Identification and recording of hedgerows: testing different methods in a pilot area of the Ljubljana Marshes

Abstract

Hedgerows are a less-known element in the cultural landscape. In Slovenia, 4522 hedgerows are officially registered, covering a total length of 458.5 km. Due to various factors, their number and quality are decreasing. As a landscape vegetation feature that changes rapidly, their proper identification and recording are paramount to their conservation and management. Using lidar-captured data, two approaches were developed and evaluated for future applicability. We found that a suitable combination of methods, including geographic fieldwork, is required for effective identification and recording of hedgerows. In addition to methodologically appropriate and up-to-date recording, cross-sectoral coordinated actions and targeted awareness-raising among farmers and the general public on the multiple functions of borders in the cultural agricultural landscape will be crucial for the conservation of hedgerows.

Keywords: landscape features, hedgerows, lidar-captured data, the Conservation of Hedgerows operation, the Ljubljana Marshes
1 INTRODUCTION

The loss of landscape diversity and inadequate management of individual landscape components are among the major factors contributing to biodiversity loss in most EU countries and in Slovenia. Landscape features (the term landscape features or elements is used in places where the text of official documents is summarised) increase the potential for biodiversity conservation, particularly in agricultural ecosystems (Resolucija o Nacionalnem programu ..., 2020). Many ecosystem services vital for agricultural production (such as pollination, natural pest control in agriculture, mitigation of the negative impacts of wind, drought, etc.) are directly and strongly dependent on an adequate representation of landscape features in the (agricultural) cultural landscape (Stališče stičišča SV ARUN, 2020).

In the treatment of landscape features, the paper follows the definition of landscape features in the target research project (Golobič et al., 2015), where they are divided into four groups: geomorphological and vegetation landscape elements (hilly meadows, karst hollows, boulders, terraces, etc.), vegetation landscape elements (forest patches, hedgerows, riparian vegetation, wet meadows, etc.), water landscape elements (local swamps, low-moor and high-moor, ditches) and built structures (dry stone walls).

Reduced landscape diversity is most often the result of changes in the use of (modern) agricultural technologies, major rationalisation of production costs, and modernisation and intensification of agricultural production. At the same time, in areas with less favourable natural conditions for agricultural production, there has been abandonment and overgrowth of agricultural landscapes. Purely administrative reasons linked to the eligibility conditions for farm support and, consequently, farmers' efforts to increase the eligible agricultural area are also contributing to the changes, as landscape features are largely not recognised as an eligible use for support under agricultural policy measures (Golobič et al., 2015; Stališče stičišča SV ARUN, 2020). The decline and sometimes even disappearance of landscape features is also linked to urbanisation and fragmentation, tourism and recreation, the spread of invasive (non-native) plant species and climate change.

The environmental vision of the latest Resolution on the National Programme for Environmental Protection for 2020–2030 is preserved nature and a healthy environment in Slovenia and beyond, which enables and will enable a quality life for present and future generations. Here again, the objectives of protecting, preserving and enhancing Slovenia’s natural capital include the conservation of landscape features that are important for biodiversity. The Resolution notes that landscape diversity and landscape features are largely dependent on natural processes and socio-economic conditions (Resolucija o Nacionalnem programu ..., 2020). In Slovenia, due to the diverse geographical conditions and the long tradition of land cultivation, a mosaic landscape is (still) predominant, with fine structures (watercourses and other water phenomena, individual trees or groups of trees, hedges, hedgerows, dry walls, tree
avenues), extensive agricultural areas (e.g. low-fertilised or unfertilised meadows and pastures), a mosaic of arable fields with different crops and sustainably managed forests. The “simplification of the landscape”, which is being witnessed in many parts of Slovenia, is leading to the disappearance of natural structures and cultural elements, reducing the mosaic nature and thus landscape diversity and biodiversity (Resolucija o Nacionalnem programu ...,2020).

The protection of these landscape features therefore requires the preservation of the characteristics that make parts of the landscape, or elements of it. Here, monitoring and guiding spatial interventions is crucial (Lampič, Kušar, Zavodnik Lamovšek, 2017).

Hedgerows are defined as a “landscape vegetation feature” (Golobič et al., 2015). They are composed of linear woody vegetation (trees and shrubs), which can be subject to numerous and rapid changes. If they are not properly managed, their length and shape change constantly. As they are linear structures of predominantly shrubby vegetation, they are also relatively easy to cut down. On the other hand, they also become overgrown quickly, most often on parts of farmland that the farmer has stopped cultivating due to poorer quality, less accessibility and other reasons.

In this paper, we have paid special attention to the identification and recording of hedgerows using digital orthophoto and lidar imagery. Their biggest drawback is their timeliness, as lidar data for the whole of Slovenia have been captured only once, while digital orthophotos are updated every two to four years.

In order to more effectively conserve the individual landscape features (e.g. hilly meadows, hedgerows, etc.), it is necessary to provide databases based on appropriate ways of recording these features. The absence of monitoring thus hampers the very system of monitoring the phenomenon, surveillance and appropriate action in the event of negative processes. This shortcoming has also been identified at the level of agricultural policy implementation, where the Joint Strategic Plan 2023–2027 specifically highlights the improvement and extension of the different spatial layers for the implementation of nature conservation sub-interventions, which will relate to hedgerows, wetlands, sensitive permanent grasslands in Natura 2020 sites, etc. (MAFF, 2021).

2 THEORETICAL STARTING POINTS

The hedgerow is recognised worldwide as an important landscape element. Their treatment in Western European and North American countries is well established and supported by research (e.g. Allende Álvarez, Gómez Mediavilla, López Estébanez, 2021; Allende Álvarez et al., 2021; Graham et al., 2018; Litza et al., 2022). In the UK, for example, they are protected in a targeted way through the Hedgerow Regulations (1997). However, due to large-scale and rapid spatial changes (intensification of agriculture, use of modern technology, expansion of urbanised areas, changes in farmland management policies), hedgerows are facing their gradual loss at a global
scale (Baudry, Bunce, Burel, 2000; Burel, Baudry, 1990; Molnarova, 2008), and thus conservation of hedgerows is becoming increasingly challenging.

The treatment of hedgerows is also not yet uniform in terms of terminology. The two most commonly used terms in the foreign literature are hedge and hedgerow, but their use is inconsistent. Hedges represent the woody component of the boundary vegetation, whereas hedgerows include a herbaceous component and a canal adjacent to the hedgerow (Forman, Baudry, 1984). As there is no single established term in Slovenia, terms such as “živice”, “omejki” and “živa meja” are used. Terminological conundrums have been somewhat resolved with the introduction of the Conservation of Hedgerows operation, which is part of the Agri-environmental-climate scheme (AECS) under the Common Agricultural Policy (CAP). This operation has established the term “hedge-row” (Slov. “mejica”) in the agricultural and nature conservation sector (MAFF, 2019).

There are also discrepancies in the definition of the minimum length of hedgerows. In the survey, we used the definition of the Ministry of Agriculture, Forestry and Food (MAFF), which defines hedgerows as compact and independent lines of woody vegetation at least 10 metres long and no more than 20 metres wide at the canopy, which must be more than two metres wide (MAFF, 2019).

The importance of the management and proper treatment of hedgerows lies in the multiple and complementary functions that they provide. They provide foraging habitat for many animals, which is particularly important in intensively farmed landscapes. They are important migration and flyway corridors linking different ecosystems. An important fact is that hedgerows are composed of a diversity of native species with a shrub layer developed to allow light to reach the lowest layers (Dondina et al., 2016; Garratt et al., 2017; Heath et al., 2017). Hedgerows reduce the impacts of wind, drought, storms and hail, control water flow and delay nutrient leaching from farmland into watercourses. On the one hand, they limit the spread of organisms harmful to agriculture (MAFF, 2021), and on the other hand, they serve as a refuge for animals, both wild and grazing. The great importance of hedgerows in the agricultural landscape lies in their prevention of wind erosion (Earnshaw, 2004; MAFF, 2021). The quality of the protection depends on the size of the trees, so that the effect of windbreak is 56 metres for a two-metre shrub and 560 metres for a 20-metre thicket (Forman, Baudry, 1984). Another important ecosystem service is the regulation of the local climate, as a specific microclimate is established in and around hedgerows (MAFF, 2021). In the area of the hedgerows, soil water and organic carbon contents are higher, which contributes to higher land productivity (Sanchez et al., 2010). They are also a source of raw materials, the most important of which is timber, which has played an important role especially in the past and in countries where forest cover is scarce (Burel, Baudry, 1990). However, the presence of hedgerows also has some negative effects, as hedgerows can attract some harmful insects and birds that damage crops in nearby fields (Farmers and hedgerow management, 2019), and they affect crop yields by causing shade (Oreszczyn, Lane, 2000).
Hedgerows contribute to the landscape diversity of the cultural landscape and break up its monotony (Golobič et al., 2015), and they often demarcate properties of different owners (Baudry, Bunce, Burel, 2000). They therefore have a great aesthetic importance, which is rarely written about and few studies have been conducted on it, but is an important factor in the conservation of hedgerows (Burel, Baudry, 1990).

In Slovenia, hedgerows are one of the landscape features important for biodiversity conservation identified in the project Identification of landscape diversity and features important for biodiversity conservation (Golobič et al., 2015). Landscape features include, e.g., water ditches, dry walls, riparian vegetation, hilly meadows, etc. On agricultural land, these features are crucial for the conservation of many species of flora and fauna, but also have many other beneficial functions for people and the landscape itself (Golobič et al., 2015). One of the objectives of the post-2020 Common Agricultural Policy is to strengthen the contribution of agriculture to biodiversity conservation through the protection of the diversity of landscape features (Biodiversity and farmland landscapes, 2020). The common thread running through all these features is their conservation, particularly in intensively farmed landscapes, and extensive use of their immediate surroundings. Slovenia does not have adequate data to monitor the status of these elements or a unified system for their protection (Golobič et al., 2015).

Figure 1: Well-structured hedgerows perform the most functions due to the representation of all three layers of vegetation (trees, shrubs and herbs) (Vipava Valley) (photo: A. Kastelic).
The quality of the different functions of hedgerows depends mainly on their structure. For this reason, a number of authors (Boutin et al., 2002; Burel, Baudry, 1990; Garratt et al., 2017) have addressed the typology of hedgerows in their research (e.g. Allende Álvarez et al., 2021; Allende Álvarez, Gómez Mediavilla, López Estébanez, 2021). They agree that the best quality hedgerows are those that are multi-species, dense, composed of trees and shrubs, and intermingled with other hedgerows to form a system or network of hedgerows (Baudry, Bunce, Burel, 2000; Boutin et al., 2002; Forman, Baudry, 1984; Hedgerow Survey Handbook ..., 2007).

For the purposes of our research, we have developed our own typology of hedgerows, adapted to Slovenian conditions (Kastelic, 2019). The final typology includes five types of hedgerows:

1) Structured hedgerows are those that include all three layers of vegetation: trees, shrubs and herbs. They are vertically connected and provide a variety of habitats for many species, and are therefore of the highest quality from a nature conservation point of view.

2) Shrub hedgerows are made up of shrubs and herbs. Shrub vegetation is dense, creates vertical connectivity and is difficult to pass through.

3) Semi-structured hedgerows are made up of trees, shrubs and herbaceous vegetation. The difference between the structured and the semi-structured type is that in the latter the shrub cover is thinner, lower and therefore the hedgerow is more passable.

4) Tree hedgerows are made up of trees and herbaceous vegetation.

5) Combined hedgerows are longer hedgerows in which at least two types of hedgerow alternate. Their characteristics depend on the types that make it up.

Figure 2: Combined hedgerows (a combination of shrub and tree layers) are more abundant in the Ljubljana Marshes (photo: A. Kastelic).
In terms of function (for people, fauna and landscape), structured hedgerows, which are composed of all three layers, are the most suitable, followed by shrub hedgerows and semi-structured hedgerows, while tree hedgerows are less suitable for e.g. nature conservation functions.

Figure 3: Structured hedgerows in the Ljubljana Marshes have particularly important nature conservation functions, as they are located among intensive agricultural areas (photo: A. Kastelic).

Figure 4: Tree hedgerows are formed by trees and herbaceous vegetation. An example of a tree hedgerow in the Ljubljana Marshes, which is losing its function due to intensive clearing and cutting and other uses (photo: B. Lampič).
3 PRESENCE AND VISIBILITY OF HEDGEROWS IN SLOVENIA

Hedgerows are present throughout the country, but there are significant landscape differences. In the Karst, for example, they were created along drystacks (Šmid Hribar, 2008), while in Goričko they were used to border pastures (Domanjko, Malačič, 2009). Several theses have been written on their biological function, and Janez Božič wrote a publication on windbreaks in lowland areas of Slovenia as early as 1969 (Premrl, Turk, 2013). As a result, relatively little is known about the state of hedgerows in Slovenia, and those hedgerows that are included in the agricultural operation Conservation of Hedgerows are monitored in a slightly more systematic way.

The Conservation of Hedgerows operation is one of the operations of the AECS measure in the CAP (2014–2020, to be implemented as a sub-measure also in the programme period 2023–2027). It supports the maintenance and conservation of hedgerows in different types of agricultural land use and constitutes the preservation of one of the important elements of the agricultural landscape. The operation has been running since 2017 and the farmer commits to at least five years of operation when entering it. The amount of the payment for the implementation of the operation is EUR 1.60 per running metre per year (MAFF, 2019). The maintenance of the hedgerows must include thinning, removal of dead branches and pruning. Payments are made for the farmer’s loss of income (in some cases reduced yields due to shade, more difficult cultivation) and for the extra work involved in maintaining the hedgerows (Čus, 2019; Žvikart, 2019). The most important is their pruning (every two years), but not during the bird nesting season (between 1 March and 30 September) (MAFF, 2019).

Table 1: Number and length of hedgerows included in the Conservation of Hedgerows operation in seven Natura 2000 sites.

<table>
<thead>
<tr>
<th>Natura 2000 site</th>
<th>Number of hedgerows</th>
<th>Total length (m)</th>
<th>Longest hedgerow (m)</th>
<th>Shortest hedgerow (m)</th>
<th>Average length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krakovski gozd – Šentjernejsko polje</td>
<td>404</td>
<td>44.875</td>
<td>792</td>
<td>11</td>
<td>111</td>
</tr>
<tr>
<td>Reka valley</td>
<td>383</td>
<td>27.833</td>
<td>421</td>
<td>10</td>
<td>73</td>
</tr>
<tr>
<td>Vipava valley</td>
<td>123</td>
<td>8.783</td>
<td>328</td>
<td>15</td>
<td>71</td>
</tr>
<tr>
<td>Planinsko polje</td>
<td>298</td>
<td>27.368</td>
<td>586</td>
<td>13</td>
<td>92</td>
</tr>
<tr>
<td>The Ljubljana Marshes</td>
<td>2,720</td>
<td>290.876</td>
<td>1.254</td>
<td>11</td>
<td>107</td>
</tr>
<tr>
<td>Drava</td>
<td>286</td>
<td>32.793</td>
<td>691</td>
<td>14</td>
<td>115</td>
</tr>
<tr>
<td>Mura</td>
<td>308</td>
<td>26.030</td>
<td>545</td>
<td>15</td>
<td>85</td>
</tr>
<tr>
<td>Total</td>
<td>4,522</td>
<td>458.558</td>
<td>1.254</td>
<td>10</td>
<td>101</td>
</tr>
</tbody>
</table>

Source of data: MAFF, 2018b.
In 2019, the Conservation of Hedgerows operation was implemented in seven Natura 2000 sites (Krakovski gozd – Šentjernejsko polje, Reka valley, Vipava valley, Planinsko polje, Ljubljansko polje, Drava, Mura) (MAFF, 2019). The operation includes areas where the hedgerows are most at risk of disappearing (Žvikart, 2019). The total number of hedgerows in the operation is 4,522 and their total length is 458,558 metres. The average length of a hedgerow is 101 metres, the longest is 1,254 metres and the shortest is 10 metres (MAFF, 2018b).

Figure 5: Map of the implementation areas of the Conservation of Hedgerows operation in Slovenia.

In 2018, 104 agricultural holdings took part in the Conservation of Hedgerows operation, maintaining a total of 134 kilometres of hedgerows. Around EUR 214,400 was paid to them as part of the operation. The majority of these, 90%, were farmers from the Ljubljana Marshes (Slov. Ljubljansko barje), while the number of farmers involved in the operation in other areas is modest (Čuš, 2019). The reasons for the large differences in the number of farmers registered between the areas are the number and length of the hedgerows. In the Ljubljana Marshes, they are the most numerous, the longest and a widely present element in the cultural landscape. The decision to join the operation is significantly influenced by the farmer’s attitude towards the hedge-row, the understanding of the operation itself and (above all) the activity and efforts of the agricultural advisors (Čus, 2019; Žvikart, 2019).
The Conservation of Hedgerows operation is protecting and conserving 4,522 hedgerows in seven Natura 2000 sites (MAFF, 2018b). These hedgerows are (more) safe from clearing, while the remaining ones are still regularly cleared or deforested, as their protection, even in the area of the Ljubljana Marshes Landscape Park, is difficult to achieve with the current legal framework. Even more worrying is the fact that we have no data and no information on what is happening to hedgerows in the rest of Slovenia. We have no information on their number, length, structure and current processes. If inappropriate practices are observed in the more protected areas of the operation, we can assume that the situation is even worse elsewhere. For example, in the Ljubljana Marshes Landscape Park, the clearing (i.e. destruction) of hedgerows has been found to be in breach of nature protection regulations. At the same time, after the removal of the hedgerows, the farmer was able to register the land (grassland) as arable land and receive agricultural payments without hindrance. The system of rules and agricultural regulations in Slovenia seems to work in a way that allows European agricultural payments to also be paid for practices that constitute a violation of nature and nature conservation regulations (Jančar, 2018).

4 LJUBLJANA MARSHES AS A PILOT AREA

For further work, we selected the pilot area of the Ljubljana Marshes, where we focused all further steps of the survey, including the field inventory of hedgerows. The Ljubljana Marshes are located in central Slovenia in the southern part of the Ljubljana Basin and cover 120 square kilometres (Pavšič, 2008). It is characterised by a mosaic landscape, an interlacement of arable fields, marsh meadows, pastures, canals, watercourses and hedgerows, which are one of the most important building blocks of the landscape (Strokovne podlage za ustanovitev ..., 2007). The main constraints to agricultural development are waterlogging and soil water, yet 82% of the area was cultivated in 2017. Almost half of the arable land is cultivated with (silage) maize as a crop, which poses the risk of the Ljubljana Marshes becoming a monotonous monoculture landscape. The size of farms in the Ljubljana Marshes is above average (12.72ha) in relation to Slovenian conditions (Kmetijstvo na Ljubljanskem barju, 2019).

Hedgerows are a traditional landscape feature in the Ljubljana Marshes. In the past, they were even more widespread, especially along canals. They were an important source of raw materials (timber) and marked the boundaries of plots owned by different owners, but today they are losing these functions. The density and composition of hedgerows vary considerably within the Ljubljana Marshes. For example, the vegetation of the hedgerows on the periphery is dominated by willows, while the hedgerows in the interior are dominated by alders. Much of the tree and shrub cover was cleared during the establishment of graphic units of agricultural holdings use (GERKs). The intensification of agriculture has made them a nuisance for many farmers. In the
Ljubljana Marshes, more farmers are involved in the Conservation of Hedgerows operation in the western part of the area, while the number of farmers involved in the operation is smaller in the eastern part. Most of the farmers in the operation have over 2000 metres of hedgerows, and two farmers have as much as 10 kilometres of hedgerows (Pečjak, 2019).

Figure 6: Survey area in the northern part of the Ljubljana Marshes.

The selected pilot area within the Ljubljana Marshes is two square kilometres in size and lies in a Natura 2000 site within the Ljubljana Marshes Landscape Park. The Landscape Park's protection regimes protect the hedgerows from cutting and maintenance works between 15 March and 30 September (Uredba o Krajinskem parku ..., 2008), but in practice there are problems with monitoring compliance with the regulations set out in the Regulation (Japelj, 2019). The pilot area is dominated by arable fields (54%) and marshy hedgerows (20%) (MAFF, 2018a), while structured and shrubby types are predominant among the hedgerows, which are identified as the highest quality types (Kastelic, 2019).
5 METHODS

In 2016, the Slovenian Nature Conservation Agency (ZRSVN), under the mandate of the Ministry of Agriculture and Rural Development, prepared the first inventory layer of hedgerows in Slovenia (Bucik et al., 2017). The layer was based on digital orthophotos from 2014, where aerial photographs are transformed from central to orthogonal projection and are dimensionally comparable to maps (Zbirke prostorskih ..., 2019). Due to the implementation of the Conservation of Hedgerows operation under the AECS, the layer was prepared in a short time and the identification of the hedgerows was based on the use of older orthophotos. Therefore, the quality of the first inventory layer was poorer in some places, as the hedgerows were recorded in a superficial way or there were errors due to changes in the actual use or removal of the hedgerows. The 2018 hedgerow layer has been updated and improved based on more recent orthophotos (from 2017) and field reports (Čuš, 2019; Žvikart, 2019). Both official boundary layers (2016 and 2018) were also field-checked for the purposes of the survey and a number of anomalies were found. Preliminary field work in 2017 in the north-eastern part of the Ljubljana Marshes recorded differences between the actual spatial situation and the 2016 hedgerow layer of record in 62% of the hedgerows (selected area). When the field verification was carried out again in 2019 (the 2018 hedgerow layer was verified), fewer differences were detected (Kastelic, 2019), demonstrating the key role of field verification of the status of hedgerows, as well as its complexity and time-consuming nature (Bucik et al., 2017; Kastelic, 2019).

As the identification and recording of hedgerows directly using orthophoto images and fieldwork did not prove to be optimal solutions for recording hedgerows, we identified hedgerows using lidar-captured data. We used imagery from the E-waters (Slov. E-vode) portal, which is maintained by Slovenian Environment Agency. We...
tested the method in a small pilot area (presented previously), where the hedgerows are more abundant and the location is close enough to Ljubljana. Laser scanning for the Ljubljana Marshes was carried out in 2014 and 2015, with a resolution of 10 pixels per m² (Izvedba laserskega ..., 2015).

The two-square-kilometre pilot area, located in the north of the Ljubljana Marshes, includes a variety of different types of grassland, and land use is heterogeneous. The base layer of lidar-captured data was filtered on the LAS DATASET layer and filtered on medium and high vegetation, as this corresponds to the criteria of a hedgerow. In order to find the best way to record the hedgerows using the lidar-captured data, two approaches were tested: approach 1 or canopy density, and approach 2 or reflection intensity.

*Figure 8: Schematic representation of the methodological approaches used with lidar-captured data.*
Figure 8 shows two different ways of processing the lidar data, resulting in two different spatial representations of the hedgerows. Canopy density or canopy cover is an estimate of the ratio of ground to canopy tops as seen from the air. It was calculated using ground and vegetation point density data. The method is useful for measurements in nature, such as calculating biomass and vegetation cover (Estimating forest canopy density ..., 2019).

Reflection intensity is the intensity of the reflected signal or the ratio of the intensity of the received light on the laser scanner. It is used as an aid in the identification of features and as a surrogate for aerial photographs. The map itself is a raster representation of the measured reflection intensity value. It covers one wavelength, namely the near-infrared part of the spectrum invisible to humans, which is only slightly larger than the wavelengths of the visible spectrum, so the display is quite similar to the perception of visible light. We can distinguish densely imaged points such as trees, houses, a road, especially at the surface, without height differences. It is difficult to predict the final range of values, as the final values depend on several variables, different sensors and are without a unit of measurement (Švab Lenarčič, Oštir, 2015).

In the final stage, the line structures of the hedgerows were drawn manually, resulting in two vector layers. All analyses were performed using ArcMap 10.7.

6 RESULTS

Identification of hedgerows using different procedures (1. field recording (2017), 2. two approaches based on lidar-captured data, 3. two MAFF hedgerow inventory layers (2016 and 2018)) yielded different results for the pilot area in the Ljubljana Marshes (Table 2). This is reflected in the number and total length of the hedgerows, which varies noticeably between all treatments.

Table 2: The Ljubljana Marshes pilot area – recorded number and length of hedgerows with different approaches.

<table>
<thead>
<tr>
<th>Procedures</th>
<th>Number of hedgerows</th>
<th>Total length of hedgerows (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hedgerow inventory layer 2016</td>
<td>88</td>
<td>9.468</td>
</tr>
<tr>
<td>Field recording of hedgerows 2017</td>
<td>122</td>
<td>11.427</td>
</tr>
<tr>
<td>Hedgerow inventory layer 2018</td>
<td>101</td>
<td>10.536</td>
</tr>
<tr>
<td>Lidar-captured data – Canopy density</td>
<td>127</td>
<td>13.978</td>
</tr>
<tr>
<td>Lidar-captured data – Reflection intensity</td>
<td>130</td>
<td>12.788</td>
</tr>
</tbody>
</table>

Source of data: Bucik et al., 2017; MAFF, 2016; 2018b.
Identification and recording of hedgerows: testing different methods in a pilot area of the Ljubljana Marshes

An analysis of the hedgerows of the two official boundary inventory layers from 2016 and 2018 shows that the pilot area in 2018 recorded a higher number and total length of hedgerows. This situation surprised us, as the total number of hedgerows in the whole area of the Ljubljana Marshes decreased significantly during this period, from 2952 to 2720. The total length of the hedgerows also decreased (by 50,000 m) (MAFF, 2016; 2018b). These data point to the questionable suitability of the 2014 DOF imagery used to compile the 2016 hedgerow inventory layer.

We looked at the problem in more detail in a smaller pilot area, where 88 hedgerows were included in the inventory layer in 2016 and 101 two years later. There could be several reasons for these differences. The changes are linked to an area with predominantly arable land use. The analysis of land use in both years shows an abandonment of arable land and thus an increase in overgrowth, which may lead to the creation of new hedgerows. The previously mentioned first capture of hedgerows from older DOF images may contribute to the lower accuracy. The start of the implementation of the Conservation of Hedgerows operation (in 2017) has introduced changes in the way the hedgerows are managed, which could have an impact on their reduced clearing. The main differences between the inventory layer and the field inventory layer are mainly in the shrub hedgerows in the arable areas in the eastern part of the site. Shrub hedgerows are the type of hedgerow that grows most quickly and probably for this reason were not yet visible on the DOF imagery.

In view of the above, the results of the inventory layers did not prove to be optimal, and we decided to develop two methodological approaches of our own, implemented using lidar-captured data, which are described in more detail in the methodology section of Chapter 5.

The canopy density map (D) shows the density of tree and shrub canopies. The boxes were visible as line graphs of the canopy. When recording the hedgerows, care had to be taken to capture clearly visible linear vegetation, which could not be more than 20 metres wide. Two different methods (canopy density and reflection intensity) based on lidar-captured data gave different results. This is due to the different levels of visibility of the images. The difference also lies in the image of the hedgerows themselves. In the reflection intensity map, the hedgerows are represented by strips in which no woody vegetation forms can be discerned, whereas in the canopy density map, the canopy can be discerned, providing a clear view of even narrower strips of vegetation.
Figure 9: Illustration and comparison of the different extent of recorded hedgerows identified by the different methods (on a section of the Ljubljana Marshes pilot area).
Table 3: Number of recorded hedgerows with different methodological approaches in the Ljubljana Marshes pilot area.

<table>
<thead>
<tr>
<th>Hedgerow layer</th>
<th>Inventory layer 2016</th>
<th>Inventory layer 2018</th>
<th>Field recording 2017</th>
<th>Lidar-captured data – canopy density</th>
<th>Lidar-captured data – reflection intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory layer 2016</td>
<td></td>
<td>+13</td>
<td>+34</td>
<td>+39</td>
<td>+42</td>
</tr>
<tr>
<td>Inventory layer 2018</td>
<td>–13</td>
<td></td>
<td>+21</td>
<td>+26</td>
<td>+29</td>
</tr>
<tr>
<td>Field recording 2017</td>
<td>–33</td>
<td>–21</td>
<td></td>
<td>+5</td>
<td>+8</td>
</tr>
<tr>
<td>Lidar-captured data – canopy density</td>
<td>–39</td>
<td>–26</td>
<td>–5</td>
<td></td>
<td>+3</td>
</tr>
</tbody>
</table>

Source of data: Bucik et al., 2017; MAFF, 2016; 2018b.

The least number of hedgerows were identified in the two official records of hedgerows (Inventory Layer 2016 and 2018) when recording the hedgerows in the Ljubljana Marshes pilot area. A larger number of more hedgerows were recorded through the field inventory of hedgerows and the two hedgerow layers that were created based on the lidar-captured data. The differences between these three hedgerow layers are also relatively small and we therefore conclude that these are more relevant.
Table 4: Lengths of recorded hedgerows (in metres) using different methodological approaches in the Ljubljana Marshes.

<table>
<thead>
<tr>
<th>Hedgerow layer</th>
<th>Inventory layer 2016</th>
<th>Inventory layer 2018</th>
<th>Field recording 2017</th>
<th>Lidar-captured data – canopy density</th>
<th>Lidar-captured data – reflection intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hedgerow layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inventory layer 2016</td>
<td>1.068</td>
<td></td>
<td>1.959</td>
<td>4.510</td>
<td>3.320</td>
</tr>
<tr>
<td>Inventory layer 2018</td>
<td>-1.959</td>
<td>-891</td>
<td></td>
<td>2.551</td>
<td>1.361</td>
</tr>
<tr>
<td>Field recording</td>
<td>-4.510</td>
<td>-3.442</td>
<td>-2.551</td>
<td></td>
<td>-1.190</td>
</tr>
<tr>
<td>Lidar-captured data – canopy density</td>
<td>-3.320</td>
<td>-2.252</td>
<td>-1.361</td>
<td></td>
<td>+1.190</td>
</tr>
<tr>
<td>Lidar-captured data – reflection intensity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source of data: Bucik et al., 2017; MAFF, 2016; 2018b.

Interestingly, the 2018 hedgerow inventory layer, both in terms of number and total length of hedgerows, differs less from the lidar-captured hedgerows than the 2016 inventory layer. This result is partly surprising due to the smaller temporal difference between the DOF imagery (which is the basis for the 2016 inventory layer) and the lidar imagery that was captured between 2014 and 2015. Our results suggest that the accuracy of the official 2016 hedgerow inventory layer is lower. The differences between the field inventory and the results of the two lidar approaches are minor, especially for the total number of hedgerows, but there are differences for the length of shrub hedgerows between fields.

We find that different images show different visual perception of the hedgerows. This has an impact on the differences in their lengths in all the layers we captured digitally. During data analysis, we detected several differences between lidar and DOF images. These differences also indicate the advantages and disadvantages of using one data layer or the other. One important technical difference is the size of the files. A lidar image measuring one square kilometre is 101 MB in size, whereas a DOF image covering an area of five square kilometres is approximately 315 MB in size. Identifying boundaries is also more difficult on lidar layers than on DOF layers, as the latter make it easier and faster to identify the linear structures of the hedgerows. On the other hand, lidar data has the advantage that it can be filtered, so that only the middle and high vegetation can be seen in the image, making the linear structures clearer and...
easier to identify than in DOF images. The lidar images also lack the shadows that can appear in DOF images and hinder visual identification, while the lidar images make it easier to detect gaps between hedgerows. It is also worth mentioning that the identification of tree avenues and other (linear) plantations that do not belong to the hedgerow layer is a problem when recording hedgerows from both images.

7 CONCLUSION

The Conservation of Hedgerows operation, which is implemented within the framework of the AECS measure, represents the first systematic attempt to conserve and maintain hedgerows in Slovenia. In seven areas in Slovenia (Krakovski gozd – Šentjernejsko polje, Reka valley, Vipava valley, Planinsko polje, Ljubljansko polje, Drava, Mura), where hedgerows are already identified in the hedgerow inventory layer, the issue of their maintenance and conservation has consequently started to be addressed more frequently among landowners, farmers and agricultural advisors (Čuš, 2019; Žvikart, 2019). In the new programming period, we can look forward to improving and expanding the different spatial layers for the implementation of nature conservation sub-interventions, which in practice will mean the extension of the record layer of hedgerows to other areas of Slovenia (MAFF, 2021).

In view of the problems identified by the nature conservation and agricultural sectors, related to the quality and maintenance of the official records of hedgerows, the search for more efficient ways to inventory new areas of hedgerows and to monitor their maintenance, the study focused on the development of methods to identify and establish the hedgerow layer. The existing system of monitoring and updating data is flawed and does not keep pace with the actual situation on the ground.

Our more detailed research in the Ljubljana Marshes pilot area between 2017 and 2019 shows that none of the three tested methods of identifying and recording hedgerows (from digital orthophotos, lidar-captured data, fieldwork) is entirely appropriate, but each approach has certain advantages and disadvantages. We note that an up-to-date spatial layer of hedgerows requires the use of the latest available data and different techniques, and although time-consuming, the methods need to be combined with field visits and inventories. The recording of hedgerows using lidar-captured data, in addition to the approaches presented in the paper, offers other possible solutions, but the identification and recording methods already presented (and tested) could certainly be used to extend the recording layer of hedgerows to other areas in Slovenia.

In conclusion, the illustrations of the hedgerows produced according to the different methodological approaches that we have carried out in the pilot area of the Ljubljana Marshes differ. Differences are also likely to be found in other areas of hedgerows in Slovenia. Although there are no large differences in the number and length of the hedgerows between the procedures, the differences are important due to the fact that
the agricultural payments for the Conservation of Hedgerows operation relate to the length of a hedgerow per linear metre. The payment in the 2014–2020 programming period was EUR 1.60 per linear metre of hedgerow and is intended to compensate the farmer for the costs incurred for their management and maintenance (MAFF, 2019).

As we currently have no data on the extent and quality of the hedgerows outside the inventory layer in Slovenia, and conservation measures cannot be implemented elsewhere under the hedgerow operation, it is reasonable to expect that agricultural trends and other spatial pressures will put these features at even greater risk. The existing inventory of hedgerows also needs to be upgraded in terms of content. At present, only the length and connectivity of the hedgerows are monitored, but not their quality. We have already experimentally extended the monitoring attributes in the context of our survey by adding information on the type of hedgerows. The field definition of the type of hedgerow can be used to better assess or infer the extent and quality of the functions that a particular hedgerow can perform. The identified quality of the functions of the hedgerows would make it easier to identify areas where their protection is particularly important or areas with poorer quality hedgerows that need to be improved.

The paper suggests some solutions towards upgrading the existing national hedge-row inventory layer. In addition to methodologically sound recording, measures and policies in the fields of agriculture, nature conservation and spatial planning will be crucial for the conservation and effective protection of hedgerows. Above all, there is a need for continuous awareness-raising among farmers, landowners and the general public about the role of the many functions of hedgerows in the cultural agricultural landscape.

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