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PRIMARY RESEARCH PAPER

An evidence-based study mapping the decline in freshwater ponds in the Severn Vale catchment in the UK between 1900 and 2019

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Abstract Freshwater ponds have long been an overlooked biodiversity store and changing types of land use and the land management practices has led to a steady decline in pond numbers. Establishing the regional extent of pond loss is the first step in identifying key areas for conservation action. This study calculated pond loss in the Severn Vale catchment UK since 1900. Identification of pond location and surrounding land use on historic and contemporary maps enabled a comparison of total number, density and distance between present day and historic ponds. 57.7% of ponds present in 1900 were lost and pond density declined from 7.3 to 4.5 ponds km^{-2} between 1900 and 2019. This resulted in a 24.6 m increase in the average distance between contemporary ponds. Land use was an important factor in determining pond loss. Although in 2019 the highest density of ponds are in rural areas, 62.3% of ponds lost were from agricultural settings (arable or pasture). Our results highlight the significant pond loss experienced in the Severn Vale since 1900 and provide a valuable baseline for pondscape restoration. The methods described are widely applicable to other regions either with a history of ponds or an environment that could sustain them.

Keywords Freshwater ponds · GIS · Land use change · Mapping · Pond loss · Severn Vale

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Introduction

In Great Britain (GB) 97% of standing water bodies are less than 2 ha in area (Bailey-Watts et al., 2000). Although individually small they constitute a substantial and valuable freshwater habitat. Understanding the distribution, quality, and heterogeneity of ponds at a pondscape scale is vital for directing practical conservation and restoration efforts. These smaller water bodies support around two-thirds of all wetland plants and animals found in Britain (Williams et al., 1997). When compared to other freshwater habitats, ponds support more species of macrophytes and macroinvertebrates (Williams et al., 2004; Davies et al., 2008), and often outperform lakes and rivers in the number of nationally scarce and IUCN red list species they support (Wright et al., 1996; Biggs et al., 2005). In increasingly managed and homogenous landscapes, these small but rich habitats are important biodiversity hotspots. In addition to their biodiversity value, ponds also provide ecosystem services

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(Tscharntke et al., 2005), such as floodwater attenuation (Oertli et al., 2009; Hill et al., 2016), carbon storage (Downing et al., 2008) and recreational and aesthetic amenity value (Boothby et al., 1995). There is also increasing evidence that ponds also support terrestrial species such as farmland birds (Lewis-Phillips et al., 2020), bats (Downs and Racey, 2006; Stahlschmidt et al., 2012; Heim et al., 2017) and pollinators (Stewart et al., 2017; Walton et al., 2020). Clearly, even though ponds are small features they remain key components of healthy landscapes and the numbers and quality of ponds at national and regional scale should give cause for concern (Boothby, 1999; Biggs et al., 2005; EPCN, 2007; Hill et al., 2021).

In 2007, the total number of ponds in the United Kingdom (UK) was estimated at 480,000 that collectively covered about 190,000 ha of land (Haines-Young et al., 2000; Williams et al., 2010). As no standardised inventory of ponds were available these national estimates for GB were generated by counting the ponds in 591 one square kilometre areas, and extrapolated these to calculate a national figure as part of the UK government's Countryside Survey (Williams et al., 2010). Whilst these national estimates are useful for headline indications of present day pond abundance, the data become less pertinent at the smaller, local landscape level, where the number and distribution of ponds is likely to be more idiosyncratic (Wood et al., 2003).

In addition to curating present day data on pond abundance and distribution, the value of historic pond data is increasingly being highlighted (Frajer et al., 2021). Temporal mapping of ponds using historic maps can precisely locate and quantify lost ponds, which is particularly useful to practical pond conservation efforts in several ways. Firstly, by establishing the historic location of individual ponds, we can prioritise locations at which the existing seed bank can be used to facilitate pond establishment (Alderton, 2017). Secondly, by establishing the extent and distribution of pond loss at a landscape scale, we can prioritise areas within the pond network (Céréghino et al., 2007; Hill et al., 2021). A large number of historic ponds were anthropogenic in origin, being created for a variety of purposes (Gledhill and James, 2012) and therefore have the potential to have strong socio-cultural connections for stakeholders. Mapping historic pond distribution at a landholding scale can therefore also be a useful engagement tool, potentially helping to overcome barriers to pond creation and/or restoration.

The Severn Vale management catchment (Fig. 1), hereafter referred to as the Severn Vale, is a diverse landscape of 1,487 km^2 in the Southwest of England (Environment Agency, 2019). Examining pond loss at this scale and across a diverse range of habitat types available in the Severn Vale also means the methods developed in this research are readily applicable in other countries and settings that need to accurately assess pond loss.

This study collates the location data for ponds at a regional scale from historic and present day sources and standardises these data into comparable file formats. Once the historic and present day pond locations and distributions have been established, this study then examines the change in pond number and density. The precise distance between ponds are calculated and compared with land use categorisation

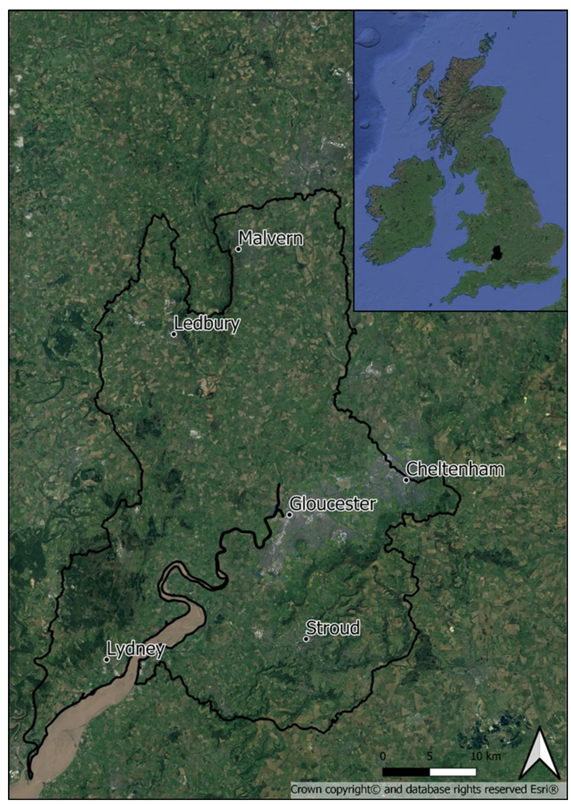


Fig. 1 The Severn Vale study area, highlighting main urban regions

from both time periods. Together these data establish the key landscape scale temporal changes that have occurred and identify the probable causes of pond loss across the catchment.

Methods

Study area

This study examines pond loss within the Severn Vale (Fig. 1), an area of 1,487 km^2 in the Southwest of England that incorporates multiple counties. It encompasses the city of Gloucester and the spa town of Cheltenham in the north, with large areas of primarily coniferous woodland to the west (the Forest of Dean) (Fig. 2A). Flat, low-lying land makes up an extensive floodplain region surrounded by hills with many small rivers, streams and brooks that drain into Severn Estuary or directly into the River Severn, the UK's longest river. The topography of the area ranges from sea level to 411 m above sea level (Fig. 2B). A large proportion is low-lying agricultural land and overall the Severn Vale represents a good range of natural environments in which to demonstrate the benefits of collating and curating precise pond data.

Pond definition

In this paper we adopt the most common definition used in UK pond research (Pond Action, 1995; Boothby, 1999; Biggs et al., 2005), whereby a pond is defined as a water body which is between 1 m^2 and 2 ha in area and can include both manmade and natural water bodies. This simple size based definition was used to ensure that small lakes were not included in the analysis, and using 1 m^2 as the lower range it ensured that all ponds present on historical

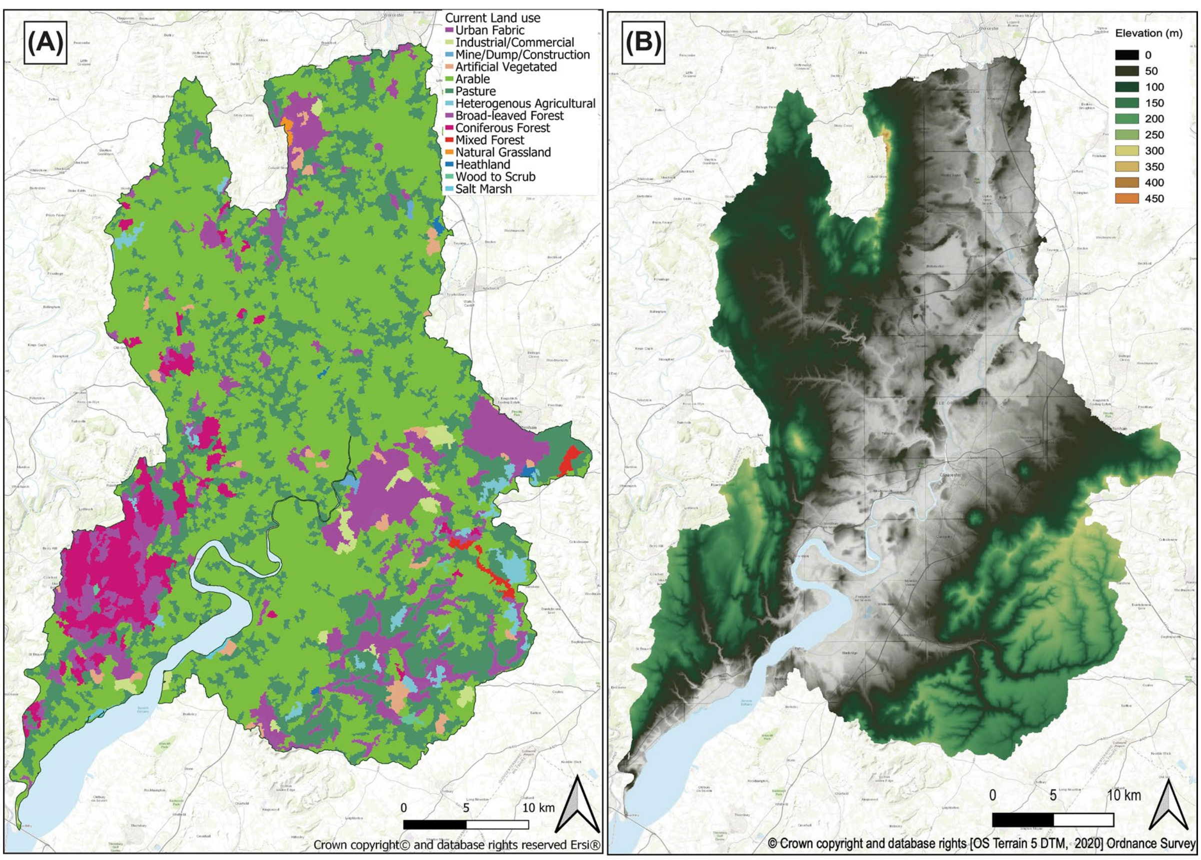


Fig. 2 **A** Classified land and **B** topographic map of the Severn Vale

and present day were included in this study. All ponds included in the data met this criterion, as ponds that appeared to be larger or were labelled as lakes on the maps analysed were measured in QGIS v 3.10.0 to confirm. The full pond categorisation used can be found in Table 1.

Pond mapping method

Ordnance Survey (OS) 1:10,560 County Series historic maps from 1900 to 1909 (EDINA Digimap Ordnance Survey Service, http://edina.ac.uk/digimap) were used to identify the location of historic ponds. Data derived from these is referred to as historic or 1900 (as the oldest date used). Digimap includes earlier maps from the 1880s and 1890s but coverage of the Severn Vale is incomplete. Maps from 1900 to 1909 provided the most complete dataset within the same map edition and included the period before the 1914 World War. This is important because pond loss has been associated with the increasing demand for crops and changes to intensive farming practise in the UK that occurred after the Second World War (Rackham 1986). Google satellite maps and an inland waterbodies shapefile layer (OS Open Zoomstack 1:10,000, https://www.ordnancesurvey.co.uk/business-government/products/open-zoomstack, downloaded 2019) were used to locate the ponds currently present. QGIS software version 3.10.0 was used to manually locate each pond.

Land use maps from 1930 to 1935 (Vision of Britain, 2017) and present day land use data from 2018 (Copernicus, 2018) were used to assign each pond with a historic land use and a current day land use (see Table 2). These data were used to evidence the habitat changes that have occurred across the Severn Vale over the last century.

Table 2 Categories of land use on the historic and present day maps. If blank there is no historical equivalent land use

Historic land cover types	Present day land use type equivalent
Arable	Arable
Common	Common
Coniferous forest	Coniferous forest
Deciduous forest	Broad-leaved forest
Garden	Garden
Heath	Heathland
Industrial	Industrial/commercial
Marsh	Salt marsh
Marsh pasture	Marsh pasture
Mixed wood	Mixed forest
New housing development	New housing development
New plantation	New plantation
Orchard	Orchard
Park	Park
Perm grass	Permanent grass
Rough pasture	Pasture
Urban residential	Urban fabric
	Artificial non-agricultural vegetated
	Heterogeneous agricultural
	Mine/dump/construction
	Natural grassland
	Wood to scrub

Analysis

Pond density in 1900 and 2019 was calculated by dividing the total number of ponds present by the catchment area, generating ponds km^{-2} and permitting a calculation of change in pond density. Using QGIS v3.10.0 a graded density map was produced using the *Count points* in the *Polygon Analysis* tool.

In addition, the *Nearest Neighbour Analysis* tool in QGIS v3.10.0 was used to determine the change

Table 1 Categorisation of pond types used in this research

Pond type	Description
Historic	Ponds which are marked on the historic OS map but have disappeared by 2019 and cannot be found on the current water body layer. These ponds have therefore been lost within the time frame
Both	Ponds which can be found marked on both the historic OS map and the current water body layer. These ponds have been retained from the early 1900s to present day
New	Ponds which can be found in 2019 on the current waterbody layer but are not marked on the historic map. These ponds have been created within the time frame examined

in the average distance between ponds over time; if the output is less than 1 the pattern exhibits clustering, whereas if the output is greater than 1 the trend is towards dispersion. This analysis also provided the expected mean distance which is calculated based on the hypothetical random distribution of the points in the same area. The z-score measures the statistical significance of the data to decide whether or not to reject the null hypothesis (in this case that features are randomly distributed). The z-scores which (when measured in standard deviation units) describe the position of a raw score in terms of its distance from the mean, a z-score of 0 is equal to the mean. A very low or very high z-score indicates it is unlikely that the observed spatial pattern reflects the theoretical random pattern represented by your null hypothesis and confirms that the data exhibit statistically significant clustering or dispersion.

For an overall representation of distances between all ponds the *NNjoin plugin* was used to obtain the distance to the nearest pond from all ponds in the same point layer (i.e. ponds present in 1900 and 2019).

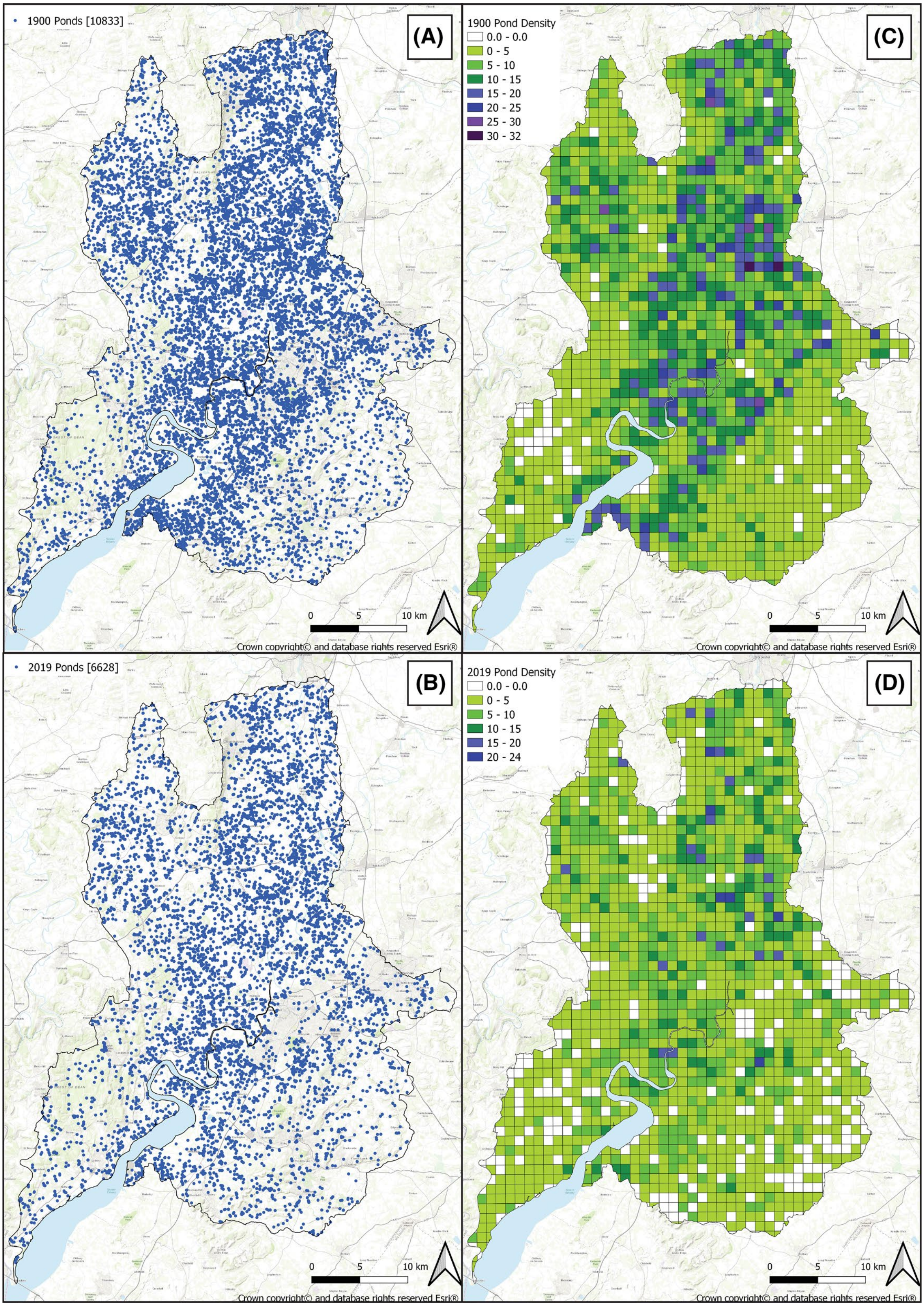
Net and percentage pond loss were calculated for each type of land use that changed. Then historic land use in the Seven Vale was categorised according to the maps from Vision of Britain (Vision of Britain, 2017), current descriptions of land use were then categorised as close as possible to historic uses (see Table 2). Land use which matched in both historic and present day maps were given the same category name, however not all categories were present in both time frames so could not always be matched. In this study no ponds were identified in contemporary maps for land use categories that no longer exist and so on this occasion did not need to be addressed. Pond density was also calculated with respect to land use category. Using the *Count Points* in the *Polygon Analysis* tool the number of ponds present in 2019 were counted for each current land use type, this count was then divided by the area (km^{-2}) covered by the relevant land use type.

Results

A total of 10,833 ponds were identified using the historic maps, of those, 4,580 were retained in the present day maps. This indicates a 57.7% loss of all ponds present in 1900. In the same period 2,048 new ponds had been created resulting in a net loss of 38.8% (Fig. 3A, B). Mean pond density declined from 7.28 per km^2 in 1900, to 4.46 per km^2 in 2019 (Fig. 3C, D). These data evidence an increasing distance between individual ponds and their closest neighbouring pond (Fig. 4). Nearest neighbour analysis (Table 3) demonstrates that both historic and present day pond distribution show clustering tendencies, both had a nearest neighbour index of less than 1 (0.61 and 0.56, respectively). This suggests that pond locations tend to be clustered within particular areas of the landscape, with clustering levels slightly higher historically than present day. Observed mean distance of each pond from its nearest neighbour in 1900 was 154.6 m, increasing to 179.2 m in 2019. Nearest neighbour analysis generated z-scores of − 78.7 (historic) and − 68.6 (present day), values which confirm significant clustering in both time periods.

Comparison of land use maps for the two periods indicated notable land use change over the last ca. 120 years in the Severn Vale (Table 4), with many areas moving to more intensive agricultural practices. The largest number of ponds lost were associated with changes in agricultural use (agricultural uses are classified here as arable or pasture). These accounted for 62.3% of all ponds lost in the catchment. More precisely when land use changed from permanent pasture to arable, 2,747 ponds were lost which accounts for 43.9% of all the original ponds identified that no longer exist. However pond creation was also most commonly associated with arable land use, with at least 725 ponds being created in an arable setting (Table 4). In addition, net gains in pond number were also associated with areas where woodland was created or maintained.

There were 9,576 ponds located below the 100 m above sea level demarcation in 1900 which fell to 5,698 ponds in 2019. This represents 88.4% and 85.9% of all ponds across the Severn Vale for these years. In the Severn Vale in 2019 the highest density of ponds was associated with land classified as mine/dump/construction followed by heathland, 5.53 and 5.48 ponds per km^2 respectively, despite the small area that these represent within the study area (Table 5). The analyses show that the number of ponds in arable and pasture have reduced significantly since 1900, although they maintain a relatively high density of ponds in present day compared to other


1900 Ponds [10833]
(A)
0
5
10 km
Crown copyright© and database rights reserved Esri®
1900 Pond Density
0.0 - 0.0
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 32
(C)
2019 Ponds [6628]
(B)
2019 Pond Density
0.0 - 0.0
0 - 5
5 - 10
10 - 15
15 - 20
20 - 24
(D)

◂**Fig. 3** Pond change between 1900 and 2019 respectively for total pond position shown in blue (**A** and **B**) and pond density by count (**C** and **D**)

land uses (Table 5). The lowest pond density was associated with wood to scrub land use at 0.81 ponds per km^2 and natural grassland where no ponds were recorded (Table 5).

Discussion

The most accurate estimate of total contemporary pond numbers for GB is from the 2007 Countryside Survey Report (Williams et al., 2010), which gives an estimate of 478,000. The current study identified a total of 6,628 ponds currently within the 1,487 km^2 of the Severn Vale, representing ca. 1.7% of GB's estimated total.

Available evidence suggests that current pond numbers are significantly lower than they have been historically (Biggs et al., 2005). This study calculated a 57.7% loss of ponds, with 6,252 of the ponds present in 1900, being lost by 2019. Percentage of pond loss in the Severn Vale is comparable to other regional estimates which range from 85% in Birmingham (Thornhill et al., 2017), to 61% in Cheshire (Boothby and Hull, 1997), and 69% in Essex (Heath and Whitehead, 1992). Outside of the UK there are similar reports of significant pond loss over similar time frames. Over approximately 100 years, up to 70.2% of ponds were lost in Pomerania, Poland (Pieńkowski, 2003), and 90% in Rio Grande do Sul, South Brazil (Guadagnin et al., 2005). Over 80 years 51.8% of ponds were lost in northwest Croatia (Hutinec and Struna, 2007), and 35% from Tuscany, Italy in 70 years (Scoccianti, 1999).

Biggs et al. (2005) estimated national pond loss in the UK to be 18.4% over a 50-year period (1948–2000). These data were generated using estimates from previous studies, and compared those to their current evaluations. Notably, all these data describing pond loss in regional areas are considerably larger than the national estimate generated by Biggs et al. (2005). The regional studies typically covered longer time scales (90–120 years), and therefore also included ponds lost in the years before 1948. Notably, Alderton (2017) examined pond loss in Norfolk over a similar time frame (1955–2014), and reported a 47% pond loss; also larger than that generated at a national scale. Disparities between regional and national percentages loss estimates could be attributed the disparity in spatial scale. It is therefore important to standardise estimates of pond loss per unit area, by calculating a pond density value.

National estimates of present day pond density are 1.8, 2.5 and 2.2 ponds km^{-2} for England Scotland and Wales, respectively (Williams et al., 2010). This study has demonstrated present day pond densities of 4.46 ponds km^{-2} for the Severn Vale. Indicating that the Severn Vale remains an important hotspot for ponds in a national context. However the historical pond density of the Severn Vale (7.28 ponds km^{-2}) indicates that the Severn Vale had a similar pond density to other areas of the country. In 1870 Cheshire records show approximately 11.9 ponds km^{-2} (Boothby 1995) and Birmingham an estimated 7.1 ponds km^{-2} (Thornhill et al., 2017).

The decline in pond density evidences an increase in the average distance between ponds. For the Severn Vale average distances between ponds increased from 154.6 to 179.2 m between 1900 and 2019. Similar increases of distance between ponds have been previously reported (Alderton, 2017; Thornhill et al., 2017). A number of studies demonstrate the detrimental effect increased distance can have on plant species (Bosiacka and Pieńkowski, 2012), amphibians (Jeliazkov et al., 2013), invertebrates (Delettre and Morvan, 2000) and water birds (Sebastián-González et al., 2009). There is potential for increasing pond isolation to play a role in pond degradation as well as negatively impacting species richness. However it is also acknowledged that the benefits of connectivity between ponds needs to be considered carefully, especially in the context of non-native and invasive species (Oertli et al., 2009; Jeffries, 2011).

In England and Wales two-thirds of ponds have more than 50% of their surroundings categorised as 'intensive' agricultural land (Williams et al., 2010). In England alone, since 1900, thousands of hectares of crop and fallow land has been created, increasing from 3,406,000 to 4,201,000 ha in 2010 (Defra, 2010). Agricultural land use now makes up 69% of the UK's total area (Defra, 2019). In Cheshire, 81.3% (4096) of the ponds lost were attributed to changes in agricultural practice between 1870 and 1985 (Boothby et al., 1995). Even within agricultural area the extent of pond loss can vary substantially. For

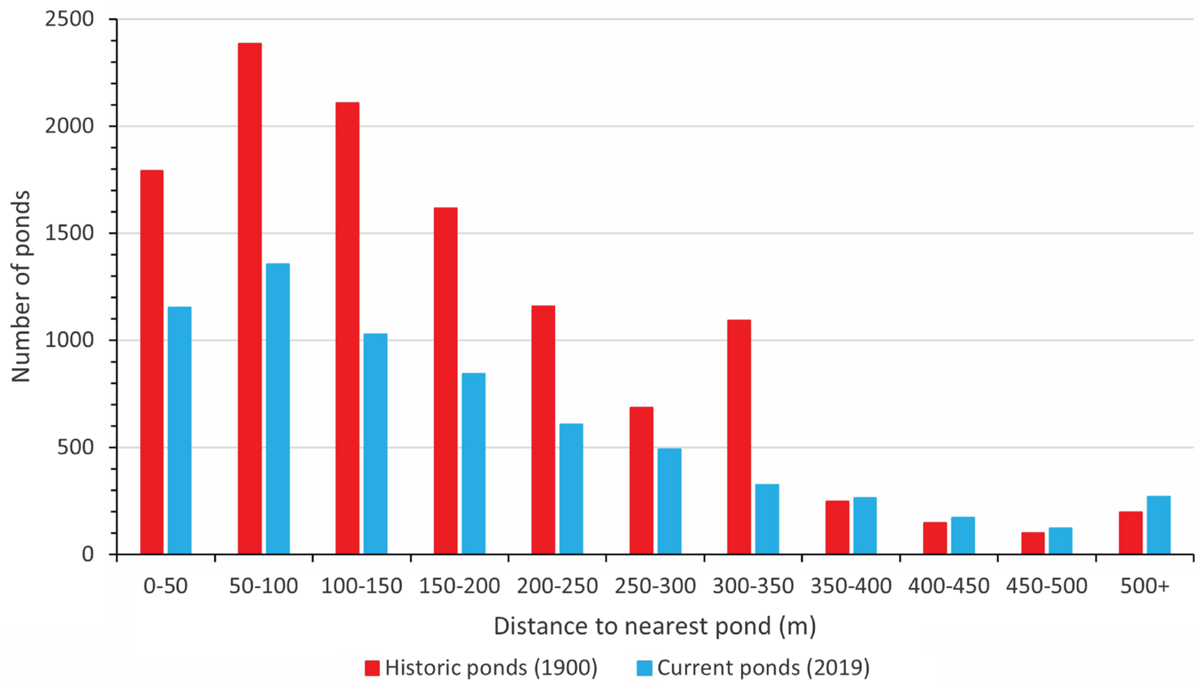


Fig. 4 The distance from each pond to the nearest pond in 1900 (red) and 2019 (blue)

Table 3 Results of the nearest neighbour analysis (2dp)

	Historic (1900)	Present day (2019)
Nearest neighbour index	0.61	0.56
Observed mean distance (m)	154.61	179.16
Expected mean distance (m)	255.75	320.10
Z-score	− 78.75	− 68.59

example, Alderton (2017) described pond losses of 17.1%, 45.1% and 47.5% within three farmed landscapes examined in North Norfolk. A similar value of percentage loss was observed in the Severn Vale, where 40.2% (2,514 ponds) of ponds were lost when land primarily located in lowland areas converted from permanent grass to arable. Within the Severn Vale, ponds lost in areas associated with changes of agricultural use totalled 62.3% of all the ponds lost.

Table 4 Land use changes associate with pond loss, shown are only land use changes where more than 50 net ponds were lost

Land use		Pond type			Total ponds		Number of ponds lost
Historic	Current	Historic	Both	New	Current	Historic	
Permanent grass	Arable land	2747	2042	752	2794	4789	1995
Permanent grass	Pastures	1020	838	341	1179	1858	679
Permanent grass	Urban fabric	310	47	39	86	357	271
Garden	Arable land	375	316	123	439	691	252
Arable	Arable land	362	226	131	357	588	231
Orchard	Arable land	291	325	93	418	616	198
Garden	Urban fabric	124	30	21	51	154	103
Garden	Pastures	125	121	53	174	246	72
Orchard	Pastures	99	88	32	120	187	67
Arable	Pastures	98	72	43	115	170	55
	Total	5551	4105	1628	5733	9656	3923

Table 5 Density of ponds km^{-2} present in 2019 according to current day land use type

Current day land use type	Land use area (km)	Density of ponds km^{-2}
Mine/dump/construction	1.81	5.53
Heathland	2.19	5.48
Arable	796.52	5.23
Pasture	355.37	4.88
Artificial non-agricultural vegetated	17.61	4.60
Heterogeneous agricultural	20.27	3.06
Industrial/commercial	15.92	2.51
Mixed forest	5.62	2.49
Broad-leaved forest	82.25	2.18
Coniferous forest	74.12	1.89
Urban fabric	109.79	1.53
Salt marsh	1.46	1.37
Wood to scrub	2.48	0.81
Natural grassland	1.14	0

The link between pond loss and agricultural land use change is not limited to the UK. Agricultural practices have changed worldwide, often leading to increased land use intensity. Croplands and pastures now cover around 40% of global land surface (Foley et al., 2005). For example, over the period 1975–2006 ponds in north-western France were mapped in relation to land use, with pond loss mainly attributed to decreasing grassland and an increase in arable fields. Small manmade ponds and drinking trough ponds were impacted the most and saw higher rates of loss than semi-natural ponds such as those used for duck hunting (Curado et al., 2011).

Other studies have demonstrated higher rates of pond loss to urban expansion. For example, in Birmingham between 1904 and 2009 there was an 82% decline that resulted in 1,573 ponds lost (Thornhill et al., 2017), and in Essex there was a 69% pond loss from 1870 to 1989 (Heath and Whitehead, 1992). However, it is worth noting that in Essex and Birmingham the initial number of ponds was lower than in more rural areas such as the Severn Vale. Though pond loss in Birmingham was largely attributed to suburban expansion, the second highest category of net pond loss was within farmland areas (Thornhill et al., 2017), confirming that agricultural land use change affects diverse regions of the UK, even those areas not typically associated with farming and agriculture. In the Severn Vale only 0.1% of ponds were lost to urban expansion, reflecting the clear differences in urbanisation in the two landscapes.

Other factors with the potential to influence the location of pond loss should also be considered, for example this research identified topographical elevation as an important factor of where ponds are present in the landscape. This relationship has not been examined in previous studies, however within the Severn Vale there is a wide topographical range, which allowed for this potential relationship to be investigated. Additionally variations in pond presence can be influenced by the underlying reasons that lead to pond creation. Often the purpose or function of a pond is linked to their disappearance. For example, ponds used for irrigation of orchards were lost when those orchards were removed (291 ponds in the Severn Vale data set). The purpose of a pond varies and may be unique between regions and land use leading to varying levels of pond loss. Using national generic values is likely to underrepresent the complexity of the situation on the ground. The methods employed in this study to record each pond resolve this problem and land use biases do not arise. However if only general estimates are required then analysing a small subsection of the larger catchment using these methods (of identification and land use analysis) and extrapolating will increase the confidence in the data by considering the categories of land use coverage.

Despite the overall picture of declining pond presence in the UK, there have also been some important gains recorded. In the Severn Vale more than two thousand new ponds were created between 1900 and 2019. Many of these were associated with woodland creation or maintenance. The most notable woodland in the Severn Vale is the Forest of Dean. Here ponds were typically created as water supplies for local industry or villages and through habitat and wildlife conservation efforts. When executed well pond creation can be extremely important to the wider biodiversity of that area. In heterogeneous farmland landscapes local habitat creation and management of ponds can reduce the isolation of species from coloniser sources (Tscharntke et al., 2005). Williams et al., (2008) found that newly established pond complexes were quickly inhabited by macroinvertebrates over 3–4 years and by macrophytes in 6 years.

It is also common, especially when the original purpose of anthropogenically created ponds no longer exists, for ponds to succeed and become terrestrialised areas of scrub (Sayer et al., 2012; Goodrich et al., 2015). Restoration of "ghost" ponds can facilitate the rapid re-colonisation of aquatic macrophytes (Alderton, 2017) in addition to providing a range of other biodiversity benefits (Williams et al., 2004; Oertli et al., 2005; Davies et al., 2008; Lewis-Phillips et al., 2020).

The value of a standardised pond mapping protocol

Despite increasing recognition of the multiple benefits that ponds provide, substantial knowledge gaps remain (Oertli et al., 2009). Data to describe the number and location of present day and historical ponds may be held by several organisations (Hull, 1997) and in a variety of formats. The lack of readily available data to describe pond distribution highlights the need for a standardised, accurate method for landscape level mapping, this study provides an important key step toward this goal.

The evidence suggests that the pond loss observed in the UK has been experienced right across Europe (Scoccianti, 1999; Pieńkowski, 2003; Hutinec and Struna, 2007). This loss of habitat is likely to be widespread and many regions have insufficient data to describe their current pondscapes or how these might have altered through time. Clearly a need exists for a standardised method to track these losses worldwide to provide a better holistic understanding of overall pond health and distribution. The GIS analysis of historic maps described here provides an opportunity to retrospectively generate historic data to describe ponds that would otherwise not be possible and creates longitudinal studies of pondscape changes.

Any pond survey relying on maps can only include ponds that were recorded on the maps and it is possible that some ponds may have been misidentified or overlooked. In general only permanent ponds are mapped, those which are semi-permanent (and dry out during periods of drought), although ecologically important are often not classified on maps (Williams et al., 2001). Semi-permanent ponds were not differentiated on the maps used to generate the data in this study. In addition, maps especially historical maps, have a tendency to only identify larger ponds (Wood et al., 2003). An absence of the smallest ponds recorded on historic maps can result in recording bias and an underestimate of pond numbers, and potentially an overestimation of 'new' ponds. Historic maps provide a unique resource to explore pond locations that may not have been recorded in any other form. Therefore despite the potential for bias historic maps remain valuable for mapping small-scale features. This method was used for historic pond counts by Jeffries (2011) who successfully audited pond features greater than 4 m in diameter from 1:10,000 maps of Northumbria from the 1860s. In addition research from Poland identified waterbodies from 1:28,000 military maps of the 1800s at minimum 0.5 ha (Pavelková et al., 2016) and maximum 3 ha (Frajer et al., 2020) scale. Minimum features size should be considered when analysing map data. Ordnance Survey maps change in detail after 1880 and the minimum size for depiction of many features became 4×4 m (Oliver, 2005). In this study, a minimum pond size of 1 m^2 was adopted to ensure all ponds were captured. This ensures the complete size range of ponds from more detailed contemporary maps are included. It also provides a robust method of pond identification that can be applied regardless the scale of maps being used.

Without detailed pond distribution mapping a comprehensive understanding of pond density, land use associations and how pond isolation might be responding to landscape change is challenging. By demonstrating at the catchment scale, both pond loss and pond density in the Severn Vale the data evidences the increased isolation for the ponds that remain. Overall, the study provides valuable baseline data, is unique in its size, and is key to setting the scene for landscape conservation and restoration within the Severn Vale pondscape. Given the size and scope of this study the methods can be replicated to any area worldwide which has sufficient historical maps to meet similar objectives. Manual identification and digitising does provide important data about pond distribution but it is a time intensive process and cannot provide any indication of pond quality or condition. With advances in GIS technologies and the availability of remote sensing data, developing a more automated approach for small waterbody mapping is a priority. Remote sensing monitoring tools developed for large waterbodies increasingly include metrics of abiotic and biotic condition [e.g. Dörnhöfer and Oppelt, (2016)], however, fewer equivalent tools for small water bodies have been developed [e.g. (Shi et al., 2022)], therefore well-developed manual assessment techniques such as PSYM (Environment Agency and Pond Action, 2002) are more commonly used for ponds. Defining the overall condition of existing ponds would enable a more comprehensive landscape analysis which is key to understanding the vigour of the pondscape. This in turn answers questions about the most suitable conservation techniques and prioritisation of restoration or creation at sites to increase local and landscape level biodiversity.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest associated with this work.

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