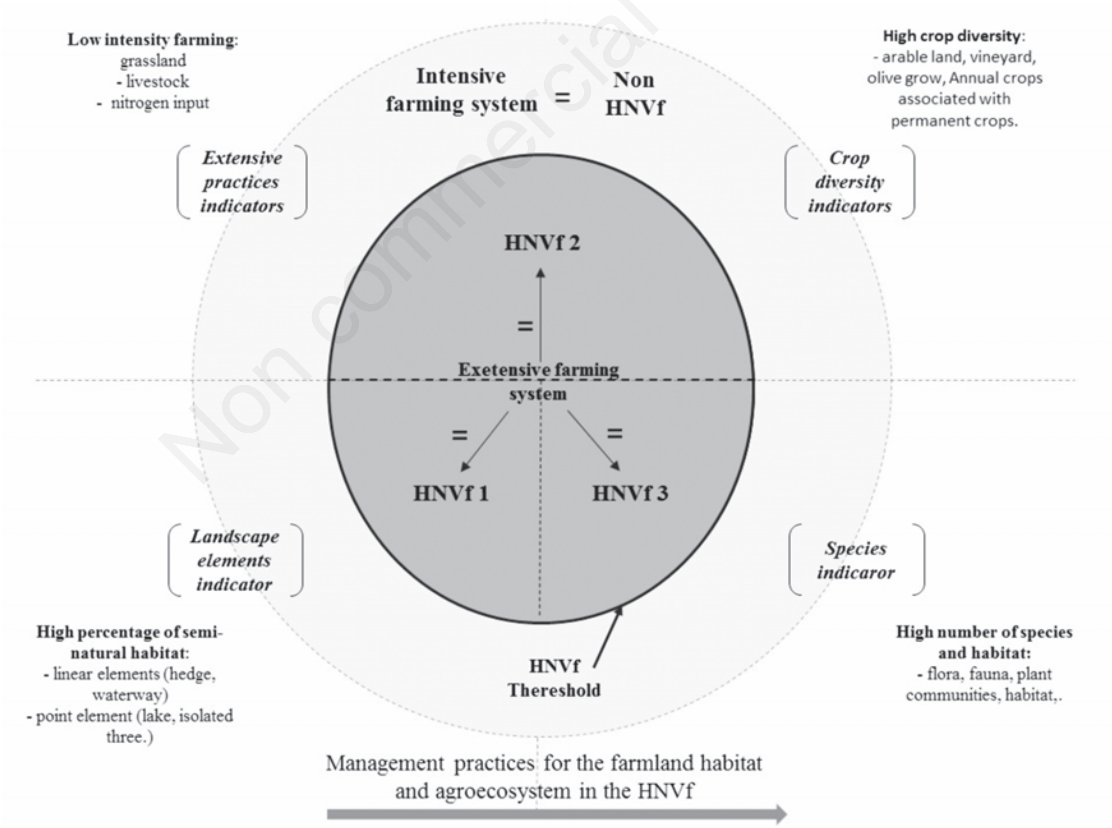

Figure 1. Scheme of analysis used for the identification of high nature value farmland (HNVf) in Tuscany, as proposed by Andersen *et al.* (2003). Three types of HNVfs are identified according to a combined and species approaches. HNVf1 comprehends farmlands with a high proportion of associated semi-natural vegetation; HNVf2 comprises farmlands with low-intensity management and high crop diversity; HNVf3 includes farmlands with rare species or high proportion of European/World populations. HNVf1 is expressed by landscape elements indicator, HNVf2 derives from the combination of crop diversity and extensive practices indicators, HNVf3 is expressed by species indicator.

the two approaches, relevant agro-ecosystems and farmland habitats were identified heuristically and described. The definition of agro-ecosystems was based on different cropping systems and landscape elements characteristics across the region, as proposed by Pointereau *et al*. (2007). Moreover, different farmland habitats were identified heuristically according to their relevance within each agro-ecosystems. For each farmland habitats, feasible management practices for the improvement of the agro-biodiversity were also proposed.

Combined approach

Data source and data integration

In order to spatially identify relevant agriculture areas were HNVf may be expected, the utilised agriculture area (cUAA) and the utilised forage area (cUFA) were retrieved extracting the corresponding codes from Corine land cover map (CLC) for the year 2006 (Büttner and Kosztra, 2007), namely codes 211, 213, 221, 222, 223, 231, 241, 242, 243, 244 for cUAA and codes 321 for cUFA, respectively. Polygons extracted from CLC map were used to calculate both EPI and CDI.

Information to determine relevant landscape elements, considered indicative for calculating LEI, were extracted from the topographic cartography of Tuscany region, which is provided in a multi-layers vector format at 1:10,000 spatial resolution. From this cartography, layers corresponding to fragmented trees (code 704), to wetlands, such as marshes ponds and lakes (code 306), to canals and waterways (codes 301, 302 and 303), to hedges (code 504) and to stone walls (code 503) were extracted and merged.

Statistical data on UAA, UFA as well as on livestock were retrieved from the agriculture statistics (ISTAT, 2010), which is available at municipality level.

Within GIS environment (ESRI-ArcGIS 10.0 and QuantumGIS 2.2), polygons of CLC codes referred to agricultural areas and natural grasslands were firstly extracted and then overlaid to the layer representing the administrative boundaries of Tuscany municipalities. In parallel, layers referred to landscape elements, deriving from the regional cartography, were merged with each other, and the resulting single polygon layer was then overlaid to the administrative boundaries of Tuscan municipalities. Finally, both two datasets were spatially integrated onto one single spatial layer, which was afterwards intersected into a fishnet of quadratic cells vector layer with 1×1 km spatial resolution, in order to create a final spatial dataset (FSD) of the study area (Figure 2). The surface/length of each CLC codes and landscape elements were calculated for each fishnet quadratic cell of FSD, in order to calculate the HNVf indicators.

Moreover, given the spatial resolution mismatch between agriculture statistical data (municipality level; ISTAT, 2010) and CLC2006 data (maximum resolution 25 ha), a correction factor was calculated according to a regression between cUAA (aggregated at municipality level) and UAA (ISTAT, 2010). The linear predictor function coefficient ($y=0.7354*x$; $r^2=0.96$; $P<0.001$) resulting from the regression analysis indicated the cUAA was overestimated with respect to UAA (ISTAT, 2010). The relevant correction factor was then applied to each polygon of the 1×1 km grid cell dataset in order to determine a eUAA. Similarly, UFA was grid-cell rescaled on the basis of the linear predictor function coefficient ($y=0.259*x$; $r^2=0.67$; $P<0.001$) resulting from the regression analysis between cUFA (deriving from the overall surface of CLC codes 231, 321, 242, 243, aggregated at municipality level) and UFA (ISTAT, 2010). A eUFA was calculated at grid cell level.

Indicators

Three indicators were calculated for estimating HNV areas at 1×1 km spatial resolution, namely: i) CDI; ii) EPI; and LEI indicators.

Crop diversity

Crop diversity was calculated using Shannon index (Shannon and Weaver, 1963), applied to the different classes of CLC (Farina, 1993; O'Neil, 1998):

$$CD = -\sum_{1}^{n}\left(Pc * \log_{n} Pc\right) \quad (1)$$

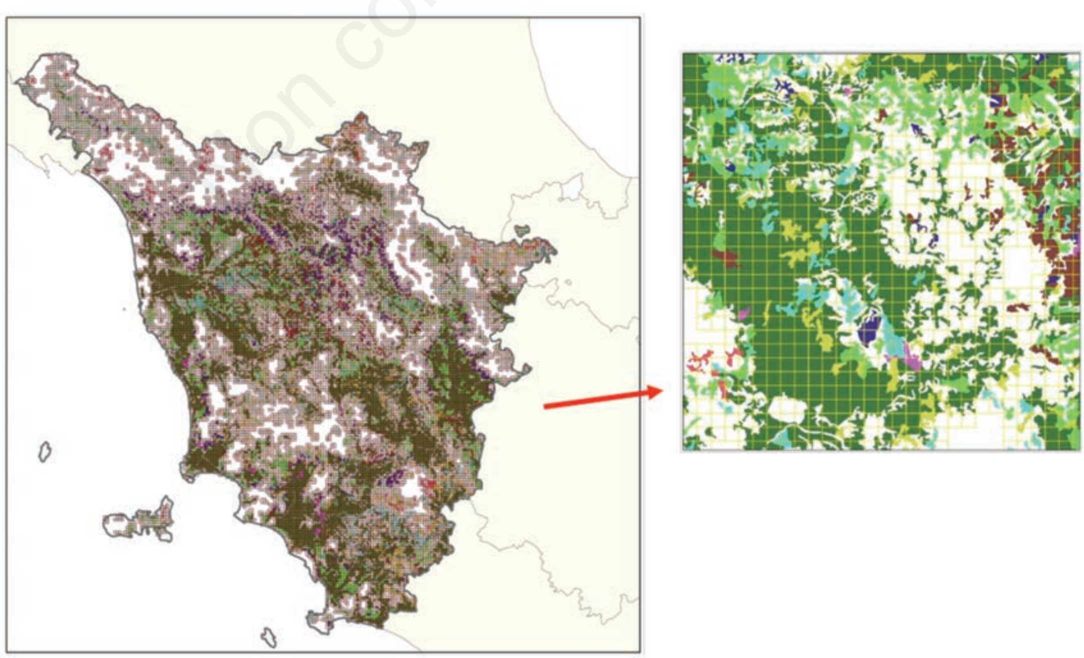

Figure 2. 1×1 km grid cell covering agriculture area across Tuscany region. The inset on the right, shows a zoom of the grid fishnet.

where: c=classes of CLC (ha); Pc=presence (%) of different Corine land cover classes with respect to the total agricultural areas (cUAA) accounted by CLC2006. Crop diversity index was calculated for each grid of 1×1 km and 1-10 normalised.

Extensive practices

Extensive practices indicator was determined summing up three sub-indicators, namely extensive breeding (EB), permanent grassland (PG), nitrogen surplus (NS). To each indicators a different weight was assigned, 3, 3 and 4, respectively. The final score of each sub-indicator was 0-1 normalised.

Extensive breeding: EB (lue ha^{-1}) indicator was calculated with following algorithm:

$$EB = -\sum_{1}^{n} (nl * lue) / eUAA \tag{2}$$

where: *nl*=number livestock; *lue*=livestock units equivalent; *eUAA*=estimated utilised agricultural area.

Permanent grassland: PG (pg ha^{-1}) indicator was calculated with following algorithm:

$$PG = -\sum_{1}^{n} (pg / eUUA) \tag{3}$$

where: *pg*=permanent grassland coverage; *eUUA*=estimated utilised agricultural area (code 321).

Nitrogen surplus: Ns (kg ha^{-1}) was calculated using the methodology IRSA-CNR (1991), with following algorithm:

$$Ns = -\sum_{1}^{n} (Nfi - (Nri * Hi)) \tag{4}$$

where: *i*=crops coverage (cUAA); *Nf*=nitrogen of fertiliser (kg ha^{-1}) (Italian Regulation, 1999); *Nr*=nitrogen removal (kg ha^{-1}); *H*=harvest (kg t^{-1}).

Table 1 shows the coefficients used for the calculation of nitrogen removal and inputs due to fertilisation inputs for each crop types.

Landscape elements

Landscape elements indicator was calculated summing up five sub-indicators, namely length of hedges and stone walls (Lh), length of canals and waterways (Lc), surface of wetlands area (*e.g.*, marshes, ponds and lagoons) (Wa), surface of lakes (Nl), number of isolated trees (Nt). Each of them was calculated with the following algorithms:

Length of hedges and stone walls:

$$Lh = if\,(Lh / eUAA > 50 = 1), instead\,(Lh / eUAA / 50) \tag{5}$$

where: 50 is a threshold value (Samoy *et al*., 2007).

Length of canals and waterways:

$$Lc = if\,(Lc / eUAA > 100 = 1), instead\,(Lh / eUAA / 10) \tag{6}$$

where: 100 is the threshold derived averaging the total values.

Surface of wetlands area (e.g., marshes, ponds and lagoons):

$$Wa = if\,(Wa / eUAA > 0.02 = 1), instead\,(Wa / eUAA / 0.02) \tag{7}$$

where: 0.02 is a threshold value (Samoy *et al*., 2007).

Surface of lakes:

$$Nl = if\,(Nl / eUAA > 0.02 = 1), instead\,(Nl / eUAA / 0.02) \tag{8}$$

where: 0.02 is a threshold value (Samoy *et al*., 2007).

Number of isolated trees:

$$Nt = if\,(Nt / eUAA > 1 = 1, instead\,(Nt / eUAA / 1) \tag{9}$$

where: 1 is a threshold value (Samoy *et al*., 2007).

The same weight (*i.e.*,=2) was given to each sub-indicator. Moreover, the five sub-indicators were calculated for each 1×1 km grid cells and 0-1 normalised. The final comprehensive Landscape elements indicator was computed summing up the five sub-indicators.

High nature value farmland computing and upscaling

For each 1×1 km grid cell, the final HNVf was calculated summing up the three indicators values (CDI, EPI and LEI), each of them reaching 10 as maximum score. The final HNVf values ranged from 0 to 30, accordingly. Afterwards, grid cells resulting in HNVf values higher than 12 (Pointereau *et al*., 2007) were selected for determining HNVf values at municipalities level. In the specific, the upscaling procedure was based on computing the number of HNVf>12 cell grids comprised within each single municipality.

Table 1. Coefficients used for the calculation of nitrogen removal and inputs due fertilisation for each type of crops (IRSA-CNR, 1991; Calabria Region, 2009).

Crops (j)	CLC code	Harvest (H) (t ha^{-1})	Nitrogen input with fertiliser (Nf) (t ha^{-1})	Nitrogen removal (Nr) by the crops (t ha^{-1})	Correction factor of nitrogen for tree crops (t ha^{-1})*	Nitrogen surplus (Ns) (t ha^{-1})
Non-irrigated arable land	2.1.1	5	150	25	0	25
Vineyards	2.2.1	17.5	145	1.4	−60	60.5
Olive groves	2.2.3	3	130	8	−40	66.0
Annual crops associated with permanent crops	2.4.1	5	150	25	0	25

CLC, Corine land cover. *A correction factor is provided for tree crops in order to take into account the nitrogen uptake of the growing and physiological activity of perennial species.

Species-based approach

Data source

Information on species and habitats of conservation interest in the region were retrieved from the long-term project *Tuscany Naturalistic Repertory* (Re.Na.To) (Sposimo and Castelli, 2005; Viciani *et al*., 2009). In particular, Re.Na.To repertory is a spatial database comprising habitats and species of conservation interest, which were identified in compliance to the European Directives 92/43/EEC and 79/409/EEC (European Commission, 1979, 1992) as well as to the Red List established at national and regional level.

Species and habitats indicator

Species and habitats indicator was calculated overlaying species and habitats of conservation interest inventoried by Re.Na.To repertory, vector in origin, to 1×1 km grid cells comprising relevant agriculture areas of high nature value as inventoried by CLC 2006 (*i.e*., codes: 211, 213, 221, 222, 223, 231, 241, 242, 243, 244, 321). Pixels denoting number of observations higher than 2 were selected as HNVf and then aggregated at municipality level.

Agro-ecosystems and farmland habitats within the high nature value farmland

The agro-ecosystems and farmland habitats were established only for those municipalities depicting an overall HNVf>12 value higher than 44.

Accordingly, agro-ecosystems were defined heuristically on the basis of cropping systems, of the characteristics of the agricultural landscape elements (*e.g*., presence of hedges, streams, lakes, scattered trees, *etc*.), as proposed by Pointereau *et al*. (2007), retrieving information from the regional agricultural statistics (ISTAT, 2010) and cartography (Tuscany Region, 2014). Moreover, agro-ecosystems were identified also on the basis of what reported by the regional strategy for the protection of biodiversity plan (Tuscany Region, 2013). This plan suggests measures for biodiversity conservation at regional scale, identifying a conservation targets list, which comprise agricultural areas. In particular, target 5 focuses on *Traditional agro-ecosystems and other agricultural areas of natural value*, whilst target 7 on *The outdoors area of mountain and hill, with grasslands primary and secondary, in mosaics with moorlands and peat bogs*.

Results

Combined approach

Figure 3 shows the maps of the three indicators EPI, CDI and LEI. Regarding the EPI, it can be noted that areas with extensive agricul-

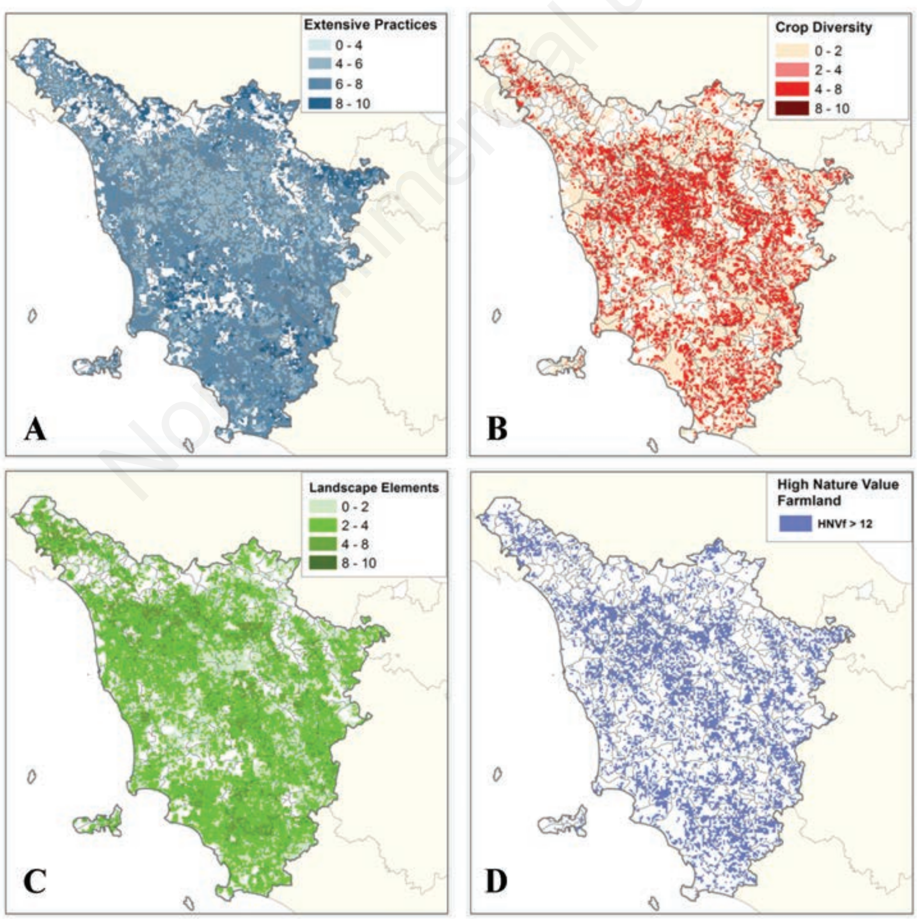

Figure 3. Grid cell maps of the three indicators calculated according to the combined approach: A) extensive practices; B) crop diversity; C) landscape elements. Panel D) shows high nature value farmland (HNVf) grid cell map with values >12 resulting from the aggregation of the three indicators.

ture (with the maximum value of 8-10 points of HNVf), are mainly concentrated across the whole area of the Apennines (*i.e.*, Lunigiana, Mugello and Casentino) and Amiata (Figure 3A). These areas are mostly characterised by HNVf1 types, *i.e.*, farmland dominated by grassland ecosystems, often associated with a low stocking rate and nitrogen surplus (Table 2).

Conversely, CDI, resulted in few areas reaching the maximum value of 10 HNVf points, is mostly concentrated across the hilly zone of central Tuscany and mainly characterised by HNVf2 types (Table 2). As such, many areas resulted 4-8 point values (Figure 3B). Similarly, the third indicator (LEI) resulted in HNVf areas with 8-10 point values mostly localised across the central hilly areas of the region, namely Valdarno zone (Arezzo), Chianti area (Siena and Florence), and Colline Metallifere area (Grosseto).

Moreover, LEI high values resulted also across the plain areas of Lucca, Prato, Pistoia and Firenze province (Figure 3C), characterised by a relevant number of HNVf2 type (Table 2).

Figure 3D shows the summing up of three indicators resulting in HNVf with values higher than 12 at grid cell level, which are mostly concentrated along the central mountainous core of the region. The aggre-

Table 2. Crops coverage, indicators values, average number of species, average value of high nature value farmland (HNVf) (>12) for the four typologies of agro-ecosystems and the three types of HNVf in Tuscany region.

Agro-ecosystem*	Landscape system		Crop surface (%)						Value of indicators (%)			Average number of species	Average value of HNVf (>12)	Types of HNVf°
		Number of municipalities	Arable crop	Annual grassland	Permanent grassland	Vineyards	Olive groves	Fruit trees	Extensive practices	Landscape element	Crop diversity			
1	Lunigiana	1	8.0	8.8	38.0	12.9	20.7	11.6	46.3	30.2	23.5	-	71.0	HNVf1
1	Amiata	1	25.8	14.3	54.4	0.5	3.8	1.2	47.9	30.0	22.1	30.0	61.0	HNVf1 and HNVf3
1	Casentino e Val Tiberina	7	20.2	32.5	45.0	0.4	0.3	1.3	57.3	21.8	20.9	64.4	33.1	HNVf1 and HNVf3
1	Mugello	3	14.3	26.8	35.3	4.7	11.8	7.0	50.7	20.1	29.1	34.0	49.7	HNVf1 and HNVf3
2	Firenze-Prato-Pistoia	1	14.5	1.1	10.4	4.2	34.5	1.4	41.0	32.5	26.5	-	61.0	HNVf1
2	Val di Nievole e Val d'Arno Inferiore	1	53.4	5.3	16.1	12.2	11.8	1.1	38.7	27.3	34.0	-	62.0	HNVf2
2	Val d'Elsa	3	39.1	5.5	4.3	31.4	19.0	0.5	40.5	21.4	38.1	17.3	59.0	HNVf2 and HNVf3
2	Val d'Arno Superiore	2	32.7	5.5	9.1	24.8	25.4	2.6	41.9	23.5	34.6	7.0	51.5	HNVf2
2	Colline Metallifere	2	47.8	13.7	15.8	3.7	16.1	2.7	48.2	24.8	27.0	20.5	84.0	HNVf2 and HNVf3
2	Val d'Orcia e Val d'Asso	1	36.6	9.7	12.8	27.6	12.4	0.9	42.6	23.3	34.2	-	89.0	HNVf2
3	Val di Cecina	4	58.0	14.8	18.8	1.1	5.6	1.7	50.7	18.2	31.1	123.3	42.8	HNVf2 and HNVf3
3	Bassa maremma e ripiani tufacei	3	52.1	24.0	15.9	2.9	4.4	0.5	48.4	22.9	28.7	52.7	96.3	HNVf2 and HNVf3
3	Colline di Siena	5	61.6	14.1	9.1	6.9	7.4	0.6	45.4	25.3	29.4	17.4	54.8	HNVf2 and HNVf3
3	Val d'Orcia e Val d'Asso	1	55.1	19.2	23.7	0.2	1.7	0.0	50.8	17.7	31.5	-	51.0	HNVf2
3	Maremma Grossetana	7	56.2	23.1	9.6	2.8	7.4	0.7	46.1	27.3	26.6	49.0	80.9	HNVf2
4	Piana di Arezzo e Val di Chiana	4	60.0	5.0	7.1	12.0	12.3	3.6	41.5	26.2	32.4	16.5	76.5	HNVf2 and HNVf3
4	Lucchesia	2	31.9	3.4	25.0	9.0	26.3	2.1	39.8	32.1	28.1	-	83.5	HNVf1
4	Firenze-Prato-Pistoia	1	60.7	5.2	22.2	1.4	8.8	0.8	-	-	-	23.0	-	HNVf3
4	Piana Livorno-Pisa-Pontedera	2	64.6	15.8	13.8	1.4	1.6	2.7	-	-	-	42.0	-	HNVf3

*Agro-ecosystem 1: Mountain area with extensive grasslands and low intensity management and presence of linear elements; Agro-ecosystems 2: Hilly area with a prevalence of extensive tree crops, in a landscape of high heterogeneity with different presence of semi-natural elements; Agro-ecosystems 3: Hilly areas, with a prevalence of extensive cereal crops, mixed with meadows and pastures, fallow, patches of woods and hedges; Agro-ecosystems 4: Reclaimed plain areas, with relevant presence of waterways and semi-natural vegetation; °HNVf1 identifies farmlands with a high proportion of associated semi-natural vegetation; HNVf2 identifies farmlands with low-intensity management and high crop diversity; HNVf3 identifies farmlands supporting rare species or high proportion of European/World populations (Andersend *et al.,* 2003).

gation at the municipal level of HNVf with a score over 12 points, highlighted areas of Tuscany region with high natural value (Figure 4A).

Species approach

Figure 4B shows the map of HNVf (type 3), aggregated at municipality level identified with the species approach. Although with some differences, municipalities with HNFv>12 resulted by this approach are almost the same with respect to those resulted from the combined approach (Figure 4A), namely the coastal area of Pisa, where San Rossore regional park is placed; the inland plain between Prato and Florence; the hilly areas of Val di Cecina and the mountain areas of Casentino, where a National Park stands.

HNVf3 type comprehends mountain areas with extensive agriculture areas as well as hilly areas, characterised by extensive cereal crops, mixed with meadows and pastures, patches of woods and hedges. HNVf3 type areas are also localised along plain areas where intensive agriculture, channels and semi-natural vegetation dominate the territory.

The total HNV areas resulting from the overlap of the two approaches (combined and species) represent 35% of the total utilised agricultural area and 16% out of them are located inside protected areas (Natura 2000 areas, national parks, regional, provincial and state reserves) (data not shown).

Agro-ecosystems and farmland habitats within the high nature value farmland

According to the results deriving from the two approaches, the most relevant agro-ecosystems were identified (Figure 5) and describe (Table 2) across Tuscany region.

For each agro-ecosystem (landscape systems they belong to as well as the number of the municipalities implied), percentage of each indicators weight (EPI, LEI, CDI), percentage of the cropping systems considered, average number of species, and type of HNVf (Andersen *et al.*, 2003) are reported. As shown in Table 2, EPI resulted the most relevant indicator amongst the others for HNVf>12 computing along the four agro-ecosystems identified.

Agro-ecosystem 1 is mainly localised across the entire area of the Apennines, characterised by secondary grassland, a relevant number of isolated trees and shrubs as well as by small pond farmland habitats. Most of municipalities (*i.e.*, 7) are concentrated across Casentino and Val Tiberina areas, mainly dominated by permanent grasslands (45%). In this area, EPI resulted the most determinant indicator (EPI value 57.3) with respect to the two other indicators (21.8 and 20.9 for LEI and CDI, respectively). Moreover, in this area (Casentino and Val Tiberina valley), a higher number species and habitat of conservation interest are observed (64.4) with respect to the other areas (0, 30, 34 for Lunigiana, Amiata and Mugello areas, respectively).

Conversely, Agro-ecosystems 2 and 3 are mainly concentrated across hilly areas of the region, the first (2) characterised by traditional olive groves, terrace, hedges and row of three; the second (3) by pasturelands, scrub and field edge farmland habitats.

In particular, Val d'Elsa area comprehends the highest number of municipalities (3). Moreover, in agro-ecosystem 2, mainly dominated by arable crops (ranging from 14.5% in Firenze, Prato, Pistoia plain and 53,4% in Val di Nievole and Val d'Arno Inferiore) and vineyards (ranging from 4.2% and 31.4% in Firenze, Prato, Pistoia plain and in Val d'Elsa), EPI and CDI are the indicators, which are mostly determinant for HNVf values computing. Furthermore, Colline Metallifere is the area denoting a highest number of species and habitat of conservation interest (20.5).

Most of the municipalities (7) belonging to agro-ecosystem 3 are localised in the Southern area of the region (Maremma Grossetana), characterised by a prevalence of arable crops (56.2%) and denoting a high HNVf>12 value (80.9) mostly due to high values of EPI (49). In this agro-ecosystem, Bassa Maremma e Ripiani Tufacei and Maremma

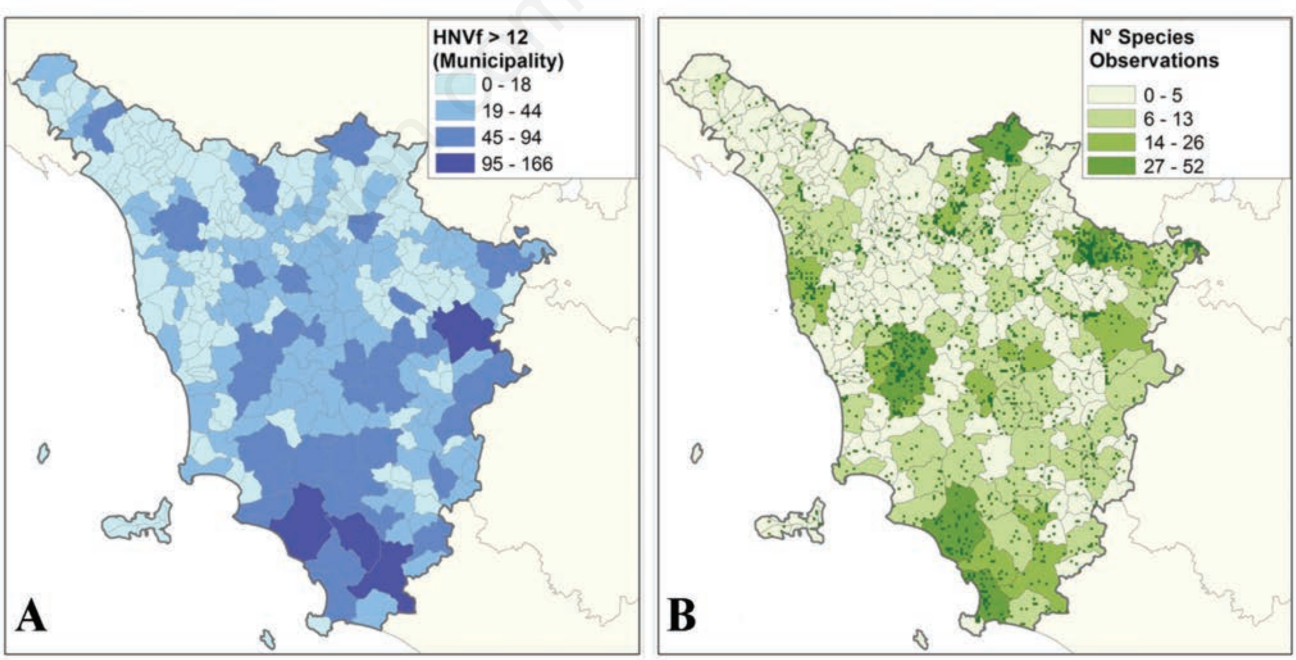

Figure 4. High nature value farmland (HNVf) map, upscaled at municipality level, according the combined approach (A) and species approach (B). In particular, panel (B) is composed by two layers: number of species and habitats of conservation interest observations (point layer) and their aggregation at municipal level (polygon layer).

Grossetana are the areas denoting the highest number of species and habitat of conservation interest (52.7 and 49.0, respectively).

Lastly, Agro-ecosystem 4 dominates the plain areas of the region (mainly Piana di Arezzo and Val di Chiana), characterised by canals and ditches vegetation, small wetlands and ponds, and arable crops in rotation farmland habitat (60% of arable crops). The HNVfs of the Arno river valley area (Firenze-Prato-Pistoia and Piana Livorno-Pisa-Pontedera) of agro-ecosystem 4 are determined only by the species approach (23 and 42, respectively). Finally, the Lucchesia area, dominated by arable crops (31.9%) and olive groves (26.3%), depicts the highest HNVf>12 values (83.5) in this agro-ecosystem.

Discussion

As evidenced by Lomba *et al*. (2014) review, several approaches can be used for mapping HNVf at regional level but, the most effective and expended is the combined one.

Recent approaches, implemented at national and/or regional scale, are based on collecting a wide range of pre-existent spatial dataset regarding biodiversity (Samoy *et al*., 2008), topography (Aquilina and Ivanovic, 2012), agronomic statistics (Pointereau *et al*, 2007), or any relevant information related to protect and conservation areas or habitats (Belényesi and Podmaniczky, 2007). In this paper, as proposed by the methodology suggested by Paracchini *et al*. (2008), two different approaches were performed and several information layers were collected and used for indicators computing, namely agricultural statistics, landscape and land use, presence of natural elements of conservation interest.

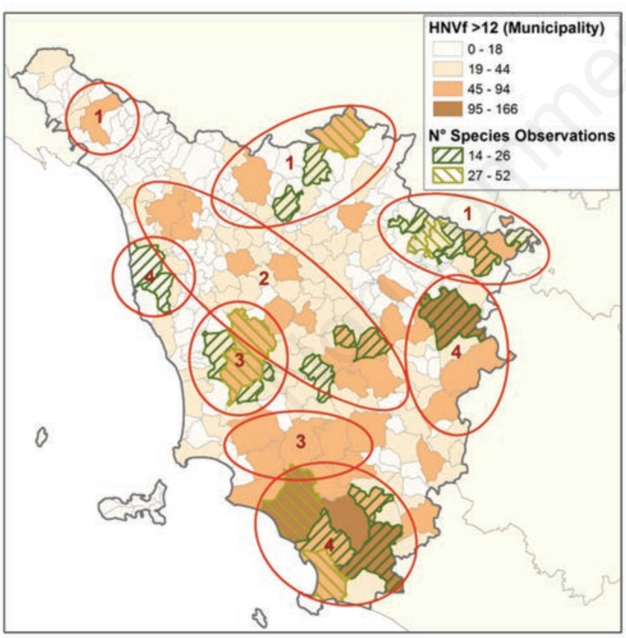

Figure 5. Maps of agro-ecosystems (numbered and circled) comprising high nature value farmland (HNVf) as resulting from the combined and species approaches. (1) Agro-ecosystems of mountain areas with extensive grasslands and low intensity management and presence of linear elements; (2) agro-ecosystems in hilly areas with a prevalence of extensive tree crops, in a landscape of high heterogeneity with different presence of semi-natural elements; (3) agro-ecosystems in hill areas, with a prevalence of extensive cereal crops, mixed with meadows and pastures, fallow, patches of woods and hedges; (4) reclaimed plain areas, with relevant presence of waterways and semi-natural vegetation.

As resulting in Samoy *et al*. (2007) and Paracchini *et al*. (2008), who identified HNV areas at European level using distinct methodologies, the two approaches applied (combined and species-based approach) in this study provided analogous results, *e.g*., HNVf spatial identification across Tuscany region.

Moreover, Samoy *et al*., (2007) suggests to use species approach, based on the computing of biodiversity value occurring in a specific area, to validate the combined approach, which aims at identifying areas where land cover/landscape elements and agriculture practices may favour biodiversity.

As pointed out by Lomba *et al*. (2014) and Paracchini *et al*. (2008), the spatial resolution of the geographical dataset used for the computation of HNVf indicators by the different approaches can be a constraint. Accordingly, though CLC map (level 3) provides information on the main agriculture system currently occurring across the European territory, it doesn't give any information on the type and intensity of agriculture management practices currently adopted. Such a kind of information can be retrieved from agriculture statistics, but this information is often aggregated at municipality level. To this end, the spatial resolution mismatch between agriculture statistical data and CLC 2006 data evidenced in this study were effectively overcome by computing a correction factor in order to homogenise the scale resolution of the different dataset and thus to estimate UAA and UFA at 1×1 km level.

The rate between the total area of HNVf and UAA resulted in this study (HNVf/UAA=35%) is coherent with other studies conducted in Italy and in Europe. For instance, at European level HNVf/UAA account for 30% (EEA, 2004, 2009; Van Doorn and Elbersen, 2012), whilst 25% resulted in the Walloon region in Belgium and in the Czech Republic (Samoy *et al*., 2007) as well as in France (Paracchini *et al*., 2008). Similarly, even if underestimated, the HNVf/UAA for Tuscany region was estimated to range from 17 to 33% by the rural development plan (2007-2013), and about 24% by the Italian Agency for Environmental Protection (APAT, 2007).

According to our results, the 16% of the identified HNV areas are located inside protected areas (national, regional parks, Nature 2000 protected areas, *etc*.), consequently currently under environmental protection and conservation managements. The same percentage is evidenced also by the regional strategy for the protection of biodiversity in Tuscany (Tuscany Region, 2013). In other regions of Europe, the percentage of HNVf embedded in protected areas ranges from 16% (Wallonia region, as reported by Samoy *et al*., 2007) to 50% (France, as pointed out by Pointereau *et al*., 2007).

As proposed by Andersen *et al*. (2003) the HNVfs, identified across the region in this study, were categorised onto three typologies (HNVf1, HNVf2, HNVf3) (Table 2). However, as also evidenced by Lomba *et al*. (2014) and the Institute for European Environmental Policy (IEEP, 2007a), the three HNVf types may overlap to each other inside a same agro-ecosystem. In fact, different HNVf types are not easy to be discriminated by simply identifying the predominant features (*e.g*., presence ecological infrastructures, farmland habitat, *etc*.). Nevertheless, different HNVf types may jointly occur within a same landscape and agro-ecosystem.

Furthermore, while HNVf1 is easy to discriminate as being connected to secondary grasslands agro-ecosystems and acknowledged in Europe as priority areas under the Directive 92/43/EEC (European Commission, 1992), both HNVf2 and HNVf3 cannot be associated with a specific type of agro-ecosystems or farmland habitats. In fact, HNVf2 consists of diverse hilly agro-ecosystems with a prevalence of arable crops or tree crops mixed with traditional semi-natural areas, whilst HNVf3 includes farmlands which favour rare species of a high proportion of European or World populations. For instance, in some lowland

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Table 3. Agro-ecosystems, farmland habitats and management practices for the improvement of the agro-biodiversity in the high nature value farmland (HNVf) in Tuscany region.

Agro-ecosystems	Farmland habitat	Management practices
1. Agro-ecosystems of mountain areas with extensive grasslands and low intensity management and presence of linear elements	Secondary grassland	Definition of a management plan, which implies the following measures: - identification of areas affected by grazing activities - evaluation of stocking rate - type of grazing (controlled, free, rationing, *etc.*) - grazing time - agronomic practices to be encouraged (grass cutting, *etc.*) - water supply points (inventory and plans) - bushes cutting
	Isolated trees and shrubs	Logging management according to the following criteria: - logging rotation (*e.g.,* shrubs that reach maturity in 15 years, must be cut 3 times per 15 years) - loggings in small patches for diversifying shrubs horizontal structure - cut in the period between September and February to avoid damaging due to birds mating season
	Small pond	Recovery works of existing pond, through deepening and/or waterproofing, greening of artificial banks Building up of new ponds according to the following rules: - not allocate them in areas already acknowledged as HNV - select a site with good quality water, well shielded from crops - create lakes with not steep shores and a maximum 2 m depth - creating a buffer zone of 10-20 m for lakes protection from the use of fertilisers and pesticides
2. Agro-ecosystems in hilly areas with a prevalence of extensive tree crops, in a landscape of high heterogeneity with different presence of semi-natural elements	Traditional olive groves	The management of these habitats implies: - installation of the nests - presence of grass cover for reducing soil erosion as well as favouring biological diversity (number of wild species) - not cutting between March and August to encourage nesting ground - treatments with herbicides forbidden - amongst olive groves, maintenance of mature trees for increasing ecological and landscape diversity and for improving of the olive quality - maintenance of dry stone walls
	Terrace	The management of these habitats implies: - dry stone walls restoration - periodic removal of weeds from the walls - the creation or restoration of drains at the basis of the wall for water drainage - maintenance of natural herbaceous covering
	Hedges and row of tree	Management of existing hedges: - pruning should be performed in any time avoiding birds wintering (January and February) - pruning should be done every two or three years in rotation - drift of the treatments should be avoided - ploughing distant from the hedge - leave at least 3 m a grassy strip near the hedge Creation or recovery of hedges: - cutting a part of the trunks is a method that has a less drastic effect on wild species - planting native species along empty spaces on the hedge - new hedges are favoured for creating ecological continuity at landscape level
3. Agro-ecosystems in hilly areas, with a prevalence of extensive cereal crops, mixed with meadows and pastures, fallow, patches of woods and hedges	Pastures	Stocking rate: - stocking rate should be less than 0.2-08 LU/ha, although this may vary depending on the fertility and the type of soil and local climate Scheme cutting: - cutting after grazing activity leaves seeds in the soil to be eaten by birds in winter time. Cut height should be 15 cm Recovery of the meadows by new herbaceous covering planting: - manure fertilisation - planting a mixture of species including legumes and grasses suited to the local territory
	Scrub woodland	Maintenance of scrub woodland: - eliminate invasive species - reduce excessive plant density by a selective thinning - diversify structure vegetation by cutting trees and shrubs and small rolling patch - cut activity should be done between September and February in order to avoid birds mating season

To be continued on the next page

Table 3. Continued from previous page.

Agro-ecosystems	Farmland habitat	Management practices
	Field margin	Management of field margins: - they can be sown, or left with the natural vegetation cover - vegetation cutting should be done in periods that limit as much as possible insects disturbance - do not use herbicides or fertilisers - grazing can be performed between March and August
4. Reclaimed plain areas, with relevant presence of waterways and semi-natural vegetation	Vegetation of waterways and ditches	Management of canal cleaning: - cleaning should be avoided between March and August - the use of herbicides to control vegetation of ditches and their banks should be avoided - leave 1/3 width of channels without removing aquatic vegetation Bank of the canal: - cutting should be avoided between March and August - maintenance of isolated trees and patches of shrubs in order to increase biodiversity
	Arable crops in rotation	Crop rotation: - crop rotation should last at least four years, including annual or perennial legumes - with respect to the total cultivated area, the percentage of the area destined to legumes crops should be at least >30%

areas of the region, the predominant agro-ecosystems are represented by channels and semi-natural vegetation, even where intensive agriculture is practiced. Furthermore, the spatial identification of HNVf1 and HNVf2 resulted in this study is coherent with the areas reported in the regional plan for biodiversity in Tuscany (Tuscany Region, 2013).

As pointed out by Beaufoy *et al*. (1994), Bignal and McCracken (1996) and Cooper *et al*. (2007), main relevant management practices for agro-biodiversity improvement, especially in those HNVfs not included in protected areas, should be recognised and promoted (Klimek *et al.*, 2014). Moreover, an aspect still poorly studied concerns the definition of measures for maintenance of habitat and species depending on agricultural management (Halada *et al*., 2011). Interesting is the experience from the Royal Society for the Protection of Birds (RSPB) in England, which proposes a series of practical advice to farmers for the management of habitats in agricultural areas (RSPB, 2008). The information available on semi-natural habitats is mostly limited to those listed in Annex I of Habitats Directive (Halada *et al*., 2011). Scientific evidence (Glemnitz *et al*., 2006; Wittig *et al*., 2006; Matzdorf *et al*., 2008; Sullivan *et al*., 2010) shows that management measures for biodiversity improvement should be prioritised in agricultural habitats (*e.g*., such as fallow land, arable areas managed at low intensity, the presence of field margins, hedges) located inside protected areas in order to maintain or enhance species diversity occurrence. Some of semi-natural habitats, such as secondary grasslands, are widely studied in long-term experiments performed throughout LIFE-EU funded projects. In fact, the EU report (European Commission, 2008) describes the results deriving from agriculture management practices in several countries in order to drive farmers for biodiversity conservation actions.

To this end, relevant management practices that could be promoted for each agro-biodiversity identified in this study are suggested in Table 3. Farmland habitat and relative management measures proposed in Table 3 are regionally scaled. However, for their effective application, these measures should be studied and validated at a higher resolution (*e.g*., farm level) in order to better analyse the ecological and environmental effects in their application (Paracchini *et al*., 2008). Nevertheless, the management measures proposed in Table 3 could be used as ground basis for the definition of a common monitoring framework to be included within regional plans management (*e.g*., integrated territorial plans proposed by Tuscany region) (Lomba *et al*., 2014) or in the forthcoming rural development plan programming for Tuscany region.

Conclusions

By the two different approaches of analysis used in this study (combined and species approach) relevant HNVfs (type 1, 2, 3) were identified and localised at high spatial resolution (1×1 km) in Tuscany region (Italy). Both approaches provided the same results in terms of extension and localisation of HNVfs. These represent 35% of the regional UAA and amongst them 16% are located inside protected areas. HNVfs were spatially aggregated in four main typologies of agro-ecosystems and different farmland habitats across the region and, for each of them, general management measures were proposed. However, these measures should be further studied and validated at a higher resolution (*e.g*., farm level) in order to better analyse and assess long lasting ecological and environmental benefits in their application.

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