Land sparing or sharing: strategies for conservation of arable plant diversity

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Highlights

- Species richness of organic arable is compared to land-sparing set-aside
- Total plant species richness is similar between organic and set-aside
- Land-sharing organic arable has greater potential to support scarce species

Abstract

Strategies to achieve agricultural production and biodiversity conservation fall into two categories, land-sparing or land-sharing. Plant species richness under organic arable (land sharing) versus conventional arable with land set-aside for conservation (land sparing) was evaluated on adjacent farms to compare these strategies. Sampled plant species richness was significantly higher under organic than conventional arable, as expected, but very similar to set-aside. Nevertheless, the Chao1 estimator of total plant species richness indicated that the larger area available to plants under organic arable may sustain more scarce species leading to a higher species richness. It appears that the conservation value of sparing versus sharing depends on the relative species richness of the portion of land spared (set-aside) compared to the larger area of shared land (organic), and not with the species richness on conventionally cropped land. Furthermore, in theory the land-shared use will have greater capacity to sustain populations of scarce low-density species simply due 100% of the land area being available to these species. These are important principals for assessing land sparing versus sharing strategies seeking to balance production and biodiversity conservation not just for arable land but all agricultural land uses.

Key words: biodiversity, organic, set-aside, species richness

1. Introduction

How to meet the high demand for food production while conserving ecosystem and biological diversity is a considerable challenge (Foresight 2011). Two scenarios are often discussed as how to combine agricultural production and biodiversity within the landscape: farming systems that support biodiversity though possibly at the expense of maximising productivity – land sharing; and maximising productivity on the best land to release more land for purely conservation purposes – land sparing (Green et al. 2005; Fischer et al. 2008). Balmford et al. (2015) concluded that land sparing has greater overall potential to conserve biodiversity although there may be differences between taxonomic groups and production systems depending whether a species is associated with natural habitats or farmed habitats. In contrast, Loconto et al (2020) considered that the predominance of land-sparing in science and policy was more due to social and ethical values of the stakeholders than supporting scientific evidence. Understanding the nature of the relationship between productivity and species diversity for different agricultural systems and species of conservation concern it critical to developing effective strategies for the conservation of biodiversity (Balmford et al 2012).

Hole et al. (2005) reviewed the impact of organic agriculture on biodiversity and concluded that organic farms had greater plant and animal species richness and/or abundance for which the non-use of pesticides and sympathetic management of non-cropped habitats were key. Nevertheless, it was not clear as to whether similar species richness could be achieved by targeted management of small cropped or non-cropped areas with conventionally cropped fields on the rest of the farm. Gibson et al. (2007) found that of the landscape elements on organic farms only organic arable fields had higher plant species richness than conventional arable fields. Gabriel et al. (2010) found greater plant, epigeal arthropod and butterfly diversity in organic arable fields, but some other arthropod groups and birds were more diverse on conventional farms. Nevertheless, at least arable annual plants organic arable appears to function as a land-sharing approach supporting species richness within the cropped area although with lower productivity (Albrecht et al 2016).

The alternative approach is to set aside fields from production and allow wild plants to establish as a land-sparing strategy. A meta-analysis by Van Buskirk and Willi (2004) demonstrated that fields set-aside from arable cultivation had significantly higher plant, insect, spider and bird species richness than conventional agricultural comparisons in North America and Europe. Taking field margins out of production, as opposed to whole fields, has also been shown to maintain higher plant species richness. Replicated studies of field margin management options under UK agri-environmental schemes by both Critchley et al (2007) and Walker et al (2007) both found that uncropped cultivated margins held the highest plant species richness and especially more species of annual arable specialists of conservation interest. Reviewing different studies across Europe Albrecht concluded that set-aside was only beneficial for the conservation of arable annual plants if soil disturbance from annual cultivation is continued (Albrecht et al 2016).

Although the species richness or diversity of set-aside, uncropped cultivated field margins and organic cultivation as against conventional arable have been well studied individually, there has been no comparative study of organic compared to set-aside or uncropped cultivated margins as representing land sparing and land sharing approaches. The review of farmland conservation interventions by Dicks et al (2020) while presenting ample evidence of the beneficial effects on species richness of plants, invertebrates and birds of reduced use of agrochemicals (the closest practice reported to organic) or uncropped cultivated margins and set-aside, it reports no studies that contrast these strategies. Thus, it has not been evaluated whether land taken out of production in land sparing would host biodiversity equivalent to that of a land sharing arable system.

In this study we compare organic arable vs. cultivated set-aide as an example of land sharing versus land sparing for conservation of plant species richness. We present a case study evaluates contrasting these two strategies: organic arable where non-crop annual plants were develop due to non-use of herbicides or a sparing strategy where some arable land was set aside but still cultivated to promote annual arable herbs (Albrecht et al (2016) refers to this practice as "arable reserves"), while the remainder was managed as conventional arable with herbicide-based weed control. We contrast the estimated species richness and similarity in species maintained by each cropping system (organic, cultivated set-aside, conventional) and by the overall land-sparing or sharing farm strategy.

2. Materials and Methods

2.1 Selection of sites for comparison

Two studies were undertaken, the first to characterise the arable plant communities on adjacent farms of contrasting management. The second to test land-sparing or sharing approaches to conserve plants in arable fields.

i) In 2014 a comparison of the effects of arable management on plant species richness on three adjacent farms with contrasting cropping systems of no-till conventional, tilled organic and tilled conventional.

ii) in 2016 a comparison of cultivated set-aside as a land-sparing strategy and organic as a land-sharing strategy to maximise plant species richness on two of the same farms.

The farms were chosen to be adjacent, within the same landscape and with similar soil types but contrasting management. Adjacent arable organic and conventional farms with cultivated set-aside were found in the North Kent Downs of southeast England, situated on the dip slope of the Downs with comparable soil types consisting of clay with a high percentage of flint overlaying chalk to a varying depth. Fields cover a shallow undulating topography of varying aspect, but do not cross onto the steep scarp slope of the downs. Their cropping system and conservation practices were as follows.

i. Ranscombe Farm is a Plantlife Nature Reserve (www.plantlife.org.uk) and working farm of 96 ha located at 51.3881° N and 00.4669° E. The farm has been recognized as an important site for rare arable plants. It has two arable fields where the total area was managed for plant conservation for at least a decade (called Kitchen and Longhoes fields), plus two sections of a larger field set aside since 2015 (see table 1 and Appendix Fig A.1a). Kitchen field has been recognised as an important site for rare arable plants for several decades and is a SSSI. The commercial arable area of the farm was managed as no-till with weed control through herbicide use. Main crops were winter wheat, spring barley, oil seed rape and field beans. The conservation areas (cultivated set-aside) were tilled annually and in some cases wheat was sown (but not harvested); no further agronomic practices are implemented.

ii. Luddesdown Organic Farm was certified to Soil Association standards since 1988. It covers 177 ha and is located at 51.3720° N and 0.3990° E. The arable cropping was winter wheat, rye or oats in rotation with rye grass/clover; soil preparation and weed control was through ploughing.

iii. Upper Bush farm at 51,3733° N and 0.4333° E was a conventional tilled farm with main crops winter wheat, spring barley and oil seed rape. Weed control was through use of herbicides.

Thus, Ranscombe Farm presents a land sparing scenario where land is taken out of productive use for conservation purposes (cultivated set-aside) while the rest of the land is farmed conventionally controlling unwanted plant species with herbicides. Luddesdown farm's organic management without use of herbicides enables sharing of the whole arable area between crops and other annual plants.

2.2 Sampling plant diversity

The 2014 cropping system study assessed plant species of three fields of winter cereals (winter wheat, except for the organic which included rye and oats) on each of the three farms (covering organic, no-till conventional, and tilled conventional). In this case eight transects were located in each field at random distances around the field boundary. Each transect had 3 x 1 m^2 quadrats placed at 5, 30 and 100 m from the edge of the field.

The field survey was conducted in mid-June 2014 the peak of flowering and abundance of annual plants associated with arable crops (Moyse pers. com). The relative abundance of all identifiable species was recorded in each sample according to an adapted version of the Braun-Blanquet cover abundance scale for vegetation analysis (Braun-Blanquet, 1932). The scale was converted to a score for each category as follows: >75% of coverage = 90; 50-75% coverage = 60; 25-50% coverage = 30; 5-25% coverage =15; < 5% coverage but > 10 individuals = 5; < 5% coverage with 2 to 10 individuals = 3 and, <5% coverage only one individual =1. Plants were identified on site and those that could not were collected and identified using Stace (1997), in the case of some non-flowering or fruiting specimens identification was only possible to genera especially for some grasses, *Valerianella spp* and *Veronica spp*.

The 2016 comparison of plant species richness supported by the two farm conservation strategies required sampling across a similar total area with a similar sampling intensity. Four arable fields where chosen on each farm summing to a similar total area (32.0 ha & 34.8 ha). On Ranscombe these were divided into 19.2 ha of winter wheat (60% of total area) and 12.8 ha of cultivated set-aside (40% of total area), with the cultivated set-aside consisting of two small fields managed for conservation for at least a decade (fields 1 and 3 Table 1a and Appendix Fig A.1b) and two corners of a larger field (field 12 sections a and c in Fig 1 and Table 1a) converted from commercial arable two years prior to the study. All four fields at Luddesdown were sown with winter wheat or spelt (Table 1b and Appendix Fig A.1b).

The field surveys for the preliminary study were conducted in the first two weeks of July 2016 (sampling and flowering were delayed compared to 2014 by cold wet weather). Sampling intensity was approximately one 1 m^2 quadrat per 0.5 ha. Samples were randomly located in the fields by selecting a random distance along the field perimeter then a randomly chosen distance perpendicular into the field. The relative abundance of all identifiable species was recorded in each quadrat as described for the 2014 survey.

2.3 Estimation of actual and estimated total species richness and species shared

Comparison of plant “diversity” between systems was assessed in terms of species richness and species shared. Traditional diversity indices such as Shannon-Weaver and Simpsons were not used due to the limitations in the interpretation of these values in terms of species supported by different systems and their sensitivity to sample size (Magurran

2004). Therefore, species richness estimates developed by Colwell et al (2012) were used that enable comparative estimation of species richness with uneven sample sizes using a rarefaction extrapolation function in the EstimateS programme (Colwell 2013). Using this function species richness was extrapolated to a sample size of 60 when comparing cropping systems (cultivated set-aside, organic, conventional) and to 100 samples for farm level comparisons (EstimatesS recommends that the extrapolation function is not used to more than double the number of samples of field data extrapolated from). EstimatesS also provides 95% confidence limits for species richness, although Payton et al. (2004) considered that 95% confidence limits were too conservative having calculated that for two normal distributions non-overlapping at 84% confidence was comparable to a $p<0.05$ probability of difference. This has been proposed to be applied to rarefaction curves by Gotelli and Colwell (2011) but was not available in EstimateS at the time of analysis.

An alternative approach to estimating total species richness is the abundance based coverage estimate Chao1, that estimates the number of unseen species (i.e. rare species that were not found in the sampling) based on the frequency of singleton and doubleton species in the actual sample (Colwell and Coddington 1994). This is also computed by EstimatesS together with an estimated SD for this proportion.

To differentiate species richness supported by the different land-uses and farm conservation strategies the following comparisons were made. In the 2016 study selections were made to ensure a similar sampling area, and number of sample points across the comparison (see table 1 for management and areas of fields included in each comparison).

i. Comparison of land-uses: Ranscombe conventional fields 2 and 4b, vs Ranscombe cultivated set-aside fields 1, 3, 4a and 4c, vs Luddesdown organic fields 5, 6 and 7.

ii. Comparison of 40% land sparing vs. sharing: Ranscombe conventional fields 2 and 4b plus cultivated set-aside on fields 1, 3, 4a, and 4c vs. Luddesdown organic fields 5, 6, 7 and 8.

iii. Comparison of 20% land sparing vs sharing: and Ranscombe conventional fields 2 and 4B plus cultivated set-aside on fields 4a and 4c, vs organic Luddesdown fields 5, 6 and 8.

A further component to the conservation value different systems is whether they conserve the same species. In the 2014 study species composition was characterised by generating clusters based on the plant species abundance scale through the Ward method using Euclidean distance. The frequency of occurrence of clusters was compared between farming systems to assess whether the different farms shared the same plant communities.

In the 2016 study the number of shared species in the actual samples was calculated using the Jaccard index (Magurran 2004). The number of potentially shared species including the estimated presence of rare species was calculated using the Chao-Jaccard abundance-based index in EstimatesS (Chao et al. 2006). The Morisita-Horn index of similarity is also presented as a metric to assess the similarity of species composition that gives weighting to differences in species abundance (Magurran 2004).

3. Results

3.1 Species richness and composition between cropping systems

In the 2014 study species richness was substantially greater under organic arable cropping as estimated by the number of species sampled, the number of species by estimated by rarefaction and Chao1 number of species compared to the two conventional cropping systems (Table 2). Furthermore, the tilled conventional had significantly higher species richness than no-till conventional (i.e. 95% confidence limits do not overlap). There was no effect on species richness of distance from the field edge.

3.2 Species richness under different land-uses and conservation strategies

The total species richness extrapolated by rarefaction to 60 samples for the different cropping and conservation systems in the main study was significantly smaller for the conventional (24.7 species) than the cultivated set-aside (62.7 species) and organic (68.7 species) systems, while the estimates for the latter two systems very similar (Figure 1a, Table 3a). However, the Chao1 estimate of total potential species was considerably higher for the organic system (91.9 species) than the cultivated set-aside (59 species). Although the 95% confidence limits for these two estimates overlap, as noted by Payton et al. (2004), this is probably too strict for assessing significant difference. It is noted that the mean species richness for cultivated set-aside is outside the 95% confidence limits of the organic.

When analysis is conducted at a farm-level, the conventional with 40% cultivated set-aside at Ranscombe and organic at Luddesdown have the same estimated species richness when extrapolated to 100 samples (Fig 1b). However, the Chao1 estimate was 63 total species at Ranscombe and 104 species at Luddesdown, again with overlapping 95% confidence limits, but the means of each fall outside the 95% confidence limits of the other system (Table 3b). Under the scenario with 20% of arable area set-aside again the mean extrapolated estimate of total species and the mean Chao1 estimate are outside 95% confidence range for the organic system, but the 95% confidence limits of the two measures do overlap (Fig 1c and Table 3b).

3.3 Species shared between land-uses and conservation strategies

The proportion of species in common observed between the conventional and organic arable was quite low, only about 27.7% (Jaccard index), although the Chao-Jaccard estimate that took into account potential rare species estimated a much higher 78.8% of species likely to be in common (Table 4). The proportion of species observed in common between the cultivated set-aside and organic was higher at 48.6%, with the Chao-Jaccard estimate this increased to a potential 62.7% of species in common. The lower Morisita-Horn index of similarity between cultivated set-aside and organic, compared to other variables, indicates the relative dominance of species was substantially different between these systems. As per the Jaccard index, 48.1% of observed species were in common between the two farms, but this would rise to 93% in common if all species were accounted for under the Chao-Jaccard estimate.

Several species associated with arable conditions (e.g. *Anthemis cotula*, *Euphorbia exigua* or *Leguosia hybrida*) were found in both the cultivated set-aside and organic (see Appendix Table A.1). The exception was *Filago pyramidata* (an endangered species) that only occurred on the cultivated set-aside at Ranscombe. Most species present in the sampling at one site but absent from samples at the other were "common" species such as *Rumex crispus* (only found in the organic) or *Arabis hirsuta* (only found in the set-aside), although as common species in general it is likely that both these species would be present on both farms but by chance did not occur in the samples. This illustrates the relevance of using the probabilistic Chao1 metrics of species richness, and Chao-Jaccard index of species in common, that account for the random presence/absence of species occurrences in the samples and include the likely presence of scarce species on both sites that may only occur in samples from one site.

4. Discussion

Plant diversity under organic arable and conventional arable plus cultivated set-aside were compared as a case study of land-sharing and land-sparing strategies, to understand the factors that contribute to which strategy may be more effective. Organic arable and cultivated set-aside hosted similar numbers of plant species and significantly more than conventional arable. While the difference between organic and conventional has been widely documented (Hole et al. 2005), the similarity in species richness between cultivated set-aside, a purely conservation practice, and organic arable that is productive has not been studied previously. Albrecht et al (2016) in a review of management strategies to conserve rare arable plants concluded that organic and low-intensity cultivation achieved “good results” with many arable plants species responding positively under organic cultivation. Nevertheless, other strategies such as uncropped cultivated margins or arable reserves of fields specifically managed for conservation may be needed to maintain populations of some species that may not be adapted to specific elements of organic cultivation such as the inclusion of grass leys.

It must be recognized that the data presented are from just one geographic location and generalizable conclusions of the relative benefits of organic and cultivated set-aside would need further replication. Also the land-sparing case at Ranscombe farm is a nationally recognized site for rare arable plants, which may introduce a bias towards higher plant diversity under this strategy. Given the conservation value of the cultivated set-aside areas there is a comprehensive plant list that totals 111 herbaceous plant species (Moyse pers. comm.). This is greater than the upper estimate of species richness from either the extrapolation or Chao1 estimates of species richness for cultivated set-aside. There may be various reasons for this discrepancy, principal amongst them is that the plant species list from PlantLife is accumulated from different observations through the year while the current study is based on a one-time survey. A one-time survey also makes differentiating species not in flower or fruit (e.g. *Valerianella* spp.) more difficult to differentiate. This may have led to an underestimate of species diversity in some genera in the current study affecting the extrapolated species richness. Nevertheless, these same limitations would affect all systems studied and should not have affected estimates of relative species richness.

Nevertheless, there are important lessons in terms of the factors that affect the relative performance of land-sparing of sharing options that can be made. The conventional arable only added 3 or 4 more species above that found in cultivated set-aside, to the total species richness estimated for Ranscombe. While halving the area in cultivated set-aside to 20% led to the loss of about 10-15 species to the estimate of total plant species richness under the sparing scenario. Therefore, the total plant species richness appears more sensitive to the relative biodiversity of the sharing production system compared to the spared conserved area and not the remnant conventionally cropped land.

The species accumulation curves and the Chao1 estimate of species richness indicate that the organic arable system may accrue more rare species than the set-aside/conventional system, possibly due to the larger area available to host scarce species. This would agree with the finding of Clough et al. (2007) of higher beta diversity on organic farms than conventional farms (additional to higher alpha diversity). Gabriel et al. (2013) analysed the trade-off between productivity and biodiversity under organic and conventional arable, after controlling for differences in productivity, only plant diversity demonstrated a residual positive effective of organic management but not other taxonomic groups. As with our results this suggests that plant diversity may benefit from an organic land-sharing strategy of species conservation, but that other taxonomic groups may not. Furthermore, as indicated by Gabriel et al. (2010) there is an important landscape scale effect on plant diversity on organic or conventional farms. The land-sparing/sharing trade-off analysed here is based on a farm-level scale of decisions on how to use land. While appropriate for a farmer or land-holder, the nature of such trade-offs may differ if larger landscape scales are considered.

The organic arable in representation of a “biodiversity production sharing” system hosted at least as many plant species as the scenario with 40% of land spared from conventional arable as cultivated set-aside. A meta-analysis by Seufert et al. (2012) found that wheat productivity was on average 60% lower in organic than conventional arable systems, while Gabriela et al. (2013) found organic wheat production to be 54% of conventional in a systematic landscape survey across major arable regions of England. These are roughly in accordance with relative yields reported by the two farms in this study with organic wheat producing about two-thirds of conventional production. Therefore, potentially the same level of gross wheat production could be achieved either through 100% organic arable or 40% cultivated set-aside and 60% conventional arable, with both supporting approximately the same level of plant species richness. In the analysis of Seufert et al. (2012), they found that wheat was the crop with the greatest reduction in yield amongst the annual crops analysed, with the mean relative productivity of organic versus conventional for all crops being 75%. For smaller differences in productivity such as this, and therefore smaller proportions of land set-aside, it is likely that the land sharing organic would host greater plant species richness. This would agree with Gabriel et al. (2013) who found that even after yield differences were accounted for, there was a biodiversity benefit from organic arable for plant diversity, although not for other taxonomic groups.

A similar sparing-sharing comparison, but in a different farming system, was conducted by Chandler et al. (2013) in Costa Rica comparing bird diversity on farms that were half unshaded coffee and half forest (sparing scenario), compared to farms that were 100% shaded coffee (sharing scenario). While bird diversity was greater in shaded coffee than unshaded, the farm-level total bird diversity was greater in the un-shaded coffee/half forest farms. Balmford et al (2015) identified how different taxonomic groups may respond differently to land-sparing or sharing strategies depending on whether they were restricted to natural habitats (and so only occurred on spared land), or were adapted to farmed land (and thus can persist in sharing land-uses). In the Chandler et al (2013) study the land sparing scenario encompassed two habitats, coffee and forest which would support species with differing ecological needs and thus perhaps not surprisingly support more species than the single habitat of shaded coffee. In contrast in our study the "spared" land is managed to conserve annual plant species, the same ecological grouping of species as under organic agriculture, and adapted to low-input agriculture as had been practiced for millennia across Europe. While for species that can only persist in natural habitats land-sparing will always be more advantageous, many habitats of high conservation value in Europe (such as heathland, chalk grassland, wood pasture) are a result of traditional low-input agriculture, where species are adapted to, or may even depend on, agricultural management. For these communities, as with the case for annual arable plants, land-sharing is likely to be the most effective conservation strategy.

5. Conclusion

Most comparisons of conventional or organic arable have concentrated on the relative capacities of the cropping systems to support biodiversity. However, this case study indicates that under a land sparing/sharing analysis it is the biodiversity of the portion of land spared for conservation relative to the larger area of land under a shared system that is most important in determining which system has greater species richness. In the of case organic 100% of the land is available to plant species adapted to these conditions, while under land sparing only a percentage of land is available to the higher plant species richness community. As plant species richness is area dependent, there is an inherently greater area over which the organic land-sharing can accumulate species. Or to put it in biodiversity conservation terms more land to host scarce species with low population densities. For species that are adapted to low-input traditional agriculture land sharing over a larger land area may be a more effective conservation strategy the land-sparing of smaller areas specifically managed for these species.

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References

Albrecht, H., Cambecèdes, J., Lang, M., Wagner, M. (2016). Management options for the conservation of rare arable plants in Europe. *Botany Letters* 163: 389-415, DOI: 10.1080/23818107.2016.1237886

Balmford, A., Green, R., Phalan, B. (2012). What conservationists need to know about farming. *Proceedings of the Royal Society B* 279: 2714-2724 doi:10.1098/rspb.2012.0515

Balmford, A., Green, R., Phalan, B. (2015). Land for Food & Land for Nature? *Daedalus* 144, 57-75

Braun-Blanquet, J. (1932). *Plant Sociology* (Transl. G. D. Fuller and H. S. Conrad). McGraw-Hill, New York.

Chandler, R.B., King, D.I., Raudales, R., Trubey, R., Chandler, C., Chávez, V.J.A. (2013). A small-scale land-sparing approach to conserving biological diversity in tropical agricultural landscapes. *Conservation Biology* 27: 785–95. https://doi.org/10.1111/cobi.12046

Chao, A., Chazdon, R.L., Colwell, R.K., Shen, T-J., (2006). Abundance-Based Similarity indices and their Estimation when there are unseen species in samples. *Biometrics* 62: 361–371

Colwell, R.K., Coddington, J.A. (1994). Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions Royal Society London B*. 345: 101-118

Colwell, R.K. (2013). *EstimateS: Statistical estimation of species richness and shared species from samples*. Ver 9. Persistent URL <purl.oclc.org/estimates>

Colwell, R.K.,. Chao, A., Gotelli, N.J., Lin, S-Y., Mao, C.X., Chazdon, R.L., Longino, J.T. (2012) Models and estimators linking individual-based and sample-based rarefaction, extrapolation, and comparison of assemblages. *Journal Plant Ecology* 5:3-21.

Critchley C.N.R., Walker K.J. & Pywell R.F. (2007). The contribution of English agri-environment schemes to botanical diversity in arable field margins. *Aspects of Applied Biology* 81: 293-300

Clough, Y., Holzschuh, A., Gabriel, D., Purtauf, T., Kleijn, D., Kruess, A., Steffan-Dewenter, I. and Tscharntke, T. (2007). Alpha and beta diversity of arthropods and plants in organically and conventionally managed wheat fields. *Journal of Applied Ecology* 44: 804–812

Dicks, L.V., Ashpole, J.E., Dänhardt, J., James, K., Jönsson, A., Randall, N., Showler, D.A., Smith, R.K., Turpie, S., Williams, D.R. & Sutherland, W.J. (2020) Farmland Conservation. Pages 283-321 in: W.J. Sutherland, L.V. Dicks, S.O. Petrovan & R.K. Smith (eds) *What Works in Conservation 2020.* Open Book Publishers, Cambridge, UK.

Fischer, J., Brosi, B., Daily, G.C., Ehrlich, P.R., Goldman, R., Goldstein, J., Lindenmayer, D.B., Manning, A.D., Mooney, H.A., Pejchar, L., Ranganathan, J., Tallis, H. (2008) Should agricultural policies encourage land sparing or wildlife-friendly farming? *Frontiers in Ecology and the Environment* 6: 382–387.

Foresight (2011). *The Future of Food and Farming: Challenges and Choices for Global Sustainability*. The Government Office for Science, London.

Gabriel, D., Sait, S.M., Kunin, W.E., Benton, T.G. (2013). Food production vs. biodiversity: comparing organic and conventional agriculture. *Journal of Applied Ecology* 50: 355–364

Gabriel, D., Sait, S.M., Hodgson, J.A., Schmutz, U., Kunin, W.E., Benton, T.G. (2010). Scale matters: the impact of organic farming on biodiversity at different spatial scales. *Ecology Letters* 13: 858–869

Gibson, R.H., Pearce, S., Morris, R.J., Symondson, W.O.C., Memmott, J. (2007). Plant diversity and land use under organic and conventional agriculture: a whole-farm approach. *Journal of Applied Ecology* 44: 792–803

Gotelli, N.J., Colwell, R.K. (2011). Estimating species richness. In Magurran, A.E., McGill, B.J. (Eds), *Frontiers in Measuring Biodiversity* (pp. 39-54). Oxford University Press, New York

Green, R.E., Cornell, S.J., Scharlemann, J.P.W., Balmford, A. (2005). Farming and the fate of wild nature. *Science*: 307, 550–555

Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, P.V., Evans, A.D. (2005). Does organic farming benefit biodiversity? *Biological Conservation* 122: 113–130

Loconto, A., Desquilbet, M., Moreau, T,. Couvet, D., Dorin, B. (2020). The land sparing – land sharing controversy: Tracing the politics of knowledge. Land-use Policy 76: 103610 DOI: 10.1016/j.landusepol.2018.09.014

Magurran, A.E. (2004). *Measuring biological diversity*. Blackwell Publishing, Oxford.

Payton, M.E., Greenstone, M.H., Schenker, N. (2004). Overlapping confidence intervals or standard error intervals: What do they mean in terms of statistical significance? *Journal of Insect Science* 3:34

Seufert, V., Ramankutty, N., Foley, J.A. (2012) Comparing the yields of organic and conventional agriculture. *Nature* 485: 229–232

Stace, C. (1997). *New Flora of the British Isles*. 2nd edition, Cambridge University Press, UK.

Van Buskirk, J., Willi, Y. (2004). Enhancement of farmland biodiversity within set-aside land. *Conservation Biology* 18: 987-994

Walker K.J., Critchley C.N.R., Sherwood A.J., Large R., Nuttall P., Hulmes S., Rose R. & Mountford J.O. (2007). The conservation of arable plants on cereal field margins: an assessment of new agri-environment scheme options in England, UK. *Biological Conservation* 136: 260-270

Table 1 – Characteristics of fields selected for sampling of cropping systems

Field	Crop	Area (ha)	Number of sampling plots
a) Ranscombe Farm			
2	Winter wheat	6.57	13
4b	Winter wheat	12.66	25
Total	Winter wheat	19.23	38
1	Cultivated set-aside	4.15	8
3	Cultivated set-aside	3.15	6
4a	Cultivated set-aside	1.93	4
4c	Cultivated set-aside	3.58	7
Total	Cultivated set-aside	12.81	25
Total	Overall	32.04	63
b) Luddesdown Farm			
5	Winter wheat	5.73	11
6	Winter wheat	5.31	10
7	Winter wheat	7.18	15
8	Winter wheat	16.62	32
Total	Overall	34.82	68

Table 2. Species estimates for three arable cropping systems on separate farms

Cereal cultivation	Number of sampled species	Rarefaction species estimate	Rarefaction 95% confidence limits	Chao1 species estimate	Chao1 95% confidence limits
Organic tilled	50	53.3	43.4 – 60.3	55.0	50.8 – 82.1
Conventional no-till	6	6.2	5.0 -7.4	6.0	6.0 – 7.0
Conventional tilled	12	14.7	8.8 -20.6	13.0	12.1 – 22.6

Table 3. Species richness estimates by land-use and farm conservation strategy.

	Number of sampled species	Rarefaction species estimate	Rarefaction 95% confidence limits	Chao1 species estimate	Chao1 95% confidence limits
Comparison of cropping and conservation systems					
Conventional	22	24.7	19.6 - 29.8	23.5	22.2 - 37.1
Cultivated set-aside	54	62.7	52.3 - 73.2	59.0	54.8 -86.1
Organic	56	68.8	54.5 - 83.0	91.9	66.2 -183.4
Comparison of sparing-sharing strategies					
Ranscombe: conventional + 20% set-aside[b]	47	51.2	41.7 - 60.6	50.0	47.4 – 70.0
Ranscombe: conventional + 40% set-aside	58	66.1[a]	56.3 - 75.9	63.0	58.9 – 86.9
Luddesdown: organic	59	66.9[a]	55.5 - 78.4	104.0	72.5 – 208.6

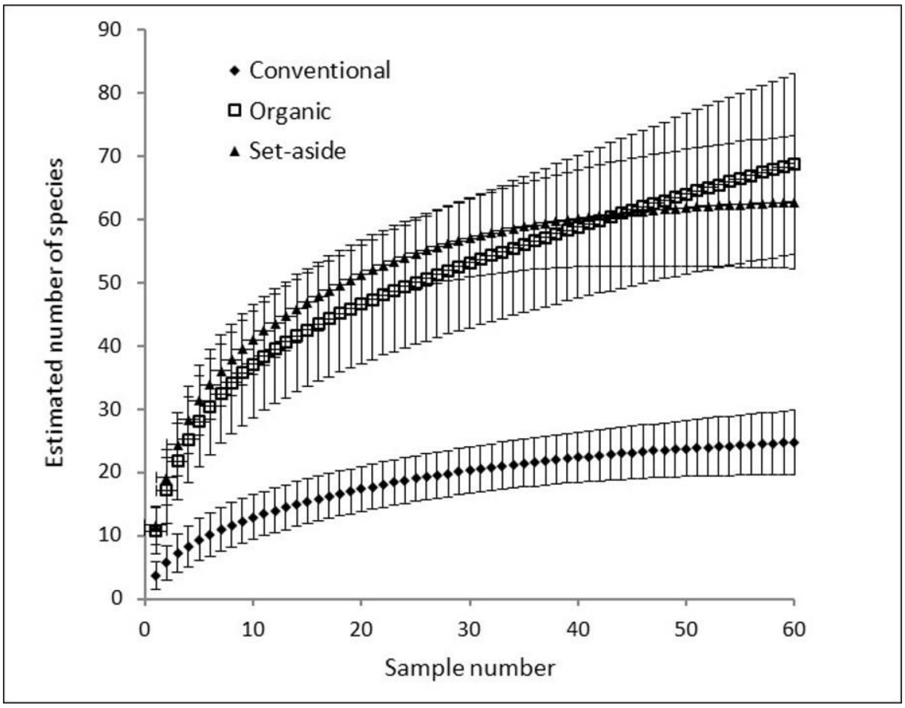
[a] values are extrapolated to 100 samples, all other extrapolations are to 60 samples
[b] to be compared to organic values in section a) that are also extrapolated to 60 samples

Table 4. Estimates of similarity of species composition between the different land-uses and conservation strategies

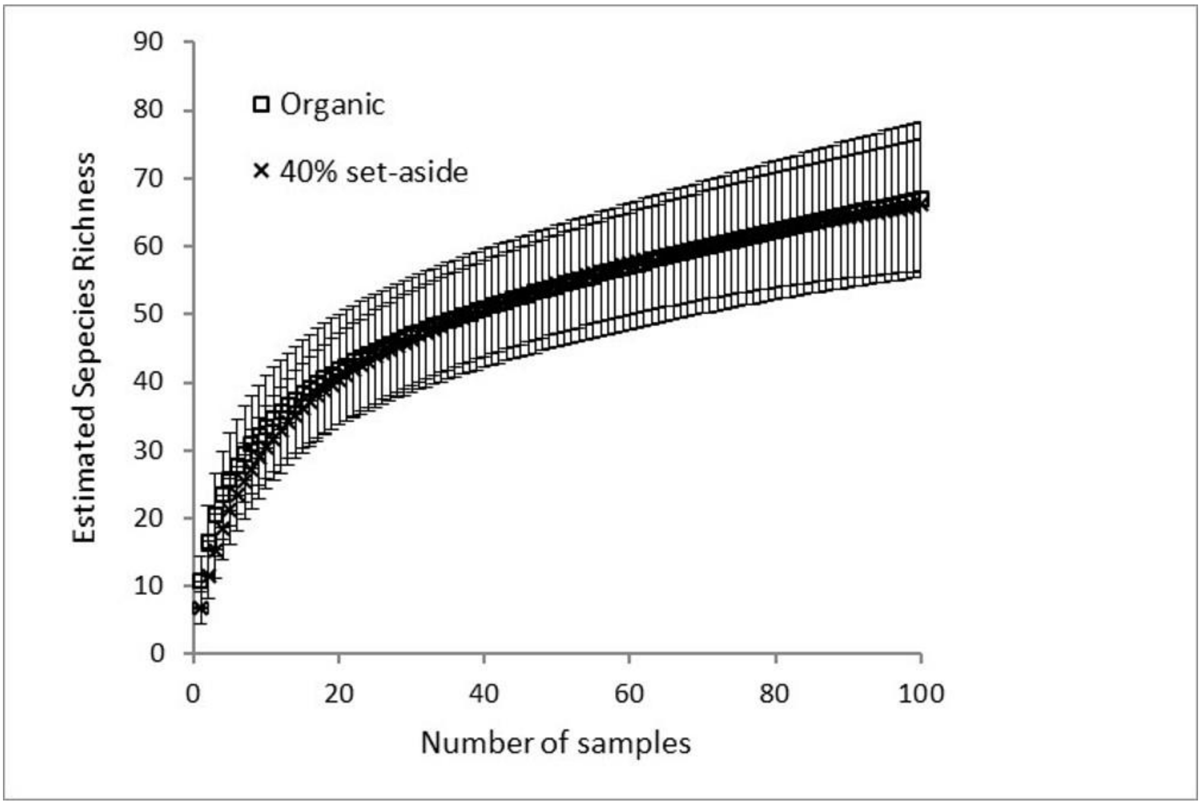
Cropping system or farm	Species observed in first system	Species observed in second system	Number of shared species observed	Jaccard – proportion of species in common	Chao-Jaccard estimate of species in common	Morisita-Horn index of similarity
Conventional & Organic	22	56	13	0.277	0.788	0.608
Cultivated set-aside & Organic	54	56	36	0.486	0.627	0.351
Luddesdown & Ranscombe	58	59	38	0.481	0.93	0.643

Figure 1. Rarefraction extrapolation of accumulated species richness with increasing sample size comparing a) conventional, cultivated set-aside and organic land-uses b) farm level conservation strategies comparing Ranscombe with 40% cultivated set-aside and 60% conventional arable with Luddesdown 100% organic and c) a comparison with 20% cultivated set-aside 80% conventional arable against 100% organic arable. Error bars are 95% confidence limits around means.

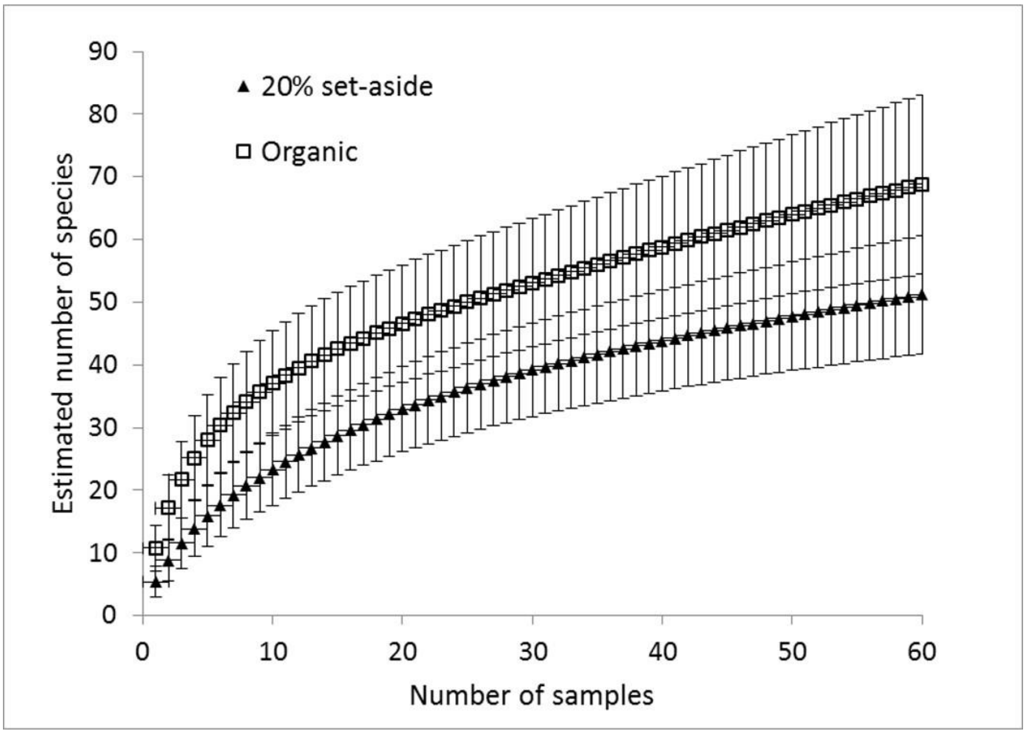
a)



b)


Organic
40% set-aside
Estimated Sepecies Richness
Number of samples
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100

c)



20% set-aside
Organic
Estimated number of species
Number of samples
0
10
20
30
40
50
60
70
80
90
0
10
20
30
40
50
60