2023

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Blogg, M.

Blogg, M. (2023) 'The effect of hedgerow age on vegetative species diversity', The Plymouth Student Scientist, 16(2), pp. 199-223.
https://pearl.plymouth.ac.uk/handle/10026.1/21839

University of Plymouth

*The Plymouth Student Scientist, 2023,**16**, (2), 199-223*

The effect of hedgerow age on vegetative species diversity

Matthew Blogg

Project Advisor: Dr Sophie Fauset, School of Geography, Earth and Environmental Science, University of Plymouth, Drake Circus, Plymouth, PL4 8AA.

Abstract

Hedgerows are a distinctive part of the English countryside and provide many ecological benefits and services. Over recent history, hedgerows have been removed and replanted, resulting in a matrix of different aged hedgerows across the country. In this study, the effect of hedgerow age on vegetative species diversity was tested to see if older hedgerows contained a higher species diversity than younger hedgerows. Four hedgerows of varying ages were tested on an urban farm in Plymouth, Southwest England. Percentage cover of each species was measured across ten samples in each hedgerow, with a Shannon's diversity score being calculated for each sample and then repeated for each of the four different aged hedgerows. Vegetative species diversity was found to differ between each of the four hedgerows with the Devon bank having the highest diversity score and the orchard hedgerow the lowest. Although some significant differences were found, these were not able to conclude that older hedgerows contain a significantly higher diversity than younger hedgerows. Differences in hedgerow functional group composition were also observed and these may be due to factors other than age such as surrounding land use or structure. Furthermore, the distribution of autumn and winter fruiting species was tested due to their ecological importance and was found that a higher proportion was contained within the old hedgerow. It could be implied that the lack of management on the hedgerows sampled was negatively affecting their diversity through all ages. Future studies would be required to see if the age of hedgerows is influencing diversity and composition by testing a wider range of hedgerow ages and by sampling during different seasons. Recommendations for future hedgerow management have been made based on the surrounding literature in order to improve hedgerow diversity and its subsequent benefits.

Keywords: Hedgerow, species diversity, hedgerow management, autumn/winter fruiting, Devon bank

Introduction

A hedgerow can be defined as any boundary line of trees or shrubs over 20m long and less than 5m wide at the base (DEFRA, 2007). Their primary use is to delimit properties, protect crops and contain livestock but they also provide several ecosystem services (Lecq *et al.,* 2017). The Countryside Survey (2007) estimated there was 402,000km of managed hedgerows in England in 2007 but this is a loss of 26,000km since 1998, with a large proportion turning into relict hedgerows due to a lack of management. However, in 1950 a Forestry Commission report concluded there was 1 million kilometres of hedgerows (Peoples Trust for Endangered Species, PTES, 2023 (a)), indicating a significant loss since. The aim of this study is to test whether the age of a hedgerow has any impact on its plant diversity.

Importance

Hedgerows are key components in the English countryside, for the species they facilitate and the natural capital they provide. They can act as habitats for both animals and plant species and are particularly important in farmland environments. A study by Sanderson *et al.,* (2009) found that mixed farming systems with abundant woody edge habitats, such as hedgerows, are likely to retain high overall avian species richness. For plant species, especially in agricultural landscapes with low forest cover, hedgerows add to the available habitat of many forest species (Wehling and Diekmann, 2009). This study also showed that hedgerows can also act as extensions of woody habitats due to their component species, with more than three quarters of all forest plant species in the sample area being found in hedgerows. Biological corridors are important for some flora and fauna as they enable movement between increasingly fragmented habitats. The cover hedgerows provide allow the safe passage of invertebrates and small mammals from the predation from larger predatory mammals and birds. For hedgerows to act as biological corridors, their individual internal characteristics and structure determine which species will be facilitated and which discouraged. For example, the most important factor for hedgerow use by predatory mammals, such as European badger (*Meles meles*), is width and a high shrub cover but for smaller mammals like the hazel dormouse (*Muscardinus avellanarius*) the most important factor is continuity with no gaps for crossing (Dondina *et al.,* 2016).

Plant species that make up hedgerows also can provide food for animal and invertebrate species. They can be especially important in winter when other food sources are scarce. Species such as blackthorn (*Prunus spinosa*) and hawthorn (*Crataegus monogyma*) produce fruit which is a useful winter food resource for small mammals and form a large part of the resident and migratory farmland bird diets (Jacobs *et al.,* 2009). Vegetation in hedgerows also has the ability to sequester atmospheric carbon and store it through the process of photosynthesis. Although there has been a recent focus on the carbon storage properties of woodlands and other agroforestry projects, hedgerows have been overlooked and little explored (Axe *et al.,* 2017). This study also showed that actively managed hedgerows showed a higher ability to store carbon and at higher densities of hawthorn and blackthorn shoots and there was a more efficient use of above ground biomass carbon storage when compared to other woody vegetation. Due to hedgerows growing with some height, they are able to act as effective wind breaks, reducing windspeed on the far side and in turn reducing soil erosion. Böhm *et al*., (2014) found that windspeeds had been significantly reduced by hedgerows when compared to windspeeds in an open environment, possibly leading to ecological and agricultural benefits.

Plants and vegetation are strongly linked to hydrological cycles due to their fundamental importance for evapotranspiration through stomatal activity and transpiration and runoff through interception and albedo (Gerten *et al.,* 2004). Hedgerows have a critical influence on soil water transfer during summer and autumn due to rainfall interception and transpiration (Ghazavi *et al.,* 2008). This increased transpiration can also affect nutrient cycling as woody hedgerows have higher transpiration rates than crops or grasslands and play a role in the nitrogen cycle, raising the question of their impact on water and nitrogen balances in watersheds (Benhamou *et al.,* 2013).

Threats to Hedgerows

Although the importance and benefits of hedgerows have been highlighted by countless articles, they have long been overlooked and not valued. After World War Two, the government encouraged the removal of hedgerows through the means of grants and financial incentives (RSPB, 2022). Since the 1950's, agriculture has shifted towards more intensive practices involving larger and more powerful machinery, higher inputs of fertilisers and pesticides and the enlargements of farms, all of which leading to significant hedgerow removal (Burel and Baudry, 1995). This hedgerow removal was believed to be necessary to facilitate the larger machinery which could not operate in small fields and to maximise crop output and efficiency. Agriculture is not the only source of pressure being applied on hedgerows. Since 2011, the population of England and Wales grew by 3.5 million or 6.3% (ONS, 2022). This increasing population needs to be housed somewhere and therefore housing developments have increased into rural areas, possibly leading to the removal of hedgerows. Land area under urban use has steadily increased from 1925 to 2007, gaining approximately 50% of its original land area cover (Bell *et al.,* 2011). The expansion of urban land can also exacerbate the problem of habitat loss by creating increasingly fragmented habitats such as woodlands. This can again be illustrated with the hazel dormouse, an arboreal species where a study by Mortelliti *et al.,* (2011) found that an important factor in the conservation of this species is the connectivity represented by a hedgerow network.

Although many hedgerows are found in agricultural systems, some of their practices can be damaging to hedgerows. Ploughing arable land too close to the base of hedgerows can directly remove ground vegetation and damage roots of hedgerow trees and shrubs, which can kill or stress these individuals and is often enhanced in times of drought (PTES, 2022). Agrochemicals such as pesticides and fertilisers applied to farmland may also have indirect effects on hedgerows. When a buffer zone is present for pesticide application, it may reduce pesticide deposition from drift to the hedgerow and its associated flora in comparison to conventional application (Longley *et al.,* 2009). Hedgerows may also buffer against fertiliser application to other habitats, its deposition at the base may lead to the proliferation of nitrophilous plant species (Tsiouris and Marshall, 1997), such as common nettle (*Urtica dioica*) or cow parsley (*Anthriscus sylvestris*).

Management of Hedgerows

Hedgerows cannot just be planted and left alone, they require periodic management to maintain their structure and fulfil their desired purpose. Degradation of hedgerows due to lack of management can lead to the transformation into “relict hedgerows” or lines of trees, to which the UK lost 6.2% over the decade to 2007 mainly to this neglect (Staley *et al*., 2015). On the other hand, the over management of hedgerows can have negative impacts. The typical current technique is to trim hedgerows with a mechanised flail every year and has resulted in some hedgerows becoming very reduced (Croxton *et al*., 2004). Hedgerow management would traditionally be done by hedge laying or coppicing on a 20–40 year cycle to maintain them as stock proof barriers (Staley *et al*., 2013). Hedge laying involves the partial removal of woody material and the severing of stems to encourage vertical growth at the base of the hedgerow, rejuvenating the hedgerow and improving structure and strength. Coppicing involves the cutting of stems close to ground level to encourage growth at the base (Staley *et al*., 2015). Hedgerow rejuvenation is being encouraged as a management method by the UK Government. Countryside stewardship grant BN5 for hedgerow laying (GOV.UK, 2022 (a)) provides a grant to lay hedgerows and sets out a list of requirements. Countryside stewardship grant BN6 for hedgerow coppicing (GOV.UK, 2023 (b)) also provides financial incentives to landowners to manage hedgerows however it does not provide as much money as the BN5 grant, possibly reflecting the study by Staley *et al*. (2013) showing that species richness had been reduced over 70 years in a coppiced hedgerow but slightly increased in a laid hedgerow.

Knowledge Gap

Many of these research articles have found or focused on the benefits of hedgerows to ecosystem services or a single species. Not as much has been found on the overall benefits of hedgerows to a local area through biodiversity, which can be shown with flora biodiversity studies as a high plant species biodiversity has the ability to support a wider range of other species. A study by Litza and Deikmann (2019) investigated the species richness in recent and ancient hedgerows in Germany. They found that while both ages did facilitate herbaceous forest specialists, the ancient hedgerows contained significantly more. They were also able to demonstrate that both ages of hedgerows can act as habitats for forest herbaceous species and if traditionally managed, recent hedgerows can develop into today’s ancient hedgerows and help conserve specialist species. However, the area in study is mainly agricultural as opposed to an environment with fewer stresses such as a non-agricultural rural setting or a less agriculturally intensive environment. Although the importance of ancient hedgerows for species connectivity between woodlands could be shown, soil acidification and facilitating the growth of competitive species has been enhanced by fertiliser applications. The effects of pesticides, grazing animals and soil disturbance through ploughing could also be affecting species richness. Hedgerow ages in the Litza and Diekmann (2019) study are only categorised into recent and ancient, but both are established with recent hedgerows being between 15 and 81 years and ancient being over 140 years old. These hedgerows have also been managed, usually by coppicing, since the 1930’s as landowners are accountable for these protected hedgerows. Hedgerows in a developing stage could have a far different range of abiotic conditions, such as windspeed and light due to different shrub densities, which could determine which plant species are able to establish. These establishing hedgerows could still be important for plant diversity as they could act as an intermediary habitat for some species or specialist forest species.

Aims, Objectives and Hypotheses

To fill this gap in the literature, the aim of this study is to investigate whether the age of a hedgerow has any effect of the vegetative species diversity it holds. This will be tested in a less intensive environment without the added agricultural stresses that may influence hedgerow species diversity or species present. It may also show the importance of different aged hedgerows and their respective benefits to their surroundings. The objective of this study is to calculate percentage cover of different species and therefore floral diversity in different aged hedgerows to see if the age has any effect on the diversity and species it can facilitate.
Hypothesis (H_1): the older hedgerow will contain a higher plant species diversity.
Null hypothesis (H_0): the age of the hedgerow will have no effect on the plant species diversity it holds.

Methodology

Site Overview

Data collection took place on an urban farm called Poole Farm, located in the city of Plymouth in the Southwest of the UK as shown in figure 1. Poole Farm is owned by Plymouth City Council and is within the Derriford community park, a series of three local nature reserves in the Northeast of the city (Plymouth City Council, 2023 (a)). Although mainly surrounded by urban areas of housing there is some connection to Seaton and Bircham local nature reserve (LNR) to the west and Bircham Valley LNR to the northwest. On the site there is a mixture of different habitats including a river running through woodland, open sheep grazed fields, protected grass fields and woodland away from the river. It is important to note that much of the land is protected from deer by deer proof fencing, including some woodland, sheep grazed fields and an enclosed orchard. The topography of the area is sloping with some high points such as in the orchard field and a river running along the base of the valley through the woodland. Although a farm, Poole Farm is not intensively managed for arable or livestock products like the typical farm. The focus is on sustainable organic food production and only sell the farm produce of eggs, honey, pork and vegetables from a community garden (Plymouth City Council, 2023 (b)).

Sample Sites

Poole Farm was chosen as the study site due to its different range of hedgerows, with a recently planted (NEW 1), a 3-year-old one located in an orchard (ORCHARD 3), an older hedgerow (OLD 160+) and a Devon bank (DBANK 160+) being chosen to highlight the different plant diversities in different aged hedgerows. The Devon bank is not a hedgerow in a typical sense as it is built about 1m off the ground on a bank of rocks and boulders but can act as hedgerow as a boundary or to delimit property whilst still providing habitats to species such as dormice (Teignbridge.gov.uk, 2020). None of the hedgerows studied had been managed in any way such as coppicing, hedge laying or mechanical flailing. The recently planted hedgerow (<1yr) (the blue line in figure 2) is located along the edge of a woodland to its westerly face and in close proximity to the river.

Figure 1: An aerial view of the city of Plymouth, Southwest England with the study site of Poole Farm highlighted in the red box (Google, 2023, Imagery ©2023 Google, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, TerraMetrics, Imagery ©2023 Airbus, CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Landsat / Copernicus, Maxar Technologies, The GeoInformation Group, Map data ©2023).

Figure 2: An aerial view of Poole Farm including the different hedgerows sampled. Red is the orchard hedgerow, blue the newly planted hedgerow, green the old hedgerow and purple the Devon bank (Google, 2023, Imagery @2023 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky., Maxar Technologies, The GeoInformation Group).

On the other face is a grass field grazed by sheep behind the deer fencing to protect it from grazing livestock and deer. Due to its age, all of the hedging plants were enclosed by plastic tree shrouds which provide protection from grazing but still allow light in for growth. This also meant that the ground around the hedging plants was mainly populated by grasses and low-level vegetation. The hedgerow in the orchard is slightly more established at 3 years old and is in the higher part of the farm (the red line in figure 2). The field in which this is located is enclosed by deer fencing to reduce damage to the orchard. Both faces of this hedgerow are open to grass field either side. All the hedgerow plants are established and well developed but still relatively open and with a distinct canopy line. To the north end of the hedgerow was a large patch of bracken (*Pteridium aquilinum*) and on the southern end a large patch of bramble (*Rubus fruticosus*). There was a distinct animal run throughout the length of the hedgerow.

The old hedgerow is located in the middle of the sheep grazing field (as shown by the green line in figure 2), somewhat dividing it apart from a large gap in the middle and southern end allowing access. There is woodland on the northern end and a distinct animal run, presumably created by the sheep, through the width of the hedgerow. This hedgerow is mainly made up of blackthorn and bramble and contains some established trees. The southern end has an animal run through the centre of the hedgerow but not for a long distance where it becomes too dense. Although the exact age is not known, the presence of established trees suggest it is old and although not present on maps, the 1854-1863 map does show a small line of trees to the north end which could be related. Although this hedgerow doesn't follow the DEFRA definition of a hedgerow due to its width greater that 5m, it still acts as one at Poole Farm. The Devon bank is estimated to be at least 160 years old too, with it being present on the same maps. It begins somewhat openly but enters a woodland on the eastern end. There are some established trees along the bank but also smaller thickets of ash (*Fraxinus excelsior*) (dead) along with hazel (*Corylus avellana*) and dog rose (*Rosa canina*) towards the end.

Field Sampling

Sampling at Poole Farm took place across 26th and 27th October 2022. Weather conditions were overcast on both days with some moderate breeze on the 26th changing to light breeze and partially bright on the 27th. Before any measurements were taken, the characteristics of the hedgerow were recorded. These included surrounding land use, any established trees in the hedgerow, the physical shape and characteristics of the hedgerow and the physical makeup of the vegetation in the hedgerow. The geographical data of each hedgerow was then recorded using a Garmin eTrex 20 to obtain the coordinates of the start of the hedgerow and the elevation, which can be seen in table 1. A tape measure was then used to measure the length of the hedgerow and recorded. This length was then divided by 10 to provide ten equidistant measurements at which repeat samples were taken. The tape measure was used to set up a transect along the edge of the hedgerow. At the first predetermined length of measure, a 1m rule was placed from the transect into the hedgerow perpendicular to the tape measure. Then a 0.5m x 0.5m metal framed quadrat was placed at the end of the rule in the hedgerow, making sure it was on the right to help standardise the sampling. Due to the nature of hedgerows, it was often impossible to place the quadrat in the hedgerow due to upright woody vegetation. In this case a string quadrat was incorporated, creating a 0.5m x 0.5m grid out of string and upright pencils/stakes. Percentage cover of vegetation species was then recorded within the quadrat. If species were not immediately identified a series of guides were used, including the Field Studies Council guide for the identification of common grasses (Gardener and Roberts, 2010) and the wildflower key (Rose, 2006). Percentage cover measurements also included the percentage of bare ground present in the quadrat. This was then repeated for the remaining nine predetermined distances to obtain a mean percentage cover for the entire hedgerow. It is important to note that due to the size of the old hedgerow, the transect was not laid along the outside, but rather along an animal run that went through the centre a short distance. This was done because it would provide a more representative sample of the hedgerow. Another transect was also laid across the cross section of the old hedgerow, along another animal path across the width, but this data was later disregarded due to the method not replicating the other hedgerows.

Statistical Analysis

Once percentage cover data was obtained, a Shannon's diversity score was calculated for each quadrat in each hedgerow. Shannon's diversity index is calculated using the equation, $H = -\sum[(pi) \times \log(pi)]$, where *H* is Shannon's diversity index and pi is the proportion of individuals of one species in the whole community. This also allowed for a mean diversity score to be calculated for each hedgerow. Shannon's diversity scores (Spellerberg and Fedor, 2003) were calculated using the "vegan" package in R studio (Oksanen *et al*., 2022). The species found in the sampling were also classified into herbaceous, woody and grass species for later analysis whether different ages hold a particular group of species. All statistical analysis was done using R studio, version 4.2.0 (R Core Team, 2022). Before any statistical tests were performed, the normality of the datasets was checked using a Shapiro-Wilk normality test. An ANOVA statistical test was then performed between the diversity scores for each hedgerow followed up by a TukeyHSD postHOC test to see statistical differences between hedgerows.

Different species sampled were classified by their type to see if different hedgerows had a different composition or if any favoured a classification. Species were divided into woody, herbaceous and grass. Multiple Pearson's Chi-squared tests were performed for the species classifications of each hedgerow to test for significant differences between each hedgerow, leading to 6 tests being performed.
Autumn and winter fruiting species were also classified and tested for any significant difference between different hedgerows. A Shapiro-Wilk normality test was performed on the data which led to a Kruskal-Wallis test being performed followed by 6 Mann-Whitney U tests as follow up tests to see any potential differences. Any significant difference in the number of autumn and winter fruiting species were tested for as some species like ivy (*Hedera helix*) are essential sources of food for insects and birds during autumn and winter (Woodland Trust, no date(a)).

Results
Table 1 shows the data obtained from the GPS from each sample site on Poole farm.

Table 1: GPS coordinates and elevation values for each of the hedgerows.

Hedgerow	Elevation (m)	North Coordinate	West Coordinate
ORCHARD 3	85	50°24.641	004°06.556
NEW 1	40	50°24.525	004°06.443
OLD 160+	47	50°24.447	004°06.414
DBANK 160+	85	50°24.527	004°06.437

Species Diversity
Between the 4 sampled hedgerows, the DBANK 160+ had the highest Shannon's diversity score with a mean 1.49 across the 10 quadrats and the ORCHARD 3 hedgerow having the lowest diversity score with a mean of 0.63 across the 10 quadrats. Between the three typical hedgerows (ORCHARD 3, NEW 1 and OLD 160+), the NEW 1 hedgerow has the highest Shannon's diversity score with a mean of 1.13 between the 10 quadrats and the ORCHARD 3 the lowest score again. This can be seen in figure 3.

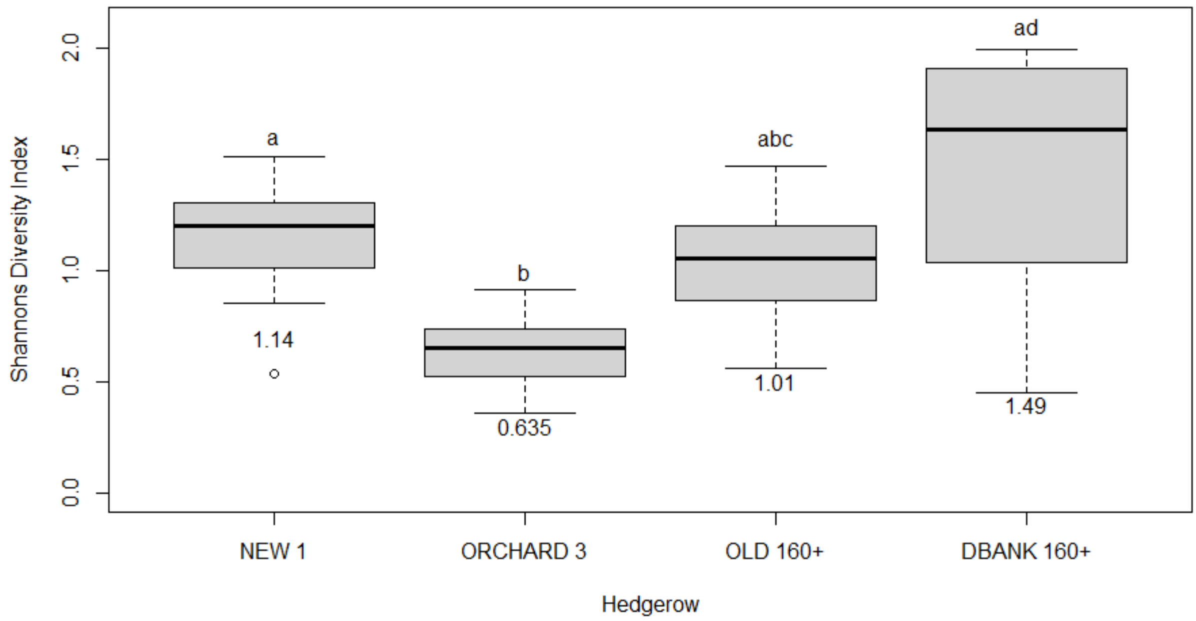

Figure 3: Mean Shannon's diversity scores for each hedgerow. Shared letters indicate no significant difference.

To determine which statistical test was to be used, a Shapiro-Wilk test was performed on the Shannon's diversity scores for each hedgerow. All the reported p-values where above 0.05, indicating with a 95% confidence interval that the data is normally distributed. This meant that the parametric ANOVA test was used due to the data's normality. The ANOVA test produced a p-value of <0.0001 (DF=3,36, F-value= 10.7) indicating with a 95% confidence level that there is a significant difference somewhere between hedgerow diversity scores. A Tukey postHOC was then performed to see which hedgerows had significantly different Shannon's diversity scores, its results shown in table 2 with differences shown in figure 3.

Table 2: Results of the Tukey postHOC test performed after the ANOVA test showing significant differences in diversity scores between hedgerows. Significant p-values are indicated in bold.

Hedgerows Being Compared	Difference	Lower	Upper	p-value
NEW 1 vs. ORCHARD 3	0.503	0.0925	0.913	**0.0112**
OLD 160+ vs. ORCHARD 3	0.378	-0.0323	0.789	0.0801
DBANK 160+ vs. ORCHARD 3	0.852	0.442	1.26	**< 0.0001**
OLD 160+ vs. NEW 1	-0.125	-0.535	0.286	0.845
DBANK 160+ vs. NEW 1	0.349	-0.0609	0.760	0.119
DBANK 160+ vs. OLD 160+	0.474	0.0638	0.885	**0.0182**

As can be seen, differences between the NEW 1 hedgerow and ORCHARD 3 hedgerow, the DBANK 160+ and the ORCHARD 3 hedgerow and between the DBANK 160+ and OLD 160+ hedgerow all produced p-values of less than 0.05, indicating with a 95% confidence level that they had significantly different diversity scores. Due to these statistics, the hypothesis can neither be accepted or rejected. This is because an older hedgerow (DBANK 160+) had a significantly higher Shannon's diversity score than a young hedgerow (ORCHARD 3 hedgerow), supporting the hypothesis. However, there was no significant difference between both older hedgerows and the NEW 1 hedgerow (see table 2), disproving the hypothesis.

Species Richness

Figures 4-7 show the mean species composition for each hedgerow. Although bare ground percentage was also measured, it has been excluded here as it is not a species. As can be seen, the DBANK 160+ has the highest number of different species with 21 and the OLD 160+ hedgerow has the fewest number of different species with 7. There was little difference in the number of different species between the ORCHARD 3 and NEW 1 hedgerows with the ORCHARD 3 hedgerow having 13 different species and the NEW 1 hedgerow having 14 different species. However, although the ORCHARD 3 hedgerow had a higher number of species than the OLD 160+ hedgerow, figures 4 and 8 show it was mostly made up of grasses, cocksfoot grass (*Dactylis glomerata*) and common bent (*Agrostis capillaris*). This is indicated by the low diversity score as roughly 80% is made up from these two species. The high Shannon's diversity score is also shown by the species richness in the DBANK 160+ as figure 7 shows no species in particular dominating the mean percentage cover, despite there being the highest number present. This is also represented with the OLD 160+ hedgerow as it has the fewest number of species sampled, 6, but not the lowest diversity score as no particular species is dominating the samples (as shown in figure 6).

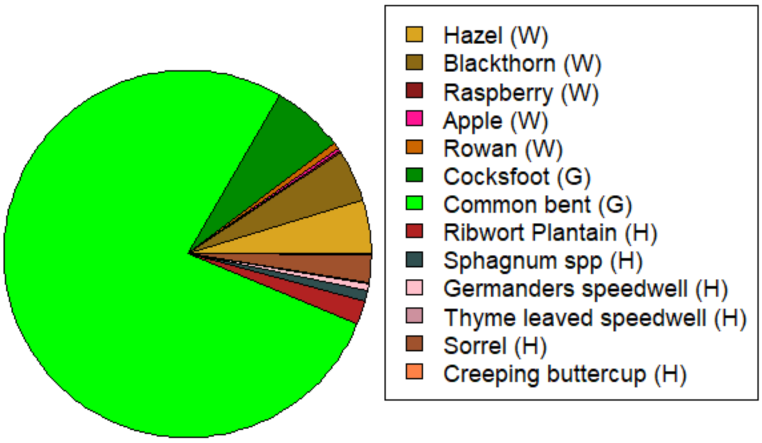

Figure 4: The mean species composition of the orchard (3yrs) hedgerow excluding bare ground. W indicates a woody species, G a grass species and H a herbaceous species.

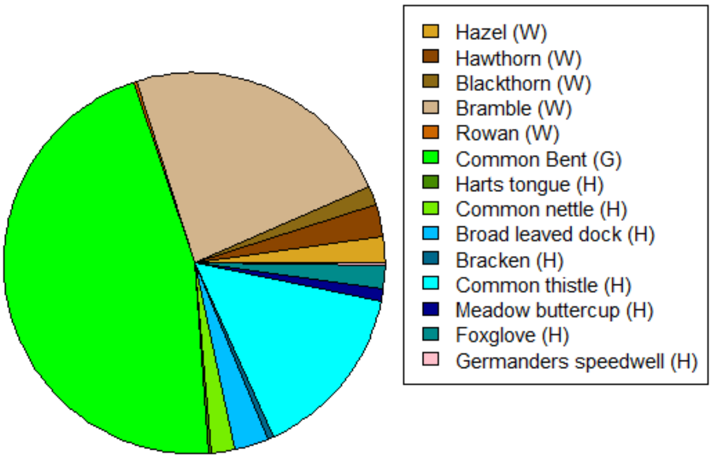

Figure 5: The mean species composition of the new (<1yr) hedgerow excluding bare ground. W indicates a woody species, G a grass species and H a herbaceous species.

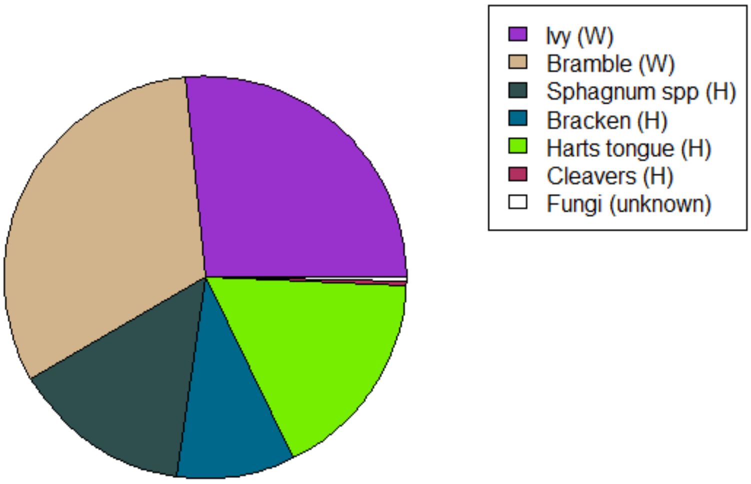

Figure 6: The mean species composition of the old (160yrs+) hedgerow excluding bare ground. W indicates a woody species, G a grass species and H a herbaceous species.

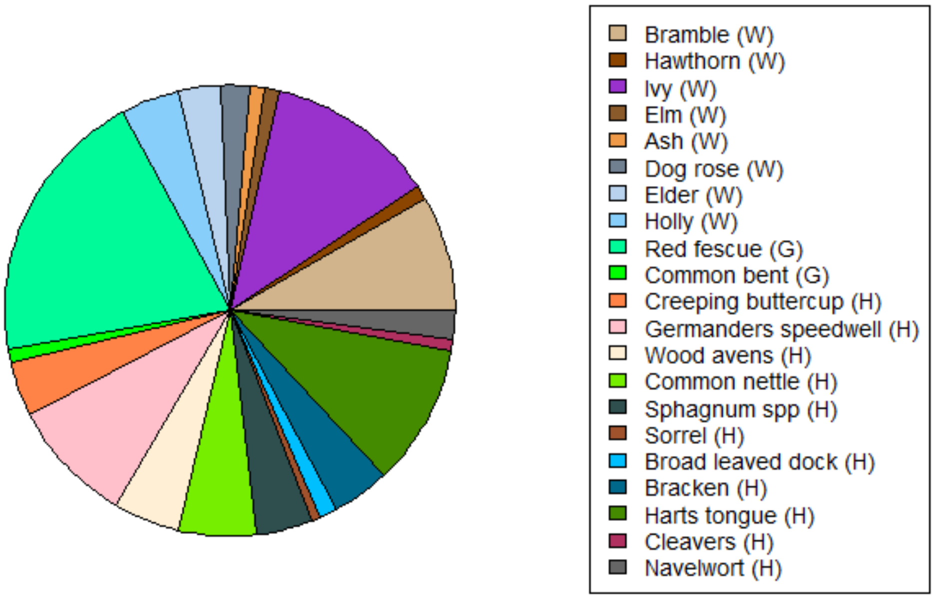

Figure 7: The mean species composition of the Devon bank (160yrs+) hedgerow excluding bare ground. W indicates a woody species, G a grass species and H a herbaceous species.

Table 3: Results of the 6 pairwise Pearson's chi-squared tests between each hedgerow. Significant p-values are indicated in bold.

Hedgerows Being Compared	**X^2 Value**	**df**	**p-value**
ORCHARD 3 vs. NEW 1	2.64	2	0.267
ORCHARD 3 vs. OLD 160+	10.8	2	**< 0.005**
ORCHARD 3 vs. DBANK 160+	6.25	2	**0.0440**
NEW 1 vs. OLD 160+	7.12	2	**0.0285**
NEW 1 vs. DBANK 160+	8.92	2	**0.0115**
OLD 160+ vs. DBANK 160+	7.72	2	**0.0211**

Figure 8 shows the mean composition of each hedgerow based on the classification of species found within. Here, they have been separated into woody, herbaceous and grass depending on their functional group. As can be seen in figure 8, the ORCHARD 3 hedgerow is dominated by grassy species while the other 3 hedgerows are made up of a more even split between the present classifications. It also shows that there were no grassy species sampled in the OLD 160+ hedgerow. In order to determine if there were any significant differences between each hedgerow composition, 6 Pearson's chi-squared statistical tests were performed pairwise between each hedgerow to see where the differences were. These results can be seen in table 3. All hedgerow pairs except between the ORCHARD 3 and NEW 1 hedgerow gave a chi squared value of at least 5.99 (the critical value for a significance level of 0.05 with 2 degrees of freedom) and a p-value of under 0.05, indicating a significant difference at a 95% confidence level.

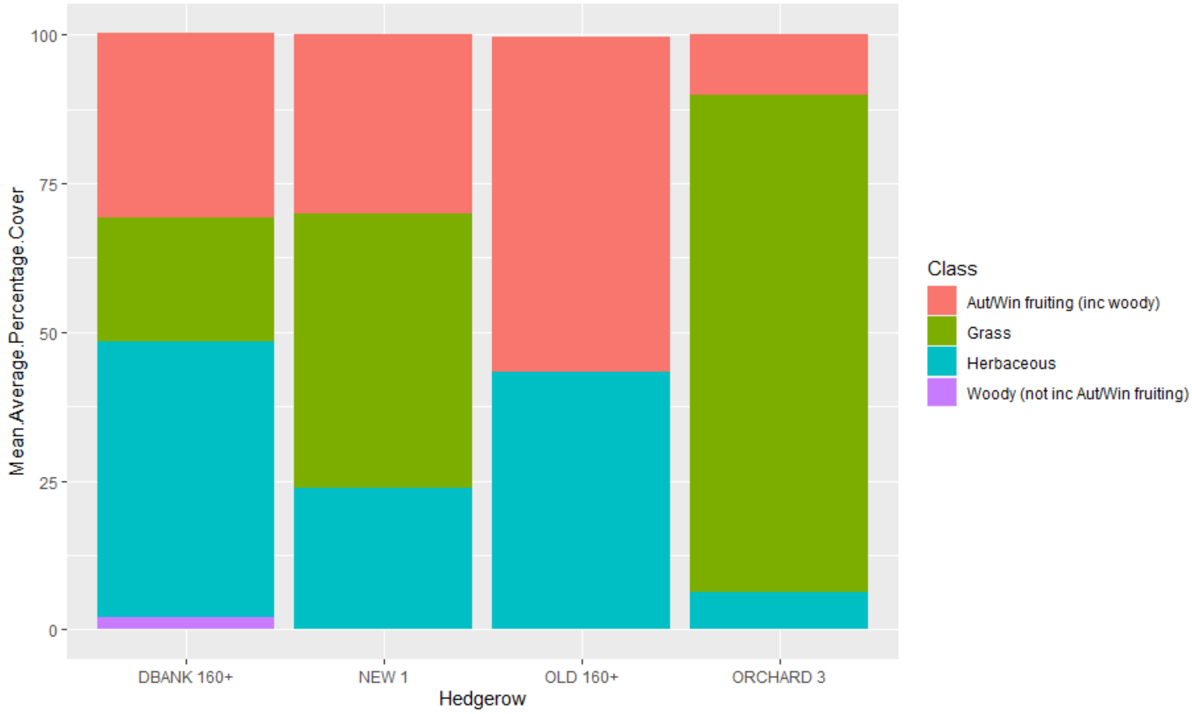

Figure 8: Mean percentage cover of different species classification in each hedgerow. Made using the ggplot2 package in R studio (Wickham, 2016).

Autumn and Winter Fruiting Species

As shown in figure 8, the OLD 160+ hedgerow contained the highest proportion of autumn and winter fruiting species, and the ORCHARD 3 hedgerow contained the smallest proportion. The DBANK 160+ and NEW 1 contained a very similar proportion of these species, despite having the highest difference in age. Although not visible on figure 8, the ORCHARD 3 hedgerow did contain a very small proportion of woody species (not including autumn/winter fruiting) with raspberry (*Rubus idaeus*) but only at a mean cover of 0.1%. Shapiro-wilk normality tests performed on the percentage cover of autumn/winter fruiting species in each hedgerow produced p-values of less than 0.05, indicating a not-normally distributed dataset with 95% confidence. This led to a Kruskal-Wallis test being performed to see the differences between the proportions of autumn/winter fruiting species within the hedgerow. The output of this test was a p-value of <0.0001 (W=0.592), indicating a significant difference somewhere. 6 Mann-Whitney U tests where then performed between datasets so each hedgerow was compared against each over to see which hedgerows were significantly different. Table 4 shows that only 4 pairwise tests produced p-values of less than 0.05, indicating only these differences were significant with a 95% confidence level. This is also shown in figure 9.

Table 4: Results of the 6 pairwise Mann Whitney U tests performed between each hedgerow. Significant p-values are indicated in bold.

Hedgerows Being Compared	W Value	p-value
ORCHARD 3 vs. NEW 1	857	0.210
ORCHARD 3 vs. OLD 160+	99.5	**< 0.0001**
ORCHARD 3 vs. DBANK 160+	1276	0.575
NEW 1 vs. OLD 160+	174	**< 0.0001**
NEW 1 vs. DBANK 160+	1798	**0.0457**
OLD 160+ vs. DBANK 160+	1010	**< 0.0001**

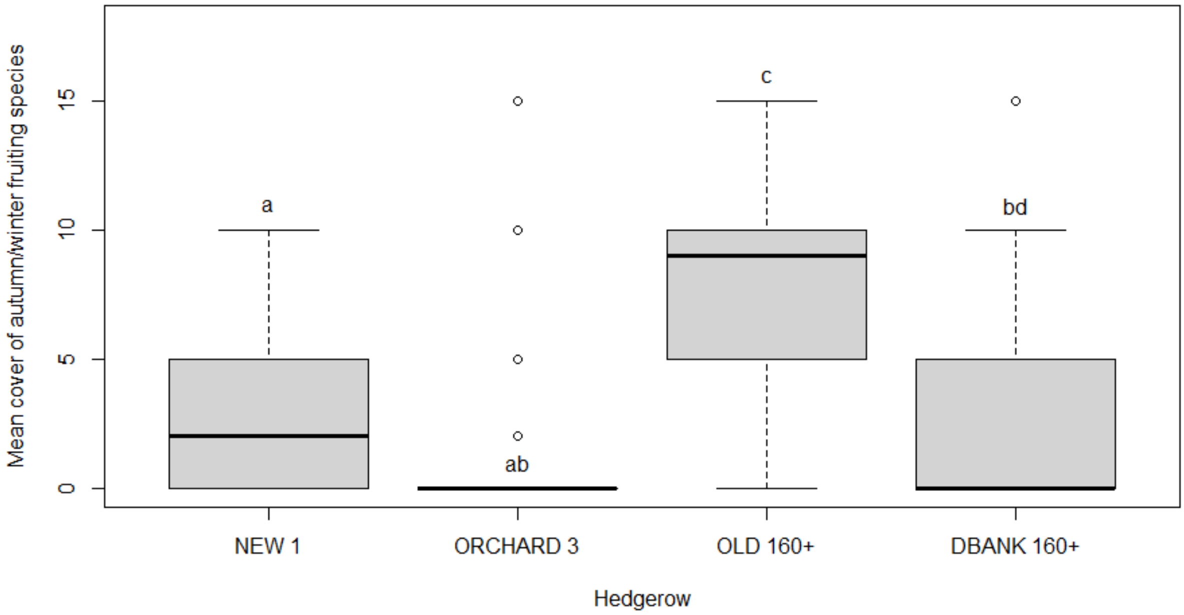

Figure 9: Mean cover of autumn and winter fruiting species between the hedgerows. Shared letters indicate no significance.

Discussion

Hedgerow Age and Diversity

Shannon's diversity scores for the hedgerows were found to differ between the hedgerows, however not all the differences were found to be significant, contrary to the hypothesis. Differences are somewhat conflicting because although an older hedgerow (DBANK 160+) has the highest diversity, it could be expected that the other older hedgerow (OLD 160+) would also have the highest, but a younger hedgerow (NEW 1) has the second highest. However, the age of the hedgerow may not be the only reason diversity scores are different.

The structures of the hedgerows sampled differed between each age, with the densest being the OLD 160+ hedgerow and the least dense being the NEW 1. Larger, denser hedgerows are being pushed by agri-environment schemes due to their abundance of resources (Graham *et al.*, 2018). This could suggest that these hedgerows are more diverse due to the higher abundance of resources coming from a wider range of species. However, this does not correspond with the findings in this study as the hedgerow most dense (the OLD 160+ hedgerow) was found to have the second lowest Shannon's diversity score. This can be highlighted with a study by Deckers *et al*., (2004) which found that variability within the structure resulted in higher species richness, rather than a continuous uniform structure or density. However, the hedgerows in the study by Deckers *et al*., (2004) were under an assortment of different management strategies leading to structural diversity and this could allude to their findings.

Another factor determining in which species the hedgerow contains, and therefore diversity, could be light levels reaching the ground, which could be further affected by the structure again. Some species, such as ivy, are remarkable for their shade tolerance (RHS, 2023 (a)) and are therefore better adapted for the darker, denser hedgerows. This can be shown with the OLD 160+ hedgerow as it was the densest and had the highest percentage of ivy with roughly 25% (see figure 6). A study by Kollmann and Reiner (1996) found that different shrub species had different establishment rates depending on their light requirements. This could suggest that the hedgerow light availability could be a factor in determining which species can establish, affecting its species diversity. This could again suggest that a variety of light levels within a hedgerow, much like structure, could be more beneficial for diversity than a uniform arrangement. On the other hand, the sparse canopy of the NEW 1 hedgerow and the subsequent increased light levels reaching the ground may also be influencing the diversity. For example, bramble leaf area index and cover rapidly increased with light availability in a study by Balandier *et al.,* (2012). All these studies have indicated that hedgerows with high structural and physical variability lead to higher diversities as there is a variety of niches for different species to fill.

A similar study by Litza and Diekmann (2019) also tested whether the age of a hedgerow affected the species richness within it. They concluded that ancient hedgerows (140yrs <) contained significantly more forest species than recent hedgerows (15-81 years old). This is different to what was found in this study with the older hedgerow here containing far fewer species that the newer hedgerows with 7 in the OLD 160+ hedgerow compared to 13 and 14 in the ORCHARD 3 and NEW 1 hedgerow respectively. This may be due to the surrounding area of the Litza and Diekmann (2019) study as theirs took place in an agricultural environment in which outside factors such as agrochemicals and management techniques were deciding which species the hedgerow holds. The hedgerows in their study were also managed, unlike those at Poole Farm, which could be influencing vegetative species diversity.

The Devon Bank

The DBANK 160+ did not follow the same pattern as the three typical hedgerows as it had the highest number of species but also the highest Shannon's diversity score, unlike the ORCHARD 3 hedgerow and NEW 1 hedgerow with a high number of species but a lower diversity score. This may be due to the more even distribution of the species within the DBANK 160+ as no one species was dominating the percentage cover samples, leading to a higher Shannon's diversity score. The species with the highest percentage cover was red fescue (*Festuca rubra*) with only

9.6% mean coverage compared to the ORCHARD 3 hedgerow's dominance by common bent with 64.4% mean coverage, shown by its low diversity score. If the OLD 160+ hedgerow contained a higher variety of species, it could be expected that its diversity would also be high based on observations from the DBANK 160+. If age were to be influencing the diversity it could be expected to have a lower Shannon's diversity score much like the OLD 160+ hedgerow, but this was not observed. This could be down to the physical structure of the DBANK 160+ as it is about 1m off the ground. The reduced space of the bank may prevent the proliferation of certain species due to the limited space. If left unmanaged, species like bramble can rapidly expand as their rooting involves the tips contacting the soil, leading to the formation of dense thickets (RHS, 2023 (b)). However, proliferation may be difficult on the DBANK 160+ as its reduced size may act as a natural control, which can be seen by its high diversity score and lower percentage of bramble than the NEW 1 hedgerow. A study by Pellissier *et al*., (2004) investigated the seed bank diversity of hedgerow banks, which the DBANK 160+ is an example of. They found that species only within older bank hedgerows were woodland species with species exclusive to the younger bank hedgerows being grassland species. This is consistent with the findings of this study as the DBANK 160+ contained a higher percentage of woody species than grasses. This could suggest that the constructed aspect of the DBANK 160+, as opposed to the planted, more natural aspect of the three typical hedgerows, is limiting the colonisation of some species and therefore its species diversity.

Differences Between Species Classifications

Species classifications differed between each hedgerow, with all but one pair (the ORCHARD 3 vs the NEW 1) having a significantly different composition as found by a series of Pearson's chi-squared tests. The reason for this significant difference in hedgerow composition could be that each hedgerow creates a different habitat for a particular classification. Since both woodlands and hedgerows are made up of a majority of upright woody vegetation, it could be suggested that woodland species may also favour hedgerows. This can be shown with a study by Wehling and Diekmann (2009) which found about 77% of all forest plant species occurring in neighbouring forests were also found in adjacent hedgerows. However, McCollin *et al*., (2000) found that plants more frequently found in hedgerows were associated with fewer woodland communities, possibly suggesting hedgerows are more similar to woodland edges than interiors. This may be expected as hedgerows and woodland edges exhibit similar environmental conditions such as increased windspeed which has been found to decrease exponentially with increasing distance from the edge in woodland environments (Wuyts *et al.,* 2008). Both studies by Wehling and Diekmann (2009) and McCollin *et al*., (2000) could suggest that hedgerow species composition is largely determined by the surrounding area, especially nearby forests.

As shown by this study, the two younger hedgerows (ORCHARD 3 and NEW 1) have a high percentage of grasses in them with roughly 80% and 75% mean coverage respectively. This may be due to the surrounding area influencing the ground flora of the hedgerow and the lack of light interception that would otherwise suppress growth. Adjacent land use has been found to be the best predictor of overall species distribution (de Blois *et al.,* 2002) and this is consistent with the high percentage of grass in the ORCHARD 3 and NEW 1 hedgerows as their surroundings are unimproved grassland. However, a study by Garbutt and Sparks

(2002) found that over a period of 27 years the amount of some species, such as hawthorn, dog rose and blackthorn, has significantly increased or decreased. This could suggest that within establishing hedgerows, like the ORCHARD 3 and NEW 1, the population dynamics of some species are shifting until establishment. It could also show that high proportions of grassy species are indicators of a hedgerow's youth as the two older hedgerows (the OLD 160+ and DBANK 160+) have much smaller proportions of grassy species and complete absence in the case of the OLD 160+ hedgerow. It has been generally found in this study that as the age of the hedgerow has increased the proportion of grassy species within the hedgerow has decreased.

During sampling at Poole Farm, it was identified that the NEW 1 hedgerow was located next to the woodland (see figure 2). Due to its locality, it would be expected that there would be a high proportion of forest species within this hedgerow as increasing nearby forest cover has been found to increase forest herb diversity and abundance (Roy and de Blois, 2008). However, the NEW 1 hedgerow was mainly found to contain grassy and herbaceous species, with only about 30% forest (woody) species. This may be due to the very young age of the hedgerow as forest species may not have been able to colonise the ever-changing vegetation. The designed aspect of this hedgerow could explain why there are few forest species too. Although they may look natural due to their composition, hedgerows are semi-natural wooded habitats (Litza *et al*., 2022). Woody species in the NEW 1 hedgerow were still in protective tree shrouds, highlighting its man-made aspect. This is shown in the findings as only woody species within the NEW 1 hedgerow were in protective shrouds with none being free-growing, indicating that the adjacent forest had not yet expanded into the hedgerow. However, it is likely in the future, when the hedgerow has established that there will be higher proportions of forest species, like those found in the mentioned studies.

Autumn and winter fruiting species

The proportions of autumn/winter fruiting species were found to differ but not all significantly between the hedgerows. The OLD 160+ hedgerow likely contains the highest proportion due to the small number of other species present. The inverse of this can be seen with the ORCHARD 3 hedgerow as it contains a high number of species and the lowest proportion of autumn/winter fruiting species. The reasoning for the distribution of these species may be due to the way they are dispersed, through animal ingestion. Species such as hawthorn produce fleshy fruits and rely on frugivore (fruit consuming) species for their dispersal (Rumeu *et al*., 2019). Although their dispersal may be wide ranging from migratory birds, local distribution may only be confined to the hedgerow in which they are present due to some native bird species relying on hedgerows for nesting and protection (Morelli, 2013). This could suggest that within a local area, the distribution of some autumn/winter fruiting species may only be confined to a hedgerow as dispersal species may have little reason to venture far elsewhere.

Although the OLD 160+ hedgerow contained the lowest species richness and the second lowest diversity, it still contained the highest proportion of autumn/winter fruiting species. This could suggest that diversity scores should not be the only attribute measured for determining the importance of hedgerows as it may not reflect other specialist or ecologically valuable species, shown by this study of the OLD

160+ hedgerow. Without this high proportion of autumn/winter fruiting species in some hedgerows, the populations that depend on them as a valuable food source in winter may be much smaller.

Management of hedgerows
None of the hedgerow's studied on Poole Farm where being managed in any way and this could possibly be reflected by the diversities found. A study by Staley *et al.,* (2015) tested different management techniques and their effects on the hedgerow and diversity. These included coppicing; hedge laying; conservation hedging which is a quicker alternative to hedge laying and involves the cutting of stems at the base and laying over along the line of the hedgerow resulting in less material being removed; wildlife hedging which involves rough cutting every stem with a chainsaw then pushing the hedgerow over with a digger bucket; mechanical cutting with a circular saw/tractor mounted tool and a control with no rejuvenation measure applied. It found that four of the management techniques (coppicing, hedge laying, conservation hedging and wildlife hedging) all produced a far denser basal structure than no active management, along with the subsequent wildlife benefits.

Management of hedgerows is essential for the maintenance of floral diversity in a hedgerow, as shown in the study by Garbutt and Sparks (2002). They found that over a period of 27 years on the same hedgerow the lack of management has led to loss of linear definition. This is the loss of the hedgerow’s dense, straight structure through large gaps and the outward spread of woody suckers. This indicates it is not an appropriate option for maintaining diversity in ancient hedgerows as it can reduce connectivity (PTES, 2023 (b)), and as shown by this study, the possible proliferation of one species leading to a reduced diversity. In the case of neglected hedgerows, a study by Croxton *et al*., (2004) found that some species exhibited poor responses to coppicing and therefore recommended that other measures such as planting between gaps and hedge laying may be required for overall restoration. If traditional management of recent hedgerows is continued over time, they can transform into valuable habitats similar to ancient hedgerows (Litza and Diekmann, 2019).

Limitations
Limitations to this study include the time of year in which samples were taken and the length of the sampling period. Sampling took place in October which is late autumn/early winter. Typically, woody species, like those sampled across the hedgerows, blossom from February to June (Woodland Trust, no date (b)) with herbaceous and grass species typically flowering in spring and summer. Due to the lack of flowers or blossom present, the identification of some species had to be done using other physiological features such as bark or leaves. This made identification particularly difficult in some cases, possibly leading to incorrect identification. The short sampling period also could have limited the study. Sampling took place across 2 days which only provided enough time for 10 repeats in each hedgerow. A longer time period would have allowed more repeat samples to be taken, further improving the accuracy and representability of the dataset.

Future Recommendations
Based on this study and those shown in related literature, it is recommended that hedgerows on Poole Farm undergo some form of management plan in order to improve their species diversity and subsequent benefits. On hedgerows where this is

possible, it is recommended that a traditional technique of hedgerow management is chosen, such as hedge laying, as this can be less destructive and more selective than other techniques such as mechanical flailing. Poole Farm's aims of education, volunteering, community, and wellbeing will also be met with these techniques (Plymouth City Council, 2023 (c)). Hedge laying would allow a universal hands-on education style, allowing volunteers to learn the process by participating and possibly learning why these processes are beneficial to diversity. This is opposed to a technique such as mechanical flailing which is carried out by a tractor or wildlife hedging which may not be as accessible due to its heavy reliance on chainsaws and the skills required to use one. Although planting hedgerows can be beneficial to local wildlife and can provide multiple ecosystem services, it is recommended that the existing hedgerows are rejuvenated and properly maintained to see benefits to diversity. Planting multiple hedgerows in places where they are not needed or may interfere with activity and could take attention away from current hedgerows in need. Based on the current literature, it can only be recommended that the maintenance of national hedgerows is continued and increased. As previously mentioned, the UK has lost 6.2% of hedgerows over the last decade due to neglect (Staley *et al*., 2015). More hedgerows should also be planted across the UK, especially where they once were present but removed due to agricultural or other reasons. This would improve connectivity between an increasingly fragmented landscape along with the other benefits diversity brings. The variety of grants provided by the government has increased the attractiveness of hedgerow planting/management and landowners should capitalise on these.

Conclusions

Overall, it was found that older hedgerows did not have a significantly higher diversity than younger hedgerows, although Shannon's diversity scores did differ between the hedgerows. The DBANK 160+ had the highest diversity score and significantly higher score than the ORCHARD 3 and OLD 160+ hedgerow, but the OLD 160+ hedgerow was not significantly higher than either younger hedgerow. The diversity of the hedgerow may be impacted by something other than age such as surrounding area or landscape. The DBANK 160+ was shown to be an interesting example of diversity and its structure could be a reason for this. Species richness did not follow any trends between ages as the old hedgerows simultaneously contained the highest number of species (the DBANK 160+) and the lowest number (in the OLD 160+ hedgerow). The composition of functional groups in each hedgerow significantly differed from the others apart from between the ORCHARD 3 and NEW 1 hedgerows. However, due to all but one pair being different, it may suggest that age is not causing the difference in composition but another factor like surrounding area is instead. The number of autumn and winter fruiting species also differed between each hedgerow. The OLD 160+ hedgerow had a significantly higher proportion of autumn/winter fruiting species individuals than the other hedgerows, highlighting that species diversity is not always the most ecological trait of a hedgerow.

Multiple studies have been performed on managed hedgerows and the benefits of managed hedgerows can be seen in these. This calls for the hedgerows to be managed, especially traditionally via coppicing or hedge laying, where appropriate. Management should continue and be maintained so hedgerows can have greater benefits to their environments. Further studies should take place over different times of the year, especially in the flowering season, and encompass a far wider range of hedgerow ages to test for the effects of age.

Future Works

In future studies, hedgerows should be sampled during all 4 seasons of the year. This would make identification of some species easier and make diversity scores more representative due to more of the species present being visible (through flowers or leaves). This would also allow for comparison between the seasons to see how diversity changes across the year and for conclusions to be drawn about which time of year is most beneficial to wildlife and ecology based on their diversity scores. Although the data collected in this study can be deemed representative due to the number of repeats taken, further studies should include more repeat samples. For example, 20 repeats for each hedgerow. This would reduce or eliminate the random aspect and variability of ecological sampling and provide a more accurate dataset. It would also better allow the inclusion of every species in the hedgerow, making the diversity score more representative of the hedgerow.

In order to better test if the age of the hedgerow is influencing diversity scores, a wider range of different aged hedgerows should be sampled. For example, hedgerows sampled could start at recently planted (<1 year old) and continue to 100 years old at intervals of 5 years, giving 20 samples. With this dataset, a correlation could be tested for to see if age is linked to species diversity. However, since most hedgerows in an area are of similar age, it may require multiple areas to be tested over a region or the country in order to collect the required data.

Acknowledgements

Firstly, I would like to thank my project advisor, Dr Sophie Fauset, for all her help and assistance in guiding me in the right direction and answering my many questions throughout this project. I would next like to thank Hayley Rogers of Plymouth City Council for granting me access to Poole Farm and showing me around the site, along with all the staff at Poole Farm. Finally, I would like to extend my thanks to all my friends and family who have supported me through the length of this project and my entire time at university. Without their support I would not be writing this project.

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