Analysis of the effectiveness of Agri-environment schemes on farmland bird species abundance

RSPB Research Report 78

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Executive Summary

1. A policy driven focus on maximising the productivity of UK farmland in the latter half of the 20th century led to more efficient food production but also contributed to substantial declines in farmland biodiversity. Amongst the best documented of these declines is within the farmland bird community, with one measure of this, the Farmland Bird Index for England (FBI; Figure E1), declining by 61% between 1970 and 2022[1]. The FBI is a multispecies indicator showing composite changes through time in the relative abundance of 19 bird species that are closely associated with farmland.

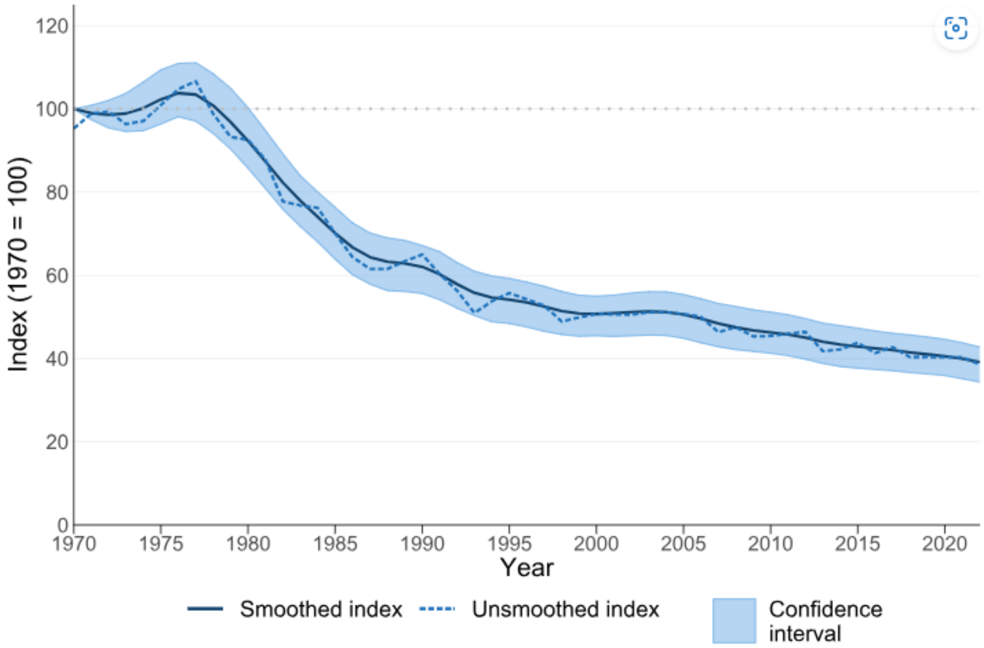


*Figure E1: Breeding farmland birds in England 1970 to 2022; the Farmland Bird Index for England (FBI). **Source:** British Trust for Ornithology (BTO), Royal Society for the Protection of Birds (RSPB), and the Joint Nature Conservation Committee (JNCC). Reproduced under an open government licence v3.0.*

2. Government support has been put into place via Agri-environment schemes (AES) to help farmers manage their land both for food production and for nature. Effective and well-funded AES schemes are key part of a nature recovery in the UK.
3. We extrapolated the results of a large-scale study in three regions of England, investigating how farmland birds respond to AES in England, to the whole of England to explore the potential recovery of farmland birds in relation to the provision of different levels and types of scheme. We focus on the Environmental Stewardship scheme, in particular the bird-friendly options within the Higher Level Scheme ('bird-friendly HLS') and bird-friendly Entry Level Scheme ('bird-friendly ELS') options. HLS was available only to a sub-set of farmers who were supported to develop a tailored package of options covering ~7% of their land. ELS was open to all and farmers had free, unguided choice of options covering 3-4% of their land.
4. We re-iterate that bird-friendly AES can stabilise or lead to local populations increases in individual farmland bird species and species assemblages, but that a greater proportion of landowners need to be supported to do more in order to stabilise or recover the FBI.
5. Our simulations suggest that we could be 50% confident of stabilising the FBI if around a third of landholdings in lowland England farmland (35.5%; Figure E2) provided bird-friendly HLS measures. In order to be more confident of stabilisation, higher provision levels would be needed (Fig. E2). If we wanted not only to halt the decline in the indicator but to start to

recover populations, again provision levels would need to be higher. To be 50% confident of the indicator heading upwards at a rate that would result in a 10% increase over ten years, bird-friendly HLS provision would need to be present in half of landholdings, increasing to 57% and 65% to be 80% or 95% confident respectively. These scenarios assume that in addition to bird-friendly HLS provision half of the remaining landholdings in lowland farmland would provide bird-friendly ELS measures.

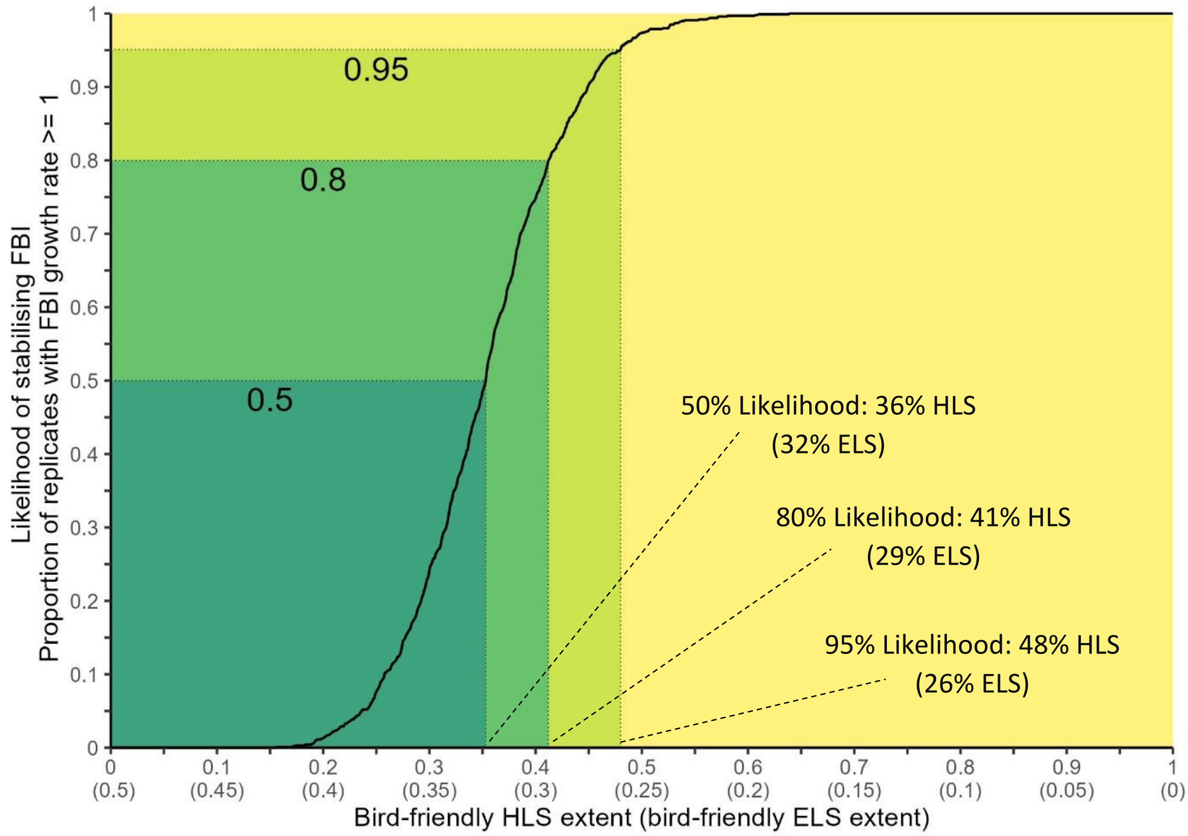


Figure E2: The estimated likelihood of stabilising the England FBI under different levels of bird-friendly HLS provision, expressed as the proportion of replicates within our simulation with an FBI growth rate at or above one. HLS provision is the proportion of farms in our simulations, with e.g. 0.4 = 40% of the farms with 7% of their land given over to bird-friendly HLS. 50%, 80% and 95% likelihoods are illustrated using coloured rectangles. At each level of HLS, half the remaining lowland enclosed farms are assumed to be in bird-friendly ELS agreements (indicated in brackets) and half with no bird-friendly AES.

6. We investigated the impact of excluding a rapidly declining, specialist farmland bird species, Turtle Dove, from the suite of FBI species included, given that it has not responded to generic bird-friendly AES options and is highly range restricted across England. If these scenarios were to guide ambitions for bird-friendly AES provision, the current bespoke species recovery package for Turtle Dove would additionally need to be continued. In this simulation, around 8-9% fewer farms would need to provide bird-friendly HLS provision to stabilise the FBI (27%, rising to 33% and 38% for 80% and 95% confidence respectively; Figure 8). Again, we assume that half of the remaining landholdings are providing bird-friendly ELS provision. To be 50% confident of the indicator heading upwards at a rate that would result in a 10% increase in the indicator over ten years, 41% of lowland farms would need to provide bird-friendly HLS (80% confidence: 47%, 95% confidence 54%).
7. A final simulation varied the level of provision of bird-friendly HLS and bird-friendly ELS simultaneously and investigated the probability of stabilising or increasing the FBI for each combination. This suggested that:

a. We are unlikely to stabilise the FBI solely by more farmers implementing bird-friendly ELS (Figure E3; likelihood less than 50% (dark blue) even when more than 90% of lowland enclosed farms in England were providing bird-friendly ELS).
b. ELS-style provision of bird-friendly options has a contribution to make to farmland bird recovery however, as where no or little bird-friendly ELS is present the level of bird-friendly HLS needed to stabilise the FBI increases markedly. In the absence of any bird-friendly ELS, half of farms would need to provide bird-friendly HLS to have a 50% chance of stabilising the FBI (cf. 36% HLS (32% ELS) in our first simulation).
c. In order to have a 50% chance of recovering the FBI (a growth rate leading to a 10% increase in ten years) in the absence of bird-friendly ELS, 61% of farms would need to provide bird-friendly HLS.

8. This final simulation was also repeated without Turtle Dove (Figure 10). The general patterns described above persisted, but with slightly lower levels of AES needed in each case. For example, there was still 50% or lower likelihood of stabilising the FBI in the absence of bird-friendly HLS regardless of the provision of bird-friendly ELS.

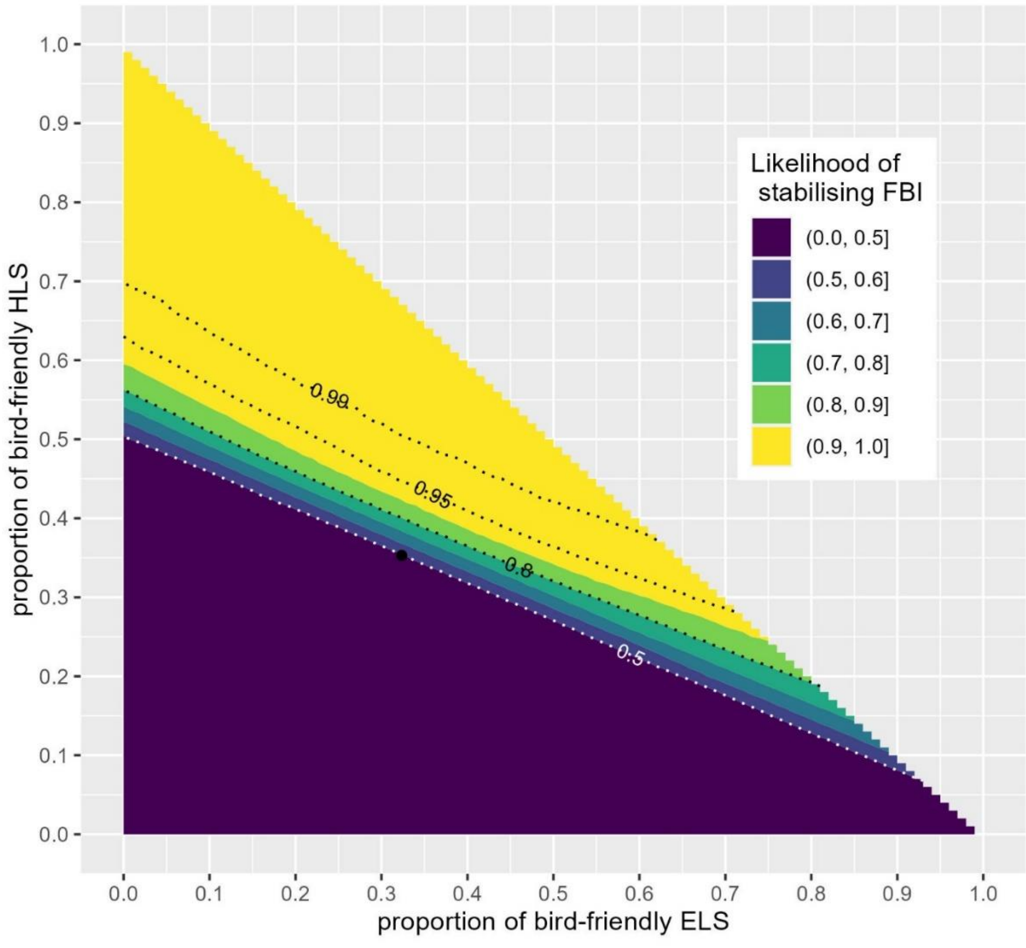


Figure E3: Across all FBI species, the likelihood of stabilising the FBI (FBI growth rate of >=1) for varying combinations of bird-friendly ELS and HLS. Likelihood of meeting the target is taken as the proportion of simulation replicates meeting it in each case. HLS provision is the proportion of farms in our simulations, with e.g. 0.4 = 40% of the farms with 7% of their land given over to bird-friendly HLS. ELS provision is the proportion of farms in our simulations, with e.g., 0.4 = 40% of farms with 2-3% of their land given over to bird-friendly ELS. To illustrate the relationship between these results and those where HLS provision alone is varied, the median bird-friendly HLS provision needed for stability in the former scenario has been plotted here as a black point (35.5% HLS (32.3% ELS)).

9. While uncertain, the Sustainable Farming Incentive (SFI), one of the current AES schemes in England, is only likely to be providing background ELS-type bird-friendly provision. Currently

neither SFI nor the other current AES scheme, Countryside Stewardship Higher Tier (CS HT), is providing sufficient bird friendly habitat equivalent to the modelled HLS bird-friendly provision considered here. The latter scheme is also currently closed to new entrants. This could be addressed by a) Introducing a targeted 7% farmland bird or farmland wildlife package into SFI that is supported by bespoke ongoing 1-1 advice, and b) Seeking to increase uptake of HLS bird-friendly package provision under the CS HT, but the latter would need to be achieved without detracting from the current focus of CS HT on increasing areas of priority habitat, protected sites and areas important for priority species under management.

10. There is good evidence to suggest the provision of nature-friendly Agri-environment options, such as HLS or HLS-like provisions, would have significant positive effects on some other farmland taxa. However, we lack empirical evidence that directly links our modelling with the abundance of other taxa so we can only speculate as to whether the provision we have modelled using birds here would deliver any equivalent or similar population recovery for other taxa.
11. Several areas of further research would give a clearer picture of the scale and type of AES provision needed to recover farmland wildlife. Similar simulation studies to this one could be carried out for other taxonomic groups and this study could be extended, to for example look at different scenarios of the rate of uptake of AES schemes, different ways you could target options to where they are likely to have most impact or to incorporate farmer attitudes or economic information. A second approach would be a programme of evaluation to understand the impact of current AES schemes like SFI and CS HT on different aspects of biodiversity and how these vary by region, land character and landscape context. In order to more directly understand the scale of conservation interventions needed to halt the decline in, and support the recovery of species more broadly, similar observational and simulation studies will be needed on other taxonomic groups and intervention types.

1. Introduction

Agricultural management is a key driver of species change in UK and elsewhere[2, 3]. A policy driven focus on maximising the productivity of UK farmland in the latter half of the 20th century led to greater food production but also contributed to substantial declines in farmland biodiversity. Amongst the best documented of these declines is within the farmland bird community, with one measure of this, the Farmland Bird Index for England (FBI), declining by 61% between 1970 and 2022 [1]. The FBI is a multispecies indicator showing composite, changes in the relative abundance of 19 bird species that are closely associated with farmland through time.

Government support has been put into place via Agri-environment schemes (AES) to help farmers manage their land both for food production and for nature. Effective and well-funded AES schemes are key part of nature recovery in UK.

Birds are well studied, both via annual monitoring of national population trends and by field studies of the impact of AES and can be used as a test case to help assess progress towards population recovery. Recent work by Sharps and Hawkes et al [4] has estimated the average growth rate of the FBI in the presence of bird-friendly AES, in the guise of the Environmental Stewardship (ES) scheme.

From 2005, Government introduced the ES scheme with two tiers, Higher Level Stewardship (HLS) and Entry Level Stewardship (ELS). These schemes were seen as critical for achieving the UK Government's Public Service Agreement (PSA) target of reversing the decline in farmland bird populations in England by 2020. This target was not meet, but scheme monitoring, and evaluation provides insight into why.

HLS was introduced as a competitive, targeted, "narrow and deep" scheme, funding either more complex actions, or ensuring a larger area of the farm was under environmentally friendly options. Agreements last for 10-years. In lowland England, the scheme aimed to encourage farmers in target areas to manage 7% of each land holding under bird-friendly habitat. The scheme included the first package of options "the Farmland Bird Package", specifically designed to deliver the three key requirements of farmland birds on a single holding: spring/summer food resources, breeding habitat and winter food resources[5]. Land holdings were targeted based on the presence of any of the target species, as revealed either by the Farm Environment Plan[1], or coincidence of holdings within the species known distributions. Farmers were given bespoke advice about which options would be most effective for their farm and where these should be placed. HLS was also used to fund appropriate management of priority habitats and designated sites (e.g. SSSIs). By the end of the scheme approximately 1.2 million hectares of land were in HLS.

In contrast, ELS was a non-competitive, untargeted "broad and shallow" scheme offering 5-year agreements to undertake basic measures to improve environmental sustainability. ELS aimed to secure a lower provision level of 3–4% of the farmed area under bird-friendly measures and did not include a farmland bird package[8]. This lower-tier scheme excluded some of the more challenging bird-friendly options and did not offer the tailored management advice or land management planning provided to landowners under the HLS. Farmers needed to select options to a 30-point threshold per hectare of farmland. This generally meant that most chose to meet this threshold by choosing options that required limited change to farm practices, such as basic hedgerow management and low input grassland. By 2010, over 50% of the budget was dedicated to basic

[1] FEP - a specific audit of the environmental features present produced as part of the farmer's HLS agreement

hedgerow management[6]. By 2013, over 6 million hectares of England was covered by an ELS agreement, representing approximately 70% of the utilised agricultural area.

The ES scheme ended for new applications in 2014 and was replaced by Countryside Stewardship (CS) which again had two tiers, a Mid-tier and a Higher-Tier. The design of the new scheme was informed by monitoring and evaluation of ES. Currently, approximately 1.4 million hectares of England is under CS, and another 0.9 million hectares are under retained HLS agreements[7]. There are still around 6000 live HLS agreements, mostly across the uplands, in priority habitat and SSSIs.

The Sharps and Hawkes study monitored farmland bird populations in farms with bird-friendly HLS (covering a median of 7.4% of each HLS farm) or bird-friendly ESL agreements (covering a median of 2.3% of each ELS farm) and those where no bird-friendly AES was provided. The farms spanned three lowland English regions (Figure 1) and they estimated species specific population growth rates per region, per AES level and the average growth rate across the FBI indicator suite. They also estimated the average proportion of species' populations in each region that would have needed access to bird-friendly HLS to either stabilise or increase the FBI [4, 8].

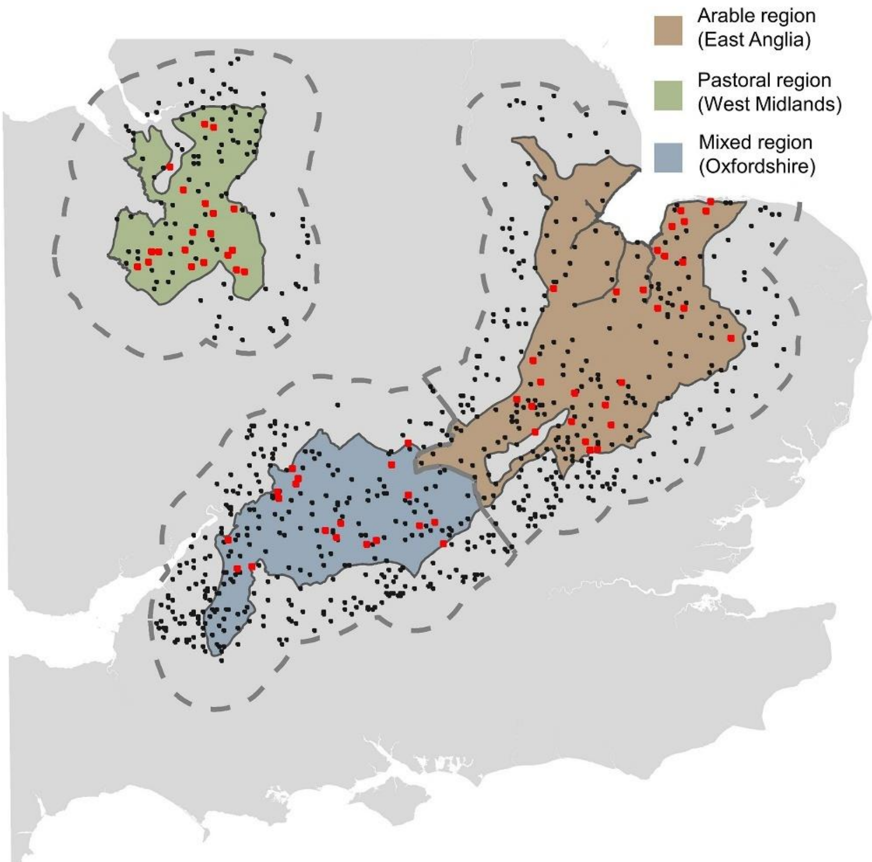


Figure 1: Location of the higher-tier farmland (red squares) and lower-tier/no AES Breeding Bird Survey (BBS) squares (black squares) across three regions in lowland England. BBS squares were also selected from a 20 km buffer around National Character Areas (NCAs, dashed line), but excluding adjacent NCAs with different landscape character. Reproduced with permission from Figure 2; Sharps and Hawkes 2023[9].

We previously extended a previous iteration of their work to extrapolate the observed impact of bird-friendly HLS-type options in the experimental regions to cover all of England, including populations in farmed and non-farmed habitats[10, 11]. We found that around 40% of farms in lowland enclosed farmland in England would need to be in bird-friendly HLS-type agreements in order to stabilise the FBI, where half of farms not in HLS-type agreements (i.e. 30% of farms) would be undertaking bird-friendly ELS-type AES. This work was published in the consultation evidence pack to the Environment Act 2021[11] and was used to advise the EIP target for '65 to 80% of landowners and farmers will adopt nature friendly farming on at least 10-15% of their land by 2030'[12].

Our previous analysis provided deterministic levels of AES uptake. Although these results were presented as indicative only, a deterministic approach may give a false sense of precision. Additionally, presenting an average doesn't allow decision makers to understand and agree upon an acceptable level of risk of non-achievement. This project is seeking to develop probabilistic outputs that can support risk-based decision making on the adoption levels of AES required to support the recovery of farmland birds. Here we extend our work to incorporate some components of uncertainty in the model parameters and to explicitly model the impact of varying levels of both ELS and HLS provision, rather than HLS alone. We set these results in context of current implementation of ELMS.

Objectives

There are three work areas, focussed at a national level as much of the proposed work is complete a landscape level (Task B:3c).

1. A simulation will be used to add stochasticity to the existing national deterministic model, sampling repeatedly from the probability distribution of the population growth rate under different levels of AES (no-EAS, ELS, HLS) and in non-farmed habitats (TaskB:3a, b), across levels of HLS provision (0 to 100) (Task B:d, g) and extrapolating the results to 2040 or for twenty years (Task B:h).

2. This model will be repeated with and without Turtle Dove (Task B:i) and at varying levels of ELS for each level of HLS covered (Task B: d, e, g).

3. Model outputs will be expressed as the likelihood of meeting a target at a given uptake level, illustrated by the proportion of replicates where the target was met (Task C: 5b, 6, 7) and our results will be set in context with regard their applicability to current AES options in England, and whether they can be used to infer beyond farmland birds (Task C: 8).

2. Methods

2. 1 Objective 1. Adding uncertainty around the existing model

The existing model gives point estimates of the FBI growth rate (the average rate of change amongst farmland bird populations between one year and the next) whilst varying the proportion of lowland farms under bird-friendly HLS. It is assumed in all cases that HLS would sit within a 'soft background matrix', where population growth rates are taken as an average of those observed under ELS and where no AES occurred. In practice this means in all cases, half the remaining proportion of lowland farms are assumed to be providing bird-friendly ELS and half no bird-friendly Agri-environment. We explore explicitly varying both HLS and ELS implementation levels as the second stage of the project.

2.1.1 FBI growth rate under different levels of AES

In order to start to understand the level of uncertainty around these point estimates we sought to account for uncertainty in the regional FBI growth rates under different levels of AES. We extracted the median and upper and lower 95% uncertainty intervals of these values from Sharps and Hawkes et al (Table 1) [4] and sampled each resulting distribution, at random, 1000 times assuming they were normally distributed on a log-scale. In doing so we created 1000 variants (hereafter termed replicates) of Table 1 each with slightly different growth rate values. A log-normal distribution is appropriate as we are considering rates of change, so that for example a population doubling would be balanced by a population halving. We tested the validity of this assumption and our choice of the number of replicates by ensuring the summary statistics (median, upper and lower CI) from across the replicates closely resembled those that they were sampled from. A greater number of replicates may have resulted in an even closer fit to the underlying data, however, the impact of this on the results is likely to be marginal, whereas processing time would have become unmanageable. It should be noted that although our previous model was also based on the FBI growth rates from the same field research, the final values published in Sharps and Hawkes et al 2023 varied slightly from those we used and so our results presented here will therefore differ slightly from our previous report.

Table 1: FBI growth rates in different regions and levels of AES, summarised from Sharps and Hawkes et al 2023

Region	Primary Farming Type	AES status	FBI growth rate	LCI	UCI
East Anglia	Arable	Bird-friendly ELS	0.987	0.969	1.004
		Bird-friendly HLS	1.056	1.031	1.077
		No AES	0.944	0.919	0.971
Oxfordshire	Mixed	Bird-friendly ELS	0.998	0.980	1.018
		Bird-friendly HLS	0.987	0.961	1.012
		No AES	0.970	0.948	0.990
West midlands	Pastoral	Bird-friendly ELS	1.032	0.963	1.108
		Bird-friendly HLS	1.117	1.050	1.174
		No AES	0.924	0.882	0.968

In order to focus on the impact of varying levels of bird-friendly HLS, we condensed the levels of AES in each region to two, bird-friendly HLS and not under bird-friendly HLS. The latter category representing the likely background mix of less targeted AES and areas without AES present in the countryside. There was notably no impact of bird-friendly HLS detected in the mixed farming landscape of Oxfordshire. It is thought that the experimental design may have been confounded in this region due to the much higher levels of AES provision. However, other research has suggested that AES may be less effective in mixed landscapes with more semi-natural habitat, such as Oxfordshire, so the lack of effects here may be real. Given the uncertainty, we have taken an average across the three experimental regions as a proxy of the FBI growth rate under bird-friendly HLS in mixed farming systems. Based on these two points we updated each replicate as follows:

1. **FBI growth rate under bird-friendly HLS**: Use the estimated FBI growth rate under bird-friendly HLS in each region to extrapolate to a type of farmland across England.
    i. Use the East Anglian results as a proxy of the FBI growth rate in Arable Farmland
    ii. Use the West Midlands results as a proxy of the FBI growth rate in enclosed lowland Pastoral Farmland
    iii. Use an average of the results under HLS across the three regions as a proxy of the growth rate in Mixed farming systems.

b. **FBI growth rate in areas not under bird-friendly HLS**: Using the same match of experimental region to farm type (here Oxfordshire alone was used as a proxy of the mixed farming landscape), for each region use the geometric mean growth rate where no AES was provided and under bird-friendly ELS. The geometric mean is an appropriate measure of central tendency when considering rates of changes and ensures that for example a population doubling is the reciprocal of a population halving [13]

2.1.2 FBI population distribution across habitats and FBI growth rate outside of enclosed farmland

In order to extrapolate these results outside the study regions and outside of lowland enclosed farmland we need to define the average proportion of FBI species' populations in each type of lowland enclosed farmland and in other habitats. We used published values of the average proportion of FBI populations in enclosed lowland farmland and in other habitat types [14] and updated the proportions within each enclosed lowland farmland used (Arable, Pastoral and Mixed Farming) by matching these to the Agricultural Landscape Types[15], which were used to classify each Natural Character Area (NCA) in England (Table 2). We used estimates of the total number of farmland birds in each NCA[8] to estimate the total number and proportion of farmland birds in each of the three farm types. NCAs classified as Upland, Upland Fringe or not classified, were omitted from this calculation.

Table 2: Conversion of Agricultural Landscape Types[15] to the farm types used in this simulation

Agricultural Landscape Type	Farm type
Eastern Arable	Arable
Western Mixed	Pastoral
Chalk and Limestone Mixed, South-East Mixed (Wooded)	Mixed farming

As well as knowing the average proportion of FBI species living outside of enclosed farmland, we also need to estimate how these sections of the population are faring. We defined the average FBI growth rate outside of enclosed farmland habitats by using the estimates of the average proportion of FBI species' population in different non-farmed habitats or upland farmed habitats estimated above, alongside habitat specific English BBS trends for each species (2008 to 2018, BTO unpublished data). Using these we calculated the geometric mean growth rate across non-farmed habitats weighted by the proportion of each species' population present in that habitat. Upland farmed areas were included in this category as there is little evidence of a positive impact of AES in these areas[16].

These estimates of the proportion of FBI populations in each habitat type and the average FBI growth rate outside of enclosed lowland farmland were added to each of the replicate AES growth rate tables produced in 2.1.1.

2.1.3 Estimate what proportion of bird-friendly HLS is likely to result in a stable FBI growth rate.

The FBI growth rate, weighted by proportion of populations in each habitat, was estimated for each of the 1000 replicates for bird-friendly HLS levels ranging from 0% to 100% in increments of 1%. In each case lowland farmland area 'not in bird-friendly HLS' was the reciprocal of the HLS level, with this half represented by bird-friendly ELS and half by areas without AES. These outputs were summarised as follows:

1. The distribution of FBI growth rate was plotted for a selection of bird-friendly HLS levels.
2. For each bird-friendly HLS level, the proportion of replicates where the FBI growth rate was at or above one was extracted as a representation of the likelihood of stabilising the FBI under different provision levels.
3. For each replicate the bird-friendly HLS provision level leading to the FBI growth rate closest to stability was extracted, taken as the growth rate closest to one, either higher or lower. The median and 2.5 and 97.5% quantiles of these 1000 estimates were taken to the represent the central tendency and uncertainty interval. This was repeated to extract the

HLS provision level leading to the FBI growth rate closest to that which would lead to an increase of 10% in the FBI over ten years.

2.1.4 Project different scenarios of bird-friendly HLS uptake into the future in relation to possible nature targets

Using the results of section 2.1.3, the FBI was projected forwards to 2030 or 2040 under the following scenarios to explore how the FBI may change over time as we work towards different possible targets.

Scenario 1. Halt decline by 2030 or 2040: Here we assume that by the target year we will reach the level of bird-friendly HLS provision likely to stabilise the FBI (including uncertainty), and infer a steady rate of increase to that value from the 10% level (that is ~10% of farms/land with each farm setting aside ~7% of land) estimated to be in place in 2022[17].

Scenario 2. Halt and Reverse decline by 2030 or 2040: Here we estimate the level of bird-friendly HLS needed by the target year to recover the FBI to its 2022 value by the target year. We assume a steady rate of increase in HLS provision from 10% of farms with 7% of their land set aside for bird-friendly HLS in 2022.

2.2 Objective 2: Sensitivity to species inclusion and varying levels of ELS

2.2.1. Omit Turtle Dove

The above analyses were repeated with updated FBI growth rates for bird-friendly HLS, ELS and no-AES in East Anglia omitting Turtle Dove. The FBI growth rate outside of lowland farmland was also updated to omit Turtle Dove. As an increasing rare, declining and more localised farmland bird in southern England, its inclusion in the original modelling framework is problematic. Because of its rarity, estimates of populations responses to different land uses were challenging. Indeed, Turtle Dove was the only farmland bird that failed to respond positively to AES in any region in the original study [4], which concluded that the ecological requirements of this species may not be readily met by generic AES. For this reason, Sharps and Hawkes et al. [4] present their results with and without Turtle Dove, as we do here. Note that omission of the declining Turtle Dove naturally lowers the amount of HLS required to stabilise or increase the FBI.

Given uncertainty around the impact of AES in the mixed farming landscape of Oxfordshire, a more optimistic variant of these minus Turtle Dove models was considered. In this scenario the Oxfordshire HLS and ELS estimates were taken as the average of the relevant AES-level for East Anglia and the West Midlands in contrast to our other scenarios where the observed growth rate for ELS in Oxfordshire is used and the HLS growth is taken as the average of the HLS estimates for all three regions. The results of this final scenario are given in the Supplementary Material.

2.2.2. Model the impact of varying both levels of HLS and ELS simultaneously.

The analysis set out in section 2.1 were updated to separate the 'not bird-friendly HLS' farmland category back into bird-friendly ELS and no AES. We then re-ran the analysis using each combination of bird-friendly HLS and ELS levels varying from zero to one, in 1% increments, omitting options where the sum was greater than one. For example, if 50% of farms are doing HLS the maximum that can do ELS is also 50%. This assumes that a farm cannot be doing both HLS and ELS.

We visualise these results using contour plots to show the likelihood of meeting a given target (stabilisation or a rate of increase equivalent to 10% increase of the FBI in ten years) for each combination of bird-friendly HLS and ELS provision. Likelihood in this case is taken as the proportion of replicates meeting a given target.

2.3 Caveats and assumptions

- Uptake of bird-friendly AES would be similar across the three lowland-enclosed farm types considered
- FBI growth rates under bird-friendly AES in the study regions are reasonable proxies for other lowland enclosed farmland regions of the same farming type elsewhere in England.
- The time lag between AES provision and an impact on bird populations is considered to be captured in the observed growth rates [4].
- Any projections assume that
    - The observed FBI growth rates under bird-friendly ELS and HLS will persist beyond the ten-year period over which they were measured, which may be an optimistic as populations increase and habitat fills up.
    - There is a continuation of the recent observed growth rate in the FBI (5-year average) between 2019 and 2022 without error/variation for all scenarios and this average is used to project a 'Business as Usual' scenario into the future.
- Our simulations do not explore the impact of targeting AES to where it may have most impact, this is explored at a regional level in Sharps and Hawkes 2023[4].

3. Results

3.1 Impact of varying bird-friendly HLS provision in relation to a 'background' mix of half bird-friendly ELS and half no AES.

3.1.1 All FBI species

From each of our 1000 replicates we extracted a weighted average growth rate for each percent provision of bird-friendly HLS, where half the remaining area of lowland farmland was in bird-friendly ELS agreements. For example, where bird-friendly HLS provision was 10% of lowland enclosed farmland landholdings, of the remaining 90%, 45% were assumed to be under bird-friendly ELS agreements and 45% having no bird-friendly AES provision. This means that although we are varying HLS provision in relation to a constant 'background' FBI growth rate, the realised ELS provision will vary in each case. The resulting distributions of FBI growth rate are plotted for a sample of bird-friendly HLS provision levels (Figure 2) and projected forward in time (Figure 3).

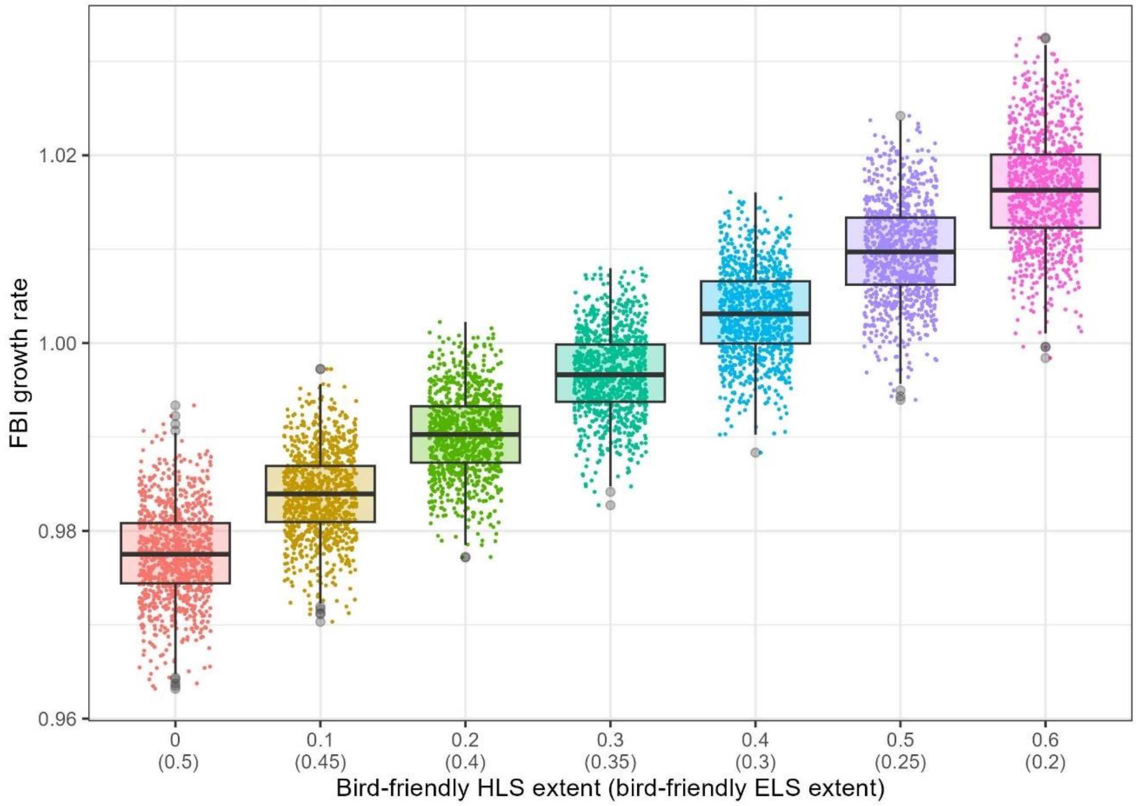


Figure 2: Boxplot of the estimated FBI growth rate under different levels of bird-friendly HLS provision with the 1000 replicate estimates shown as points. FBI growth rate is a multiplicative value, 1 = stability, 1.02 a 2% increase, 0.98 a 2% decline. HLS provision is the proportion of farms in our simulations with e.g. 0.4 = 40% of the farms with 10% of their land given over to HLS. In each case the remaining lowland enclosed farms not in HLS are assumed to be half in bird-friendly ELS agreements (value shown in brackets) and half with no bird-friendly AES.

Across our 1000 simulation replicates, the median provision of bird-friendly HLS needed in lowland farmland to stabilise the FBI was 35% (95% uncertainty interval (UI): 21% to 50%). These values would need to rise to 50% (UI: 36% to 69%) to reach a growth rate that would lead to a 10% increase in the FBI over ten years.

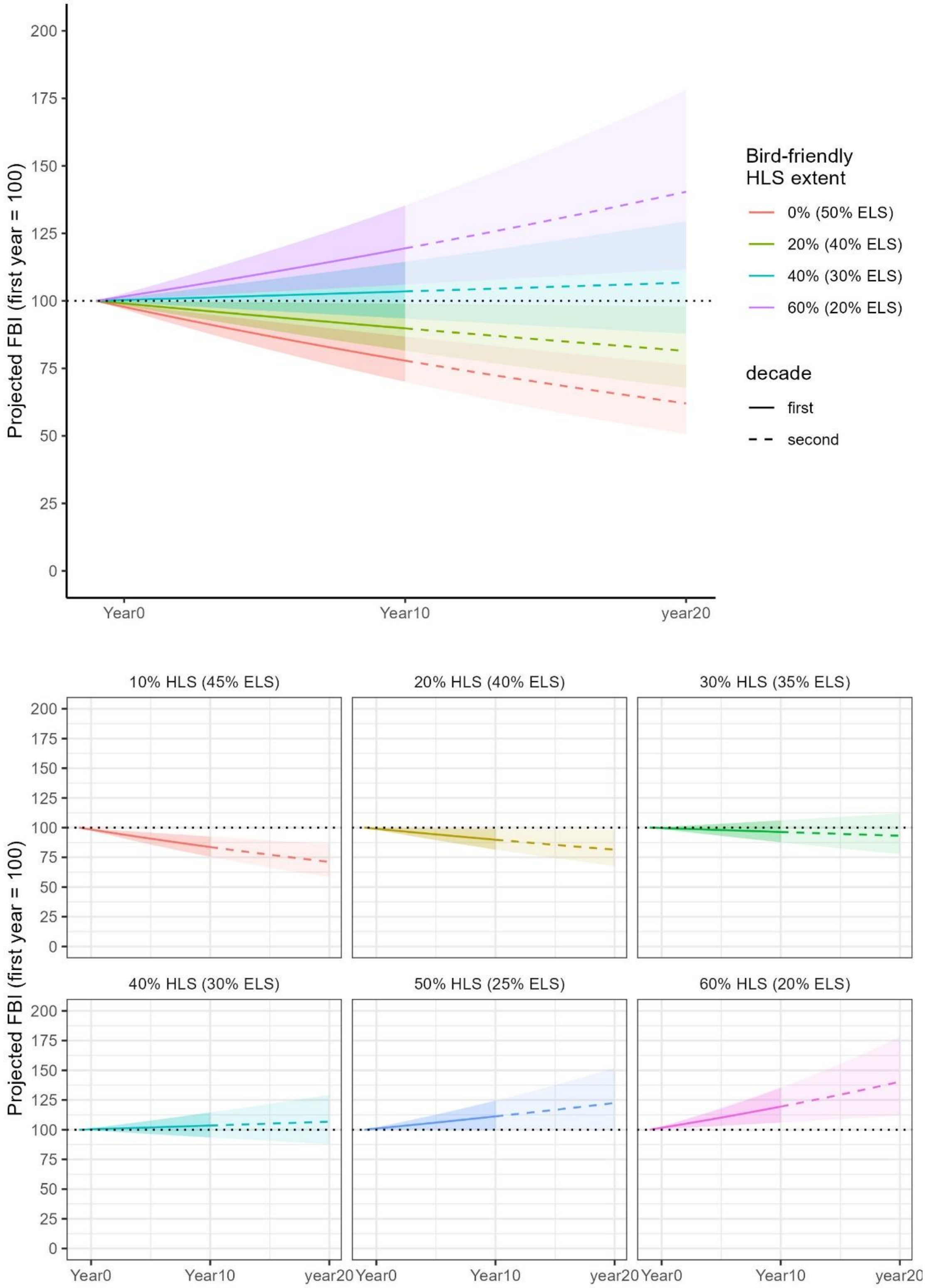


Figure 3: ***The England FBI projected into the future under different provision levels of bird-friendly HLS*** *from 0% to 60% with 95% uncertainty interval shown by the ribbons. Bird-friendly HLS provision is the proportion of farms in our simulations with e.g. 0.4 = 40% of the farms with 7% of their land given over to HLS. The underpinning empirical study was undertaken over the course of a decade and the observed responses to AES may not remain constant over a longer time period, so here the second decade is shown using a dashed line and reduced opacity. At each level of HLS, half the remaining lowland enclosed farms are assumed to be in bird-friendly ELS agreements (shown in brackets) and half with no bird-friendly AES.*

By expressing these values as the proportion of replicates where the growth rate was at or above a particular target, we can assess the likelihood of meeting that target. For example, 50% of replicates had an FBI growth rate at or above one where HLS provision was 35%, and 80% reached stability where provision was 41% (Table 3, Figure 4), indicating there is a 50% chance of meeting a target to stabilise the FBI where provision is 35% and 80% chance where provision is 41%. Expressing the results in this format allows decision makers to explicitly agree the level of confidence, and conversely risk, they are willing to accept as they work towards biodiversity targets.

Table 3: HLS implementation levels meeting a selection of thresholds of likelihood of stabilising the FBI (proportion of replicates where the FBI growth rate was at or above one)

Target	Likelihood	Farms in lowland enclosed farmland with bird friendly AES (%)	
		HLS	(ELS)
Stabilise FBI	50%	35.5	(32.3)
	80%	41.2	(29.4)
	90%	45.0	(27.5)
	95%	48.0	(26.0)
	99%	53.8	(23.1)
FBI increase of over 10% in 10 years	50%	49.8	(25.1)
	80%	57.1	(21.5)
	90%	61.1	(19.5)
	95%	64.6	(17.7)
	99%	73.1	(13.5)

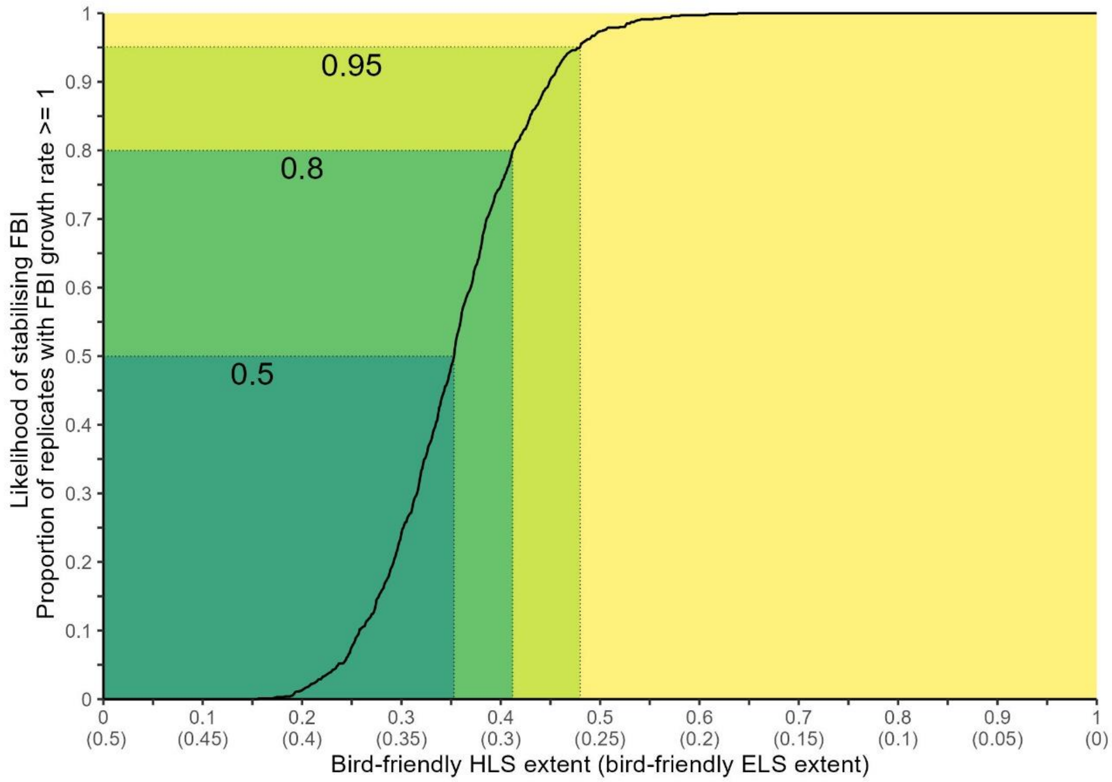


Figure 4: The estimated likelihood of stabilising the England FBI under different levels of HLS provision, expressed as the proportion of replicates with an FBI growth rate of >= 1. HLS provision is the proportion of farms in our simulations, with e.g. 0.4 = 40% of the farms with 7% of their land given over to bird-friendly HLS. 50%, 80% and 95% likelihoods are illustrated using coloured rectangles. At each level of HLS, half the remaining lowland enclosed farms are assumed to be in bird-friendly ELS agreements (values shown in brackets) and half with no bird-friendly AES.

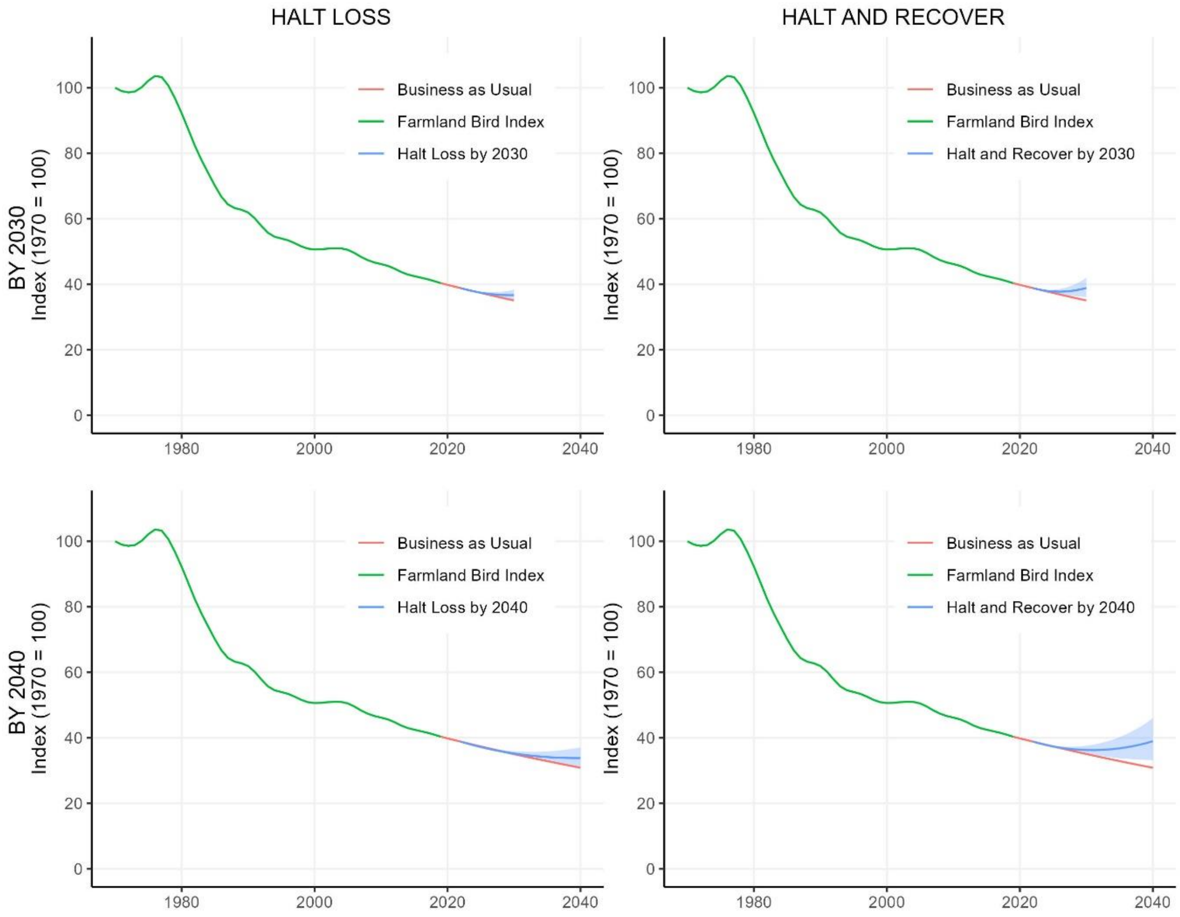


Figure 5: The observed England FBI (green) and versions projected to 2030 or 2040 assuming either a continued decline at the recently observed rate (red) or that bird-friendly HLS provision reaches the level needed for stability or recovery by the final year (blue). 95% uncertainty intervals for the latter are shown by the ribbons.

When we assumed that bird-friendly HLS provision levels would increase by 2030 to the estimated level needed to stabilise the FBI, our projection suggested that the FBI would have declined from 38.8 in 2022 by a further two pp to 36.7 (UI: 35.2 to 38.3). The equivalent figure for reaching HLS levels needed for stability by 2040 are a decline of five pp to 33.8 (UI: 31.0 to 37.1; Figure 5) by 2040. In each case this would be a smaller decline that predicted under BAU conditions where the FBI continues its recent rate of decline to 35.1 in 2030 and 30.9 in 2040.

If we again assume a constant rate of increase in HLS implementation from 2022 until the target date, we can assess what implementation level would be needed to be reached by the target date for the indicator to have recovered to 2022 levels. If the target date to halt and recover is 2030 then we would need to reach coverage levels of 55% (UI: 30% to 81%) by that year, if the target year is 2040 the final implementation levels would be similar at 58% (UI: 32% to 85%).

3.1.2 Sensitivity to Turtle Dove

Turtle Doves were included in the original model included in the Environment Act consultation. By retaining all model assumptions and repeating without including growth rates for Turtle Dove, we can assess the sensitivity of our results to this rapidly declining specialist species, whose range is now restricted and whose population broad-scale bird-friendly AES is struggling to support. Our results are sensitive to the inclusion of Turtle Dove (Figures 6, 7). Across our 1000 simulation replicates, the median provision of bird-friendly HLS needed in lowland farmland to stabilise the FBI in the absence of Turtle Dove was 27% (8% lower than the simulation including Turtle Dove)(UI: 14% to 40%). These values would need to rise to 41% (UI: 28% to 57%) to reach a growth rate that would lead to a 10% increase over ten years.

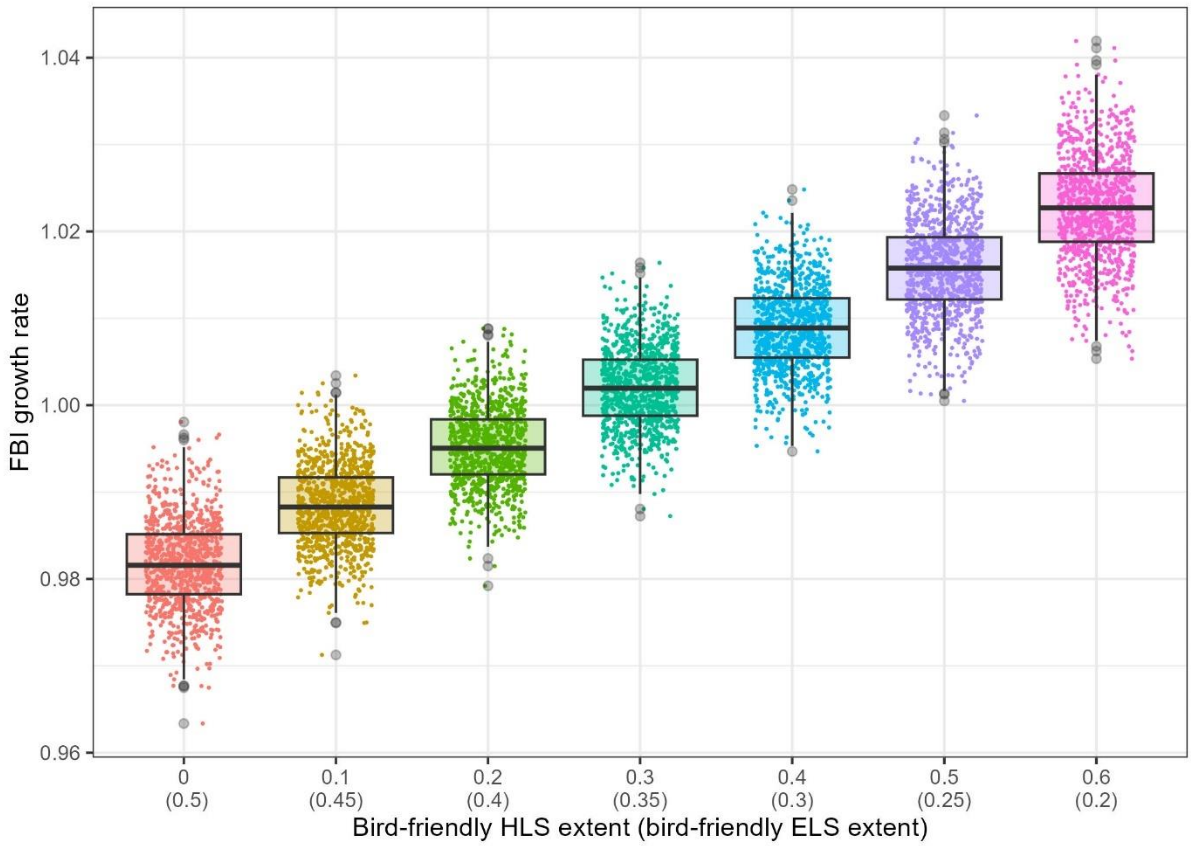
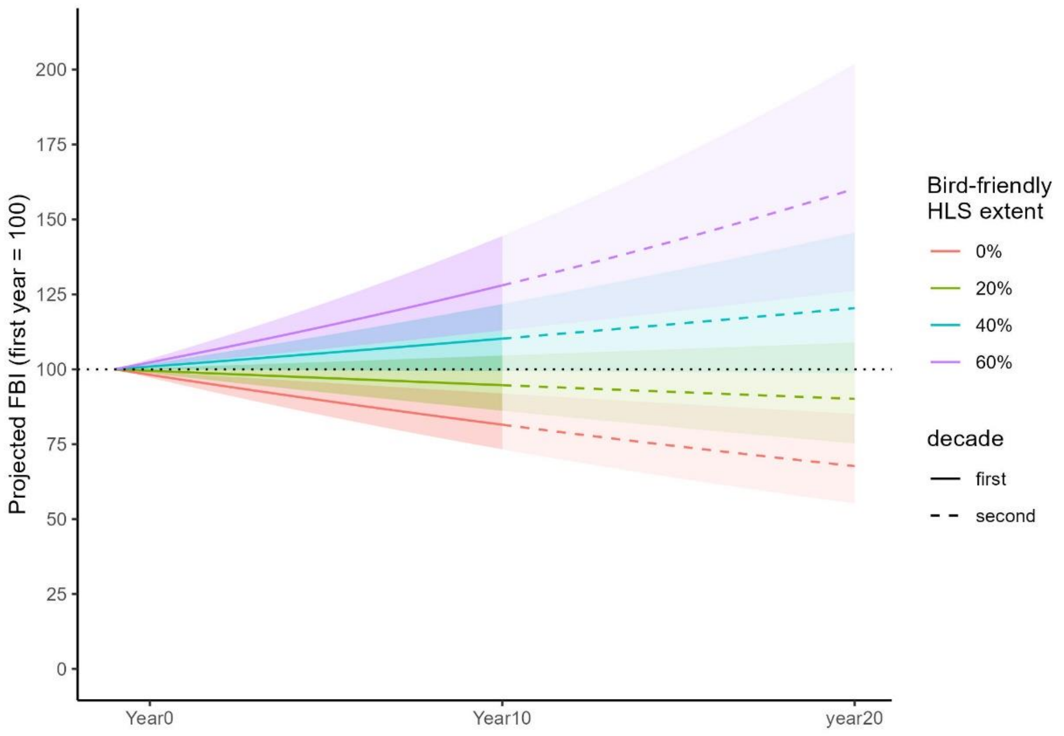


Figure 6: ***Boxplot of the estimated FBI growth rate under different levels of HLS provision omitting Turtle Dove*** *with the 1000 replicate estimates in each case shown as points. FBI growth rate is a multiplicative value, 1 = stability, 1.02 a 2% increase, 0.98 a 2% decline. HLS provision is the proportion of farms in our simulations with e.g. 0.4 = 40% of the farms with 10% of their land given over to HLS. At each level of HLS, half the remaining lowland enclosed farms are assumed to be in bird-friendly ELS agreements (values shown in brackets) and half with no bird-friendly AES.*



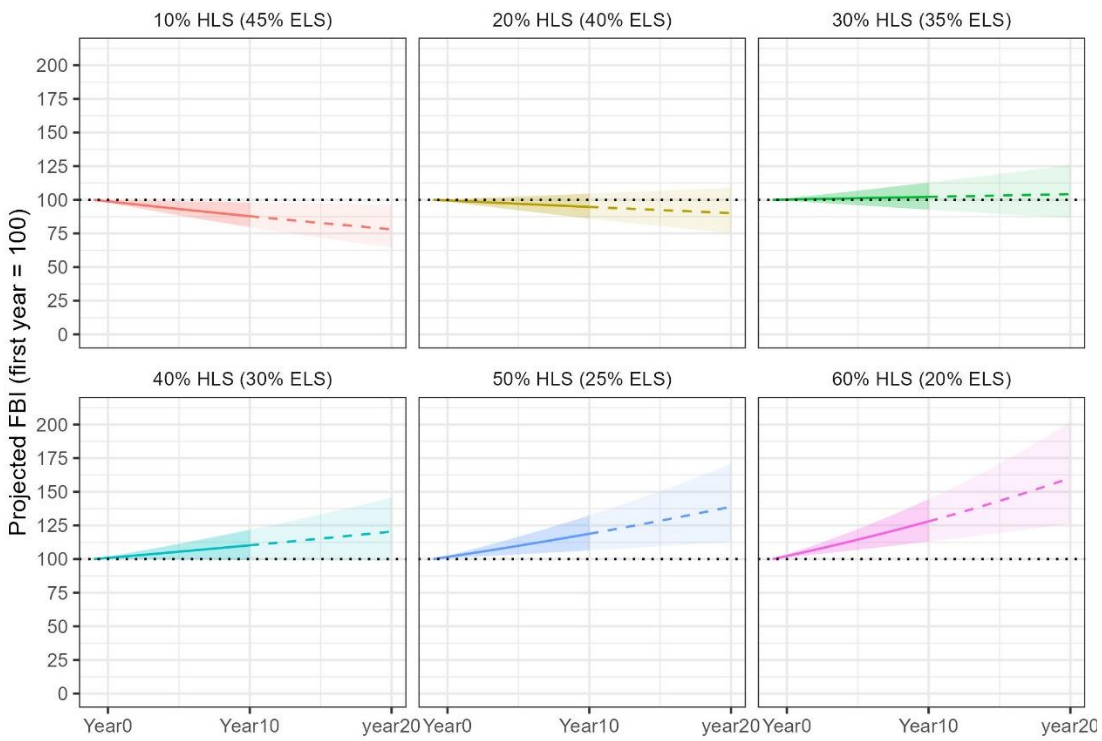


*Figure 7: **The England FBI projected into the future under different provision levels of HLS** omitting Turtle Dove from 0% to 60% with 95% uncertainty intervals shown by the ribbon. The experimental results were measured over a decade and may not remain constant over a longer time period so the second decade is shown using a dashed line and reduced opacity. At each level of HLS, half the remaining lowland enclosed farms are assumed to be in bird-friendly ELS agreements (values shown in brackets) and half with no bird-friendly AES.*

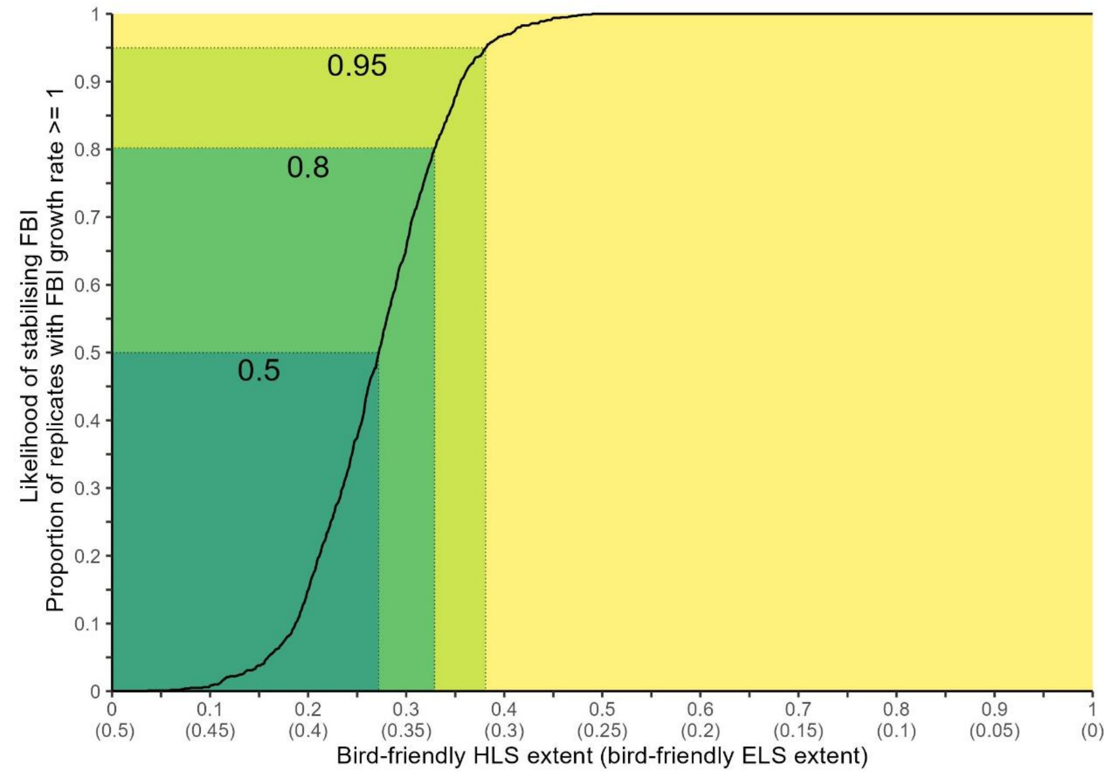


*Figure 8: **The estimated likelihood of stabilising the England FBI under different levels of HLS provision**, omitting Turtle Dove, expressed as the proportion of replicates with a growth rate of >= 1. HLS provision is the proportion of farms in our simulations, with e.g. 0.4 = 40% of the farms with 7% of their land given over to bird-friendly HLS. 50%, 80% and 95% likelihoods are illustrated using coloured rectangles. At each level of HLS, half the remaining lowland enclosed farms are assumed to be in bird-friendly ELS agreements (values shown in brackets) and half with no bird-friendly AES.*

There was a 50% chance of meeting a target to stabilise the FBI where provision in 27% and 80% chance where provision is 33% (Table 4, Figure 8).

Table 4: Bird-friendly AES implementation levels meeting a selection of thresholds of likelihood of stabilising the FBI (proportion of replicates where the FBI growth was at or above one), where Turtle Dove were excluded from the model

Target	Likelihood	Farms in lowland enclosed farmland with bird friendly AES (%)	
		HLS	(ELS)
Stabilise FBI	50%	27.2	(36.4)
	80%	32.9	(33.6)
	90%	35.6	(32.2)
	95%	38.1	(31.0)
	99%	44.2	(27.9)
Increase FBI 10% in 10 years	50%	40.9	(30.0)
	80%	47.4	(26.3)
	90%	51.1	(24.5)
	95%	54.0	(23.0)
	99%	61.5	(19.3)

3.2 Impact of varying HLS and ELS provision coincidently

3.2.1 All FBI species

When we vary the level of bird-friendly HLS and ELS provision at the same time three patterns emerge (Figure 9a, Table 5). Firstly, in the absence of any bird-friendly HLS provision the likelihood of stabilising the FBI is extremely low regardless of the level of bird-friendly ELS provision. Secondly, the level of HLS provision needed in a harsher background matrix (low levels of ELS) is much higher than in our original scenarios. Finally, for any given level of confidence of meeting a target there are a range of combinations of 'broad and shallow' and 'narrow and deep' AES that could get you there. For example, if you want to minimise the amount of bird-friendly HLS needed, but you wanted at least 80% change of stabilising the FBI you could see you would need a minimum of around 20% HLS with nearly all remaining lowland enclosed farmland in bird-friendly ELS-type agreements. These precise values are not the key here, rather the general patterns. Using the same dataset we can visualise the likelihood of meeting a range of targets. If the target is to obtain an FBI growth rate which would lead to an increase of 10% in ten years, for the same 80% likelihood of success and still aiming to minimise the level of bird-friendly HLS we can see we need around 40% HLS and 60% ELS (Fig 9b).

Table 5: Likelihood of stabilising the FBI (proportion of replicates where the FBI growth was at or above one) under a selection of combination of bird-friendly HLS and ELS implementation levels.

	Likelihood of stabilising the FBI																
Bird-friendly HLS	**Bird-friendly ELS**																
	0	**0.05**	**0.1**	**0.15**	**0.2**	**0.25**	**0.3**	**0.35**	**0.4**	**0.45**	**0.5**	**0.55**	**0.6**	**0.65**	**0.7**	**0.75**	**0.8**
0.2	0	0	0	0	0	0	0.001	0.003	0.015	0.044	0.098	0.221	0.354	0.506	0.649	0.749	0.828
0.25	0	0	0	0	0.003	0.007	0.013	0.039	0.103	0.227	0.372	0.523	0.668	0.774	0.854	0.913	
0.3	0.001	0.001	0.007	0.009	0.015	0.037	0.11	0.229	0.371	0.546	0.686	0.804	0.894	0.938	0.969		
0.32	0.005	0.007	0.009	0.015	0.035	0.104	0.209	0.347	0.519	0.666	0.798	0.9	0.943	0.972			
0.34	0.007	0.009	0.016	0.032	0.091	0.189	0.319	0.492	0.641	0.79	0.894	0.942	0.973	0.981			
0.36	0.009	0.017	0.031	0.081	0.174	0.297	0.468	0.626	0.777	0.887	0.945	0.97	0.983				
0.38	0.018	0.035	0.075	0.164	0.274	0.445	0.603	0.752	0.876	0.945	0.969	0.982	0.988				
0.4	0.035	0.078	0.153	0.257	0.423	0.583	0.728	0.863	0.937	0.968	0.98	0.988	0.999				
0.42	0.072	0.145	0.249	0.396	0.557	0.709	0.846	0.928	0.959	0.978	0.989	0.998					
0.44	0.144	0.236	0.373	0.534	0.684	0.823	0.917	0.956	0.977	0.988	0.998	0.999					
0.46	0.225	0.358	0.507	0.659	0.803	0.906	0.952	0.977	0.988	0.996	0.998						
0.48	0.346	0.497	0.634	0.781	0.886	0.942	0.969	0.983	0.995	0.999	1						
0.5	0.471	0.614	0.753	0.862	0.93	0.965	0.983	0.992	0.999	1	1						
0.52	0.588	0.721	0.841	0.917	0.954	0.981	0.99	0.998	0.999	1							
0.54	0.691	0.818	0.899	0.948	0.977	0.988	0.995	0.999	1	1							
0.56	0.791	0.879	0.939	0.971	0.986	0.994	0.999	0.999	1								
0.58	0.863	0.926	0.958	0.984	0.991	0.997	0.999	1	1								
0.6	0.91	0.949	0.98	0.988	0.995	0.999	1	1	1								
0.65	0.97	0.985	0.993	0.997	0.999	1	1	1									
0.7	0.99	0.996	0.998	0.999	1	1	1										

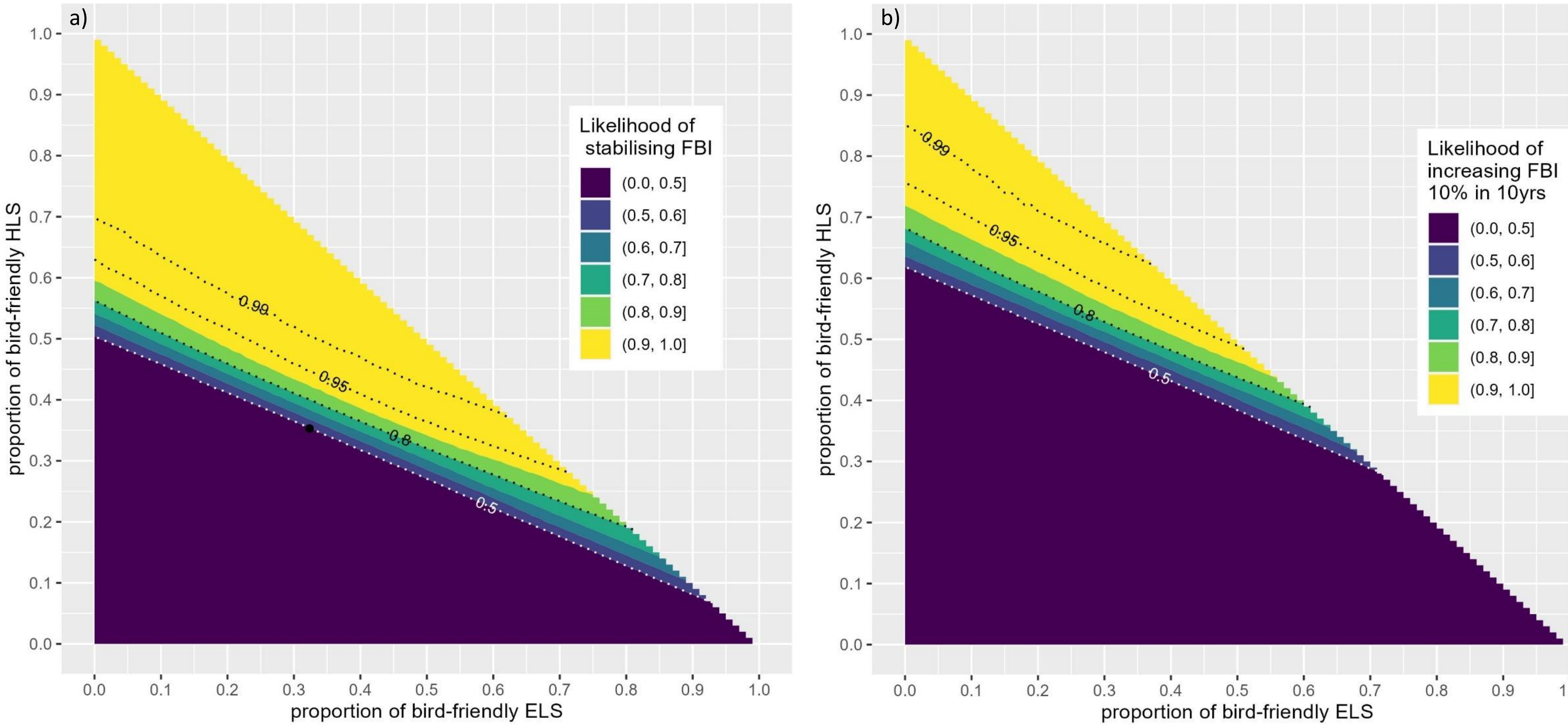


Figure 9: Across all FBI species, the likelihood of stabilising the FBI (FBI growth rate of >=1) (a) or increasing it by 10% in ten years (FBI growth rate >= 1.1^(1/10)) (b) for varying combinations of bird-friendly ELS and HLS. Likelihood of meeting the target is taken as the proportion of replicates meeting it in each case. HLS provision is the proportion of farms in our simulations, with e.g. 0.4 = 40% of the farms with 7% of their land given over to bird-friendly HLS. ELS provision is the proportion of farms in our simulations, with e.g., 0.4 = 40% of farms with 2-3% of their land given over to bird-friendly ELS. To illustrate the relationship between these results and those shown in section 3.1 the median bird-friendly HLS provision needed for stability in the first scenario has been plotted as a black point on panel (a).

3.2.2. Sensitivity to Turtle Dove

In the absence of Turtle Dove the same putative nature targets are slightly easier to meet, but the same general patterns persist. For example, there is still 50% or lower likelihood of stabilising the FBI in the absence of bird-friendly HLS regardless of the provision of bird-friendly ELS (Figure 10, Table 6).

Table 6: Likelihood of stabilising the FBI (proportion of replicates where the FBI growth was at or above one) where Turtle Dove is omitted from the assessment, under a selection of combination of bird-friendly HLS and ELS implementation levels.

Likelihood of stabilising the FBI																			
	Bird-friendly ELS																		
HLS	**0**	**0.05**	**0.1**	**0.15**	**0.2**	**0.25**	**0.3**	**0.35**	**0.4**	**0.45**	**0.5**	**0.55**	**0.6**	**0.65**	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
0.1	0	0	0	0	0	0	0.001	0.001	0.002	0.008	0.027	0.052	0.121	0.224	0.345	0.47	0.576	0.665	0.748
0.12	0	0	0	0	0	0.001	0.001	0.001	0.009	0.023	0.045	0.096	0.207	0.33	0.457	0.575	0.668	0.763	
0.14	0	0	0	0.001	0.001	0.001	0.001	0.008	0.019	0.041	0.085	0.188	0.317	0.449	0.574	0.671	0.766	0.827	
0.16	0	0	0.001	0.001	0.001	0.001	0.007	0.017	0.033	0.075	0.171	0.302	0.435	0.564	0.675	0.776	0.836		
0.18	0	0.001	0.001	0.001	0.001	0.006	0.014	0.029	0.074	0.161	0.287	0.42	0.554	0.679	0.778	0.846	0.888		
0.2	0.001	0.001	0.001	0.001	0.005	0.013	0.028	0.069	0.149	0.271	0.4	0.545	0.682	0.782	0.846	0.897	0.93		
0.22	0.001	0.001	0.002	0.006	0.013	0.031	0.065	0.14	0.259	0.396	0.545	0.677	0.783	0.86	0.903	0.94			
0.24	0.001	0.002	0.007	0.014	0.03	0.071	0.131	0.25	0.379	0.53	0.679	0.791	0.865	0.915	0.947	0.963			
0.26	0.003	0.009	0.014	0.034	0.063	0.123	0.241	0.37	0.525	0.671	0.794	0.87	0.927	0.953	0.972				
0.28	0.009	0.021	0.037	0.065	0.123	0.227	0.361	0.516	0.672	0.788	0.877	0.933	0.96	0.976	0.988				
0.3	0.023	0.039	0.065	0.125	0.22	0.361	0.504	0.654	0.786	0.88	0.939	0.962	0.977	0.99	0.995				
0.32	0.041	0.065	0.13	0.22	0.351	0.496	0.648	0.785	0.874	0.945	0.965	0.982	0.993	0.996					
0.34	0.073	0.132	0.222	0.347	0.481	0.646	0.78	0.875	0.951	0.969	0.982	0.994	0.997	0.998					
0.36	0.139	0.218	0.334	0.482	0.64	0.769	0.879	0.946	0.968	0.984	0.995	0.997	0.999						
0.38	0.222	0.329	0.481	0.624	0.759	0.872	0.937	0.968	0.985	0.994	0.998	0.999	1						
0.4	0.323	0.48	0.614	0.746	0.861	0.934	0.969	0.983	0.993	0.998	0.999	1	1						
0.42	0.48	0.61	0.738	0.852	0.924	0.965	0.983	0.993	0.998	1	1	1							
0.44	0.595	0.721	0.835	0.913	0.963	0.984	0.993	0.999	1	1	1	1							
0.46	0.702	0.829	0.898	0.954	0.984	0.993	0.998	1	1	1	1								
0.48	0.814	0.891	0.944	0.979	0.991	0.998	1	1	1	1	1								
0.5	0.874	0.932	0.974	0.99	0.997	1	1	1	1	1	1								
0.55	0.968	0.988	0.996	1	1	1	1	1	1	1									
0.6	0.996	0.998	1	1	1	1	1	1	1										

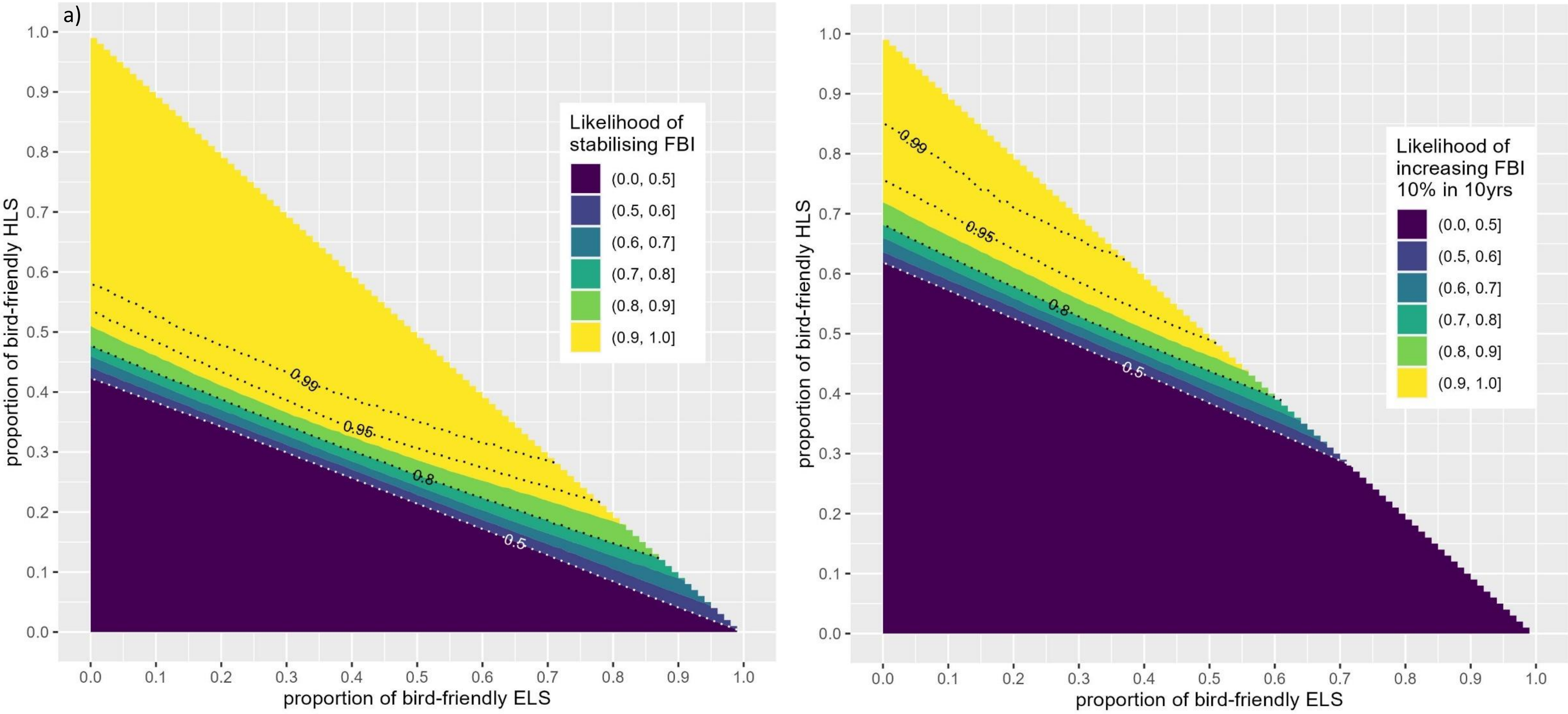


Figure 10: Omitting Turtle Dove, the likelihood of stabilising the FBI (FBI growth rate of >=1) (a) or increasing it by 10% in ten years (FBI growth rate >= 1.1^(1/10)) (b) for varying combinations of bird-friendly ELS and HLS. Likelihood of meeting the target is taken as the proportion of replicates meeting it in each case. HLS provision is the proportion of farms in our simulations, with e.g. 0.4 = 40% of the farms with 7% of their land given over to bird-friendly HLS. ELS provision is the proportion of farms in our simulations, with e.g., 0.4 = 40% of farms with 2-3% of their land given over to bird-friendly ELS.

4. Discussion

4.1 How much Bird-friendly ES AES is needed to recover farmland birds?

From our results it is clear to see that although bird-friendly AES is having positive impact on a range of farmland bird species and on average across the FBI suite, current provision levels remain far below those needed to stabilise and start to recover the FBI. These results held true even when Turtle Dove, that has thus far shown no benefit of AES, was removed.

The empirical data underpinning our scenarios relates to two levels or types of bird-friendly AES, the broad and shallow ELS and the narrow and deep HLS. When provision levels of each were varied simultaneously the results suggest that it is unlikely under any scenario variant that we will be able to halt the decline of farmland birds via bird-friendly options in ELS-type schemes, regardless of the level of uptake. Bird-friendly ELS provision was helpful in reducing the level of HLS needed, presenting a range of potential routes to population recovery depending on the balance of resources put into both types of scheme.

It should be remembered that stabilising or starting to recover the FBI does not mean that we will have halted the declines for all component species. There will likely still be a range of individual population trajectories and some species, including for example the Turtle Dove, will remain of conservation concern. If we wanted to stabilise or recover a species abundance index for the specialist subset of the FBI species, or a priority subset, the levels of bird-friendly AES required would likely be considerably higher[4].

Our results are not precise, we have incorporated important elements of uncertainty and investigated some aspects of sensitivity, but the scenarios make a range of assumptions (see section 2.3) that if different decisions were taken on would likely influence our results. This is not to detract from the results presented, but to emphasise that they should be interpreted as indicative rather than prescriptive, focussing on the broad patterns rather than the exact percentage points.

4.2 Comparability to current land management/AES schemes in England

In England, government is developing two new environmental land management schemes (ELM), the Sustainable Farming Incentive (SFI), and Landscape Recovery (LR), and has proposed retaining and improving Countryside Stewardship Higher Tier (CS HT).

4.2.1 SFI

All farms are eligible for the SFI, which is an untargeted and non-competitive “broad and shallow” scheme. The scheme currently provides almost complete free choice of actions at the land holding level, with advice only available to develop a soil, nutrient, or integrated pest management plan. The only constraint to free choice exists for a small number of actions, which combined cannot be applied to any more than 25% of the farmed area. These capped options include winter bird seed and pollen and nectar mixes, grassy field corners and unharvested headlands. The SFI was first launched in 2022, following a pilot in 2021. The 2022 offer paid for two options focused on improving soil health, the scheme was then relaunched in 2023 with 23 actions covering a mix of farmland wildlife actions and farm sustainability measures and again in summer 2024 with approximately 100 options. The new SFI offer includes a series of new SFI actions, and revised CS mid-tier options. Defra has revised these options to reduce the level of prescription and increased the emphasis on voluntary guidance to provide additional flexibility to agreement holders.

According to data from the Rural Payments Agency (RPA), SFI 2023 has just over 27,000 agreements covering 5 million hectares of farmland. It is important to note that much of the 5 million hectares are not subject to active management, this figure includes land subject to a soil, nutrient, or integrated pest management plan. Estimates suggest that under an average SFI agreement approximately 2-3% of a lowland land holding is under bird friendly measures, so broadly equivalent to ELS. One notable difference between SFI and ELS, is that under SFI more land is under actions such as herbal leys, and legume fallows (c11% of a holding under an average SFI agreement), which if left uncut in spring/summer could provide resources for farmland birds. However, SFI is a non-prescriptive scheme and as such it does not require agreement holders to leave areas uncut thus limiting the benefit of these actions to farmland birds and other wildlife.

Whilst the pattern of uptake may change overtime, the contribution of SFI to recovery of the FBI is likely to be broadly equivalent to the modelled ELS bird-friendly provision used in this study.

4.2.2 Countryside Stewardship Higher Tier

CS HT was introduced in 2015 to replace HLS. Until 2023, the scheme was available for application once a year, with ~300-500 agreements per year. Defra has yet to launch a higher tier offer for 2024 but has committed to retaining and improving the scheme. The scheme is competitive and highly targeted, with agreements having to score a certain threshold to move forward to an agreement negotiation with Natural England. Agreements have tended to focus on land holdings with larger areas of SSSIs and defined priority habitats due to resource constraints.

Due to the focus on priority habitats, SSSIs and priority species (e.g. Stone Curlew), this scheme is unlikely to be broadly equivalent to the modelled HLS bird-friendly provision used here.

4.2.3. Landscape Recovery

Landscape Recovery is a highly competitive scheme with projects subject to a tendering process. The projects focus on bringing together multiple landholdings to recover habitats and ecosystem function at a large, landscape scale. The schemes are designed to have two phases, a two-year development phase and a 20-year implementation phase. The implementation phase is subject to negotiation, leading to highly bespoke agreements. Government has funded two biding rounds for the first phase projects.

The simulations presented here do not consider Landscape Recovery, although they would likely have a beneficial impact on farmland birds at least at a local scale and depend on uptake.

4.2.4 Policy implications

Whilst the SFI may be able to provide roughly similar benefits to farmland birds than ELS bird-friendly provision, neither the SFI nor CS HT are currently providing bird-friendly AES equivalent to HLS bird-friendly provision. Possible routes to incorporate this targeted higher-level provision could be by introducing a targeted farmland bird or farmland wildlife package into SFI that is supported by advice or to seek to increase uptake of HLS bird-friendly provision under CS HT.

4.3 Inferring beyond farmland birds

There are a number of reasons to think that birds as a group might act as reasonable biodiversity indicators [13, 18, 19]. They occur high in food chains and so are sensitive to environmental change (both anthropogenic and natural). They are widespread, diverse and mobile, living in most terrestrial and marine habitats across all continents. They are relatively easy to identify, survey and census, and their phylogenetic status is well defined. Count data are realistic and relatively inexpensive to collect (especially when counts are made by skilled and motivated volunteers). Methods of survey design (i.e. sampling strategy and fieldwork methods) and analysis are well established. Plus, long-term time series exist allowing contemporary patterns to be understood in context and a mass of supplementary knowledge and information exists to aid the evaluation of bird species and composite species trends. In addition, birds have a connection to people, they deliver ecosystem services, certainly in the form of cultural services, but also in terms of provisioning, regulating and supporting services [20]. Therefore, birds can act as an excellent communication tool to raise awareness of biodiversity issues more generally and are widely adopted and used in environmental policy and reporting mechanisms.

However, the degree to which a single taxon, like farmland birds, can accurately represent the status and trends in other taxa is a matter of debate. Birds are much less specialised in microhabitat use than other taxa and generally operate at a much larger spatial scale. Their mobility compared to other taxa may be a problem as their movements mean that their population dynamics integrate environmental effects across very large areas[13, 18, 19]. We also know that some birds benefit from anthropogenic pressure when others do not, yet predicting and understanding such responses is not straightforward. Wild bird indicators have to be interpreted with care.

Surprisingly, relatively few studies have examined the degree of correspondence in the trends of different taxa through time or space [13]. Studies have shown that many vertebrate, insect and plant species of farmland have declined in parallel, whereas only a few species have increased, and these changes are thought to be driven by agricultural intensification and specialization. Gregory et al. [13] showed a consistent pattern of concomitant change in different taxa, including plants, birds and insects, across a range of studies. The best information available to us, which is somewhat limited in its coverage of taxa, supports the view that bird population trends on lowland farmland at least are correlated positively with trends in other taxa. We recognize, however, that the nature of evidence is often weak (based largely on correlation) and recommend further work to explore the temporal and spatial correspondence of across taxa trends in different systems. As well as more work to explore the temporal and spatial responses of different taxa to AES measures.

More direct support for the role of AES measures designed for birds in supporting other taxa comes from individual studies of priority bird species. For example, MacDonald et al.[21] showed that AES measures for Cirl Buntings (*Emberiza cirlus*) in SW England have benefits for a range of taxa beyond the target species, and therefore, largely through reduction of management intensity and maintenance of land-use diversity, improves the overall biodiversity of the farmed landscape. This included benefits for vascular plants, butterflies, bumblebees and carabid beetles. Similarly, MacDonald et al.[22] demonstrate that fallow plots that have been put in place for the recovery of stone curlews (*Burhinus oedicnemus*) in southern England had considerable value for a range of other farmland biodiversity, including several priority bird species, brown hares *Lepus europaeus*, carabid beetles, vascular plants, butterflies and bumblebees (though not carabids). Six rare arable plant species were recorded, predominantly from stone curlew fallow plots, and the plots were considered to perform comparably to other AES options in England designed specifically for arable plants.

Taken together, there is good evidence to suggest the provision of nature-friendly AES options, such as HLS or HLS-like provisions, would likely have significant positive effects on some other farmland taxa. However, we lack empirical evidence that directly links our modelling with other taxa so we can only speculate as to whether the provision we have modelled using birds here would deliver any equivalent or similar population recovery for other taxa.

4.4 Recommendation for further Work

Several areas of further research would give a clearer picture of the scale and type of AES provision needed to recover farmland wildlife. Similar simulation studies to this one could be done on other taxonomic groups and this study could be extended, to for example look at different scenarios of the rate of uptake of AES scheme, different ways you could target options to where they are likely to have most impact or to incorporate farmer attitudes or economic information. A second approach would be a programme of evaluation to understand the impact of current AES schemes like SFI and CS HT on different aspects of biodiversity and how these vary by region, land character and landscape context. In order to more directly understand the scale of conservation interventions needed to halt the decline in, and support the recovery of species more broadly, similar observational and simulation studies will be needed on other taxonomic groups and intervention types.

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7. Supplementary Material

Sensitivity to assumptions for AES growth rates under Mixed farming

7.1 Varying bird-friendly HLS provision against a constant background where half of the remaining lowland enclosed farmland is providing bird-friendly ELS.

When Turtle Dove is removed, the FBI growth rates under ELS and HLS become similar between our Arable region and our Pastoral region. Given the uncertainty around the FBI growth rates in the mixed farming region, it is useful to explore the sensitivity of our results to how we estimate these. Here, we estimate the bird-friendly HLS and ELS FBI growth rates for the mixed farming region as an average of the other two areas, rather than an average of all three areas as in our other simulations. Our results are sensitive to the method used (Figure S1). Across our 1000 simulated replicates, the median provision of HLS needed in lowland farmland to stabilise the FBI was 23% (95% uncertainty interval: 5% to 37%). There was a 50% chance of meeting a target to stabilise the FBI where provision is 23% and 80% chance where provision is 29% (Figure S2).

It is important to recognise that our results are sensitive to the assumptions underpinning the AES effect sizes used to represent mixed farming systems. However, we think that it is best to focus on the results from the three-region average approach as a sensible balance between using the observed values (indicating no benefit of AES), and an average of the other two regions, where significant benefits were observed.

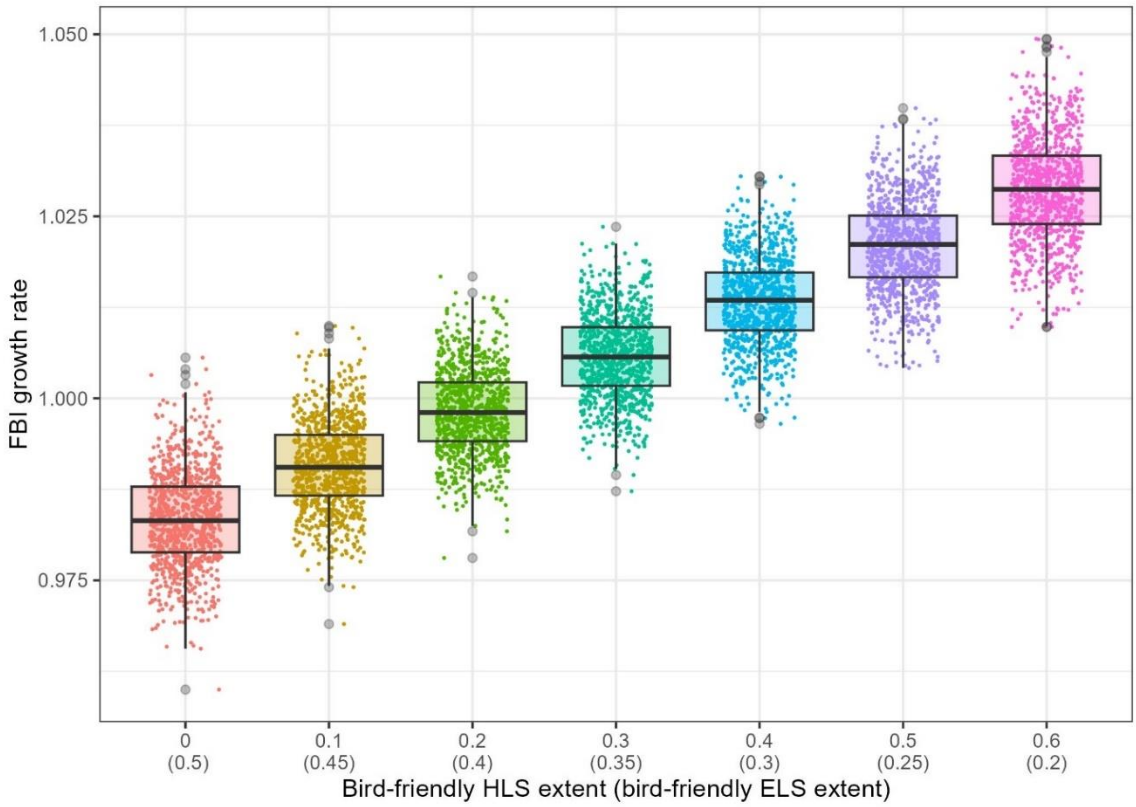

Figure S1: ***Boxplot of the estimated FBI growth rate under different levels of HLS provision omitting Turtle Dove and estimated AES growth rates in mixed farming areas as an average of those in Arable and Pastoral areas,*** *with the 1000 replicate estimates in each case shown as points. FBI growth rate is a multiplicative value, 1 = stability, 1.02 a 2% increase, 0.98 a 2% decline. HLS provision is the proportion of farms in our simulations with e.g. 0.4 = 40% of the farms with 10% of* *their land given over to HLS. At each level of bird-friendly HLS the remaining lowland enclosed farms not in HLS are assumed to be half in bird-friendly ELS agreements (value shown in brackets) and half with no bird-friendly AES.*

Table S1: Bird-friendly AES implementation levels meeting a selection of thresholds of likelihood of stabilising the FBI (proportion of replicates where the FBI growth was at or above one), where Turtle Dove were excluded from the model and AES growth rates in mixed farming were taken as an average of those in pastoral and arable regions.

Target	Likelihood	Farms in lowland enclosed farmland with bird friendly AES (%)	
		HLS	(ELS)
Stabilise FBI	50%	22.6	(38.7)
	80%	28.7	(35.7)
	90%	32.2	(33.9)
	95%	35.0	(32.5)
	99%	40.3	(29.9)
Increase FBI 10% in 10 years	50%	34.9	(32.6)
	80%	42.0	(29.0)
	90%	45.2	(27.4)
	95%	48.6	(25.7)
	99%	55.7	(22.2)

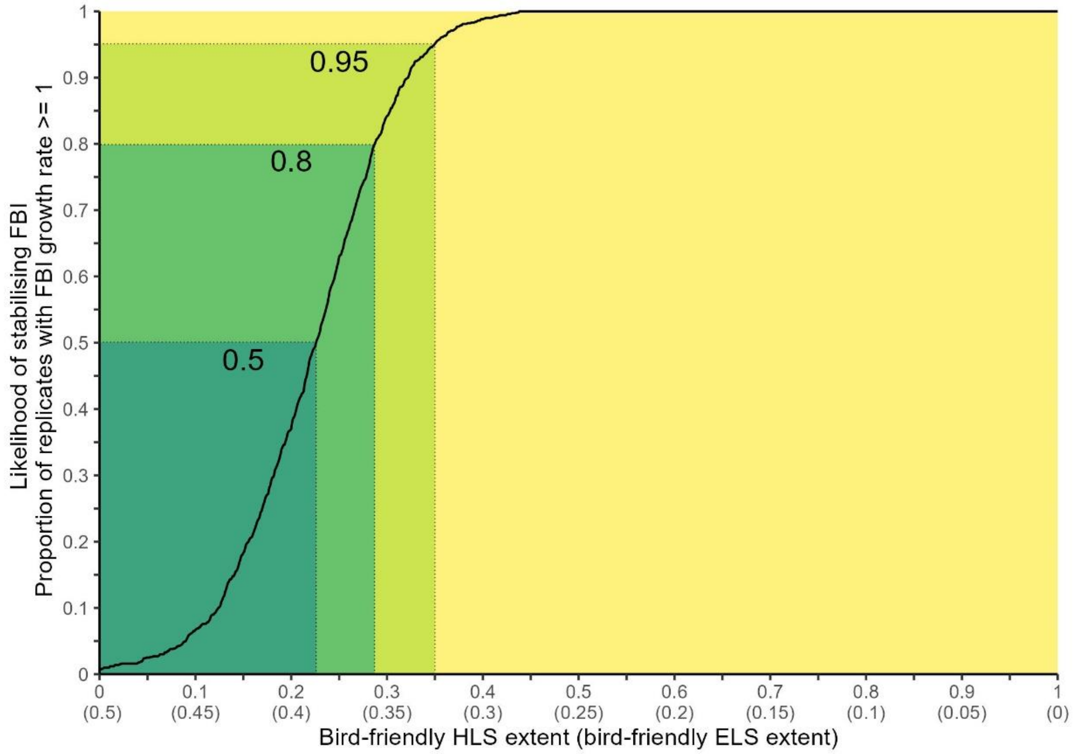

Figure S2: ***The estimated likelihood of stabilising the England FBI under different levels of HLS provision****, omitting Turtle Dove, and taking the AES impact in the mixed region as an average of the Arable and Pastoral regions, expressed as the proportion of replicates with a growth rate of >= 1. HLS provision is the proportion of farms in our simulations, with e.g. 0.4 = 40% of the farms with 7% of their land given over to bird-friendly HLS. 50%, 80% and 95% likelihoods are illustrated using coloured rectangles. At each level of HLS, half the remaining lowland enclosed farms are assumed to be in bird-friendly ELS agreements (values shown in brackets) and half with no bird-friendly AES.*

7.2 Varying provision of bird-friendly HLS and bird-friendly ELS simultaneously

If we alter the method used to estimate the FBI growth rate under bird-friendly HLS and ELS in mixed farming areas to be the average of the other two farmland types where an impact of AES was observed, the estimated impact of AES increases and therefore the provision levels needed for stability are lower. Here, in the absence of HLS there is a 50% or higher chance of stabilising the FBI when ELS provision levels are at 91% or greater (Figure S3, Table S2).

Table S2: Likelihood of stabilising the FBI (proportion of replicates where the FBI growth was at or above one) where Turtle Dove is omitted and the ELS and HLS effect sizes for mixed farming are taken as an average of those for the arable and pastoral regions, under a selection of combinations of bird-friendly HLS and ELS implementation levels. Full data provided as datasheet XXX.

Likelihood of stabilising the FBI																			
	Bird-friendly ELS																		
HLS	**0**	**0.05**	**0.1**	**0.15**	**0.2**	**0.25**	**0.3**	**0.35**	**0.4**	**0.45**	**0.5**	**0.55**	**0.6**	**0.65**	**0.7**	**0.75**	**0.8**	**0.85**	**0.9**
0.1	0	0	0	0	0.001	0.001	0.003	0.011	0.03	0.067	0.13	0.228	0.334	0.441	0.536	0.604	0.673	0.742	0.793
0.12	0	0	0	0.001	0.001	0.001	0.006	0.026	0.053	0.108	0.208	0.313	0.429	0.535	0.607	0.683	0.753	0.804	
0.14	0	0	0.001	0.001	0.001	0.005	0.018	0.045	0.087	0.187	0.295	0.417	0.528	0.61	0.688	0.765	0.814	0.844	
0.16	0.001	0.001	0.001	0.001	0.004	0.014	0.035	0.075	0.176	0.284	0.403	0.525	0.62	0.698	0.769	0.816	0.858		
0.18	0.001	0.001	0.001	0.003	0.011	0.03	0.066	0.154	0.266	0.392	0.511	0.619	0.711	0.781	0.826	0.877	0.897		
0.2	0.001	0.001	0.003	0.011	0.026	0.065	0.137	0.254	0.37	0.504	0.623	0.715	0.792	0.846	0.884	0.908	0.924		
0.22	0.001	0.003	0.01	0.026	0.058	0.124	0.237	0.355	0.5	0.618	0.727	0.804	0.856	0.894	0.916	0.936			
0.24	0.004	0.011	0.028	0.055	0.112	0.214	0.346	0.492	0.619	0.733	0.811	0.873	0.904	0.926	0.945	0.963			
0.26	0.015	0.03	0.054	0.112	0.199	0.34	0.486	0.626	0.74	0.827	0.879	0.917	0.934	0.954	0.971				
0.28	0.032	0.055	0.112	0.191	0.326	0.48	0.623	0.74	0.836	0.889	0.924	0.943	0.966	0.979	0.985				
0.3	0.06	0.115	0.192	0.323	0.475	0.617	0.752	0.842	0.903	0.929	0.958	0.975	0.982	0.985	0.991				
0.32	0.121	0.191	0.316	0.462	0.613	0.744	0.846	0.91	0.938	0.964	0.976	0.983	0.992	0.995					
0.34	0.201	0.309	0.455	0.607	0.736	0.848	0.916	0.948	0.967	0.982	0.99	0.995	0.996	0.998					
0.36	0.303	0.457	0.598	0.734	0.847	0.915	0.955	0.972	0.988	0.992	0.996	0.998	0.998						
0.38	0.45	0.591	0.727	0.847	0.913	0.956	0.978	0.988	0.993	0.998	0.998	0.999	0.999						
0.4	0.582	0.718	0.832	0.912	0.957	0.982	0.988	0.995	0.998	0.998	0.999	1	1						
0.42	0.705	0.822	0.905	0.955	0.98	0.989	0.995	0.998	1	1	1	1							
0.44	0.814	0.895	0.947	0.978	0.989	0.995	1	1	1	1	1	1							
0.46	0.881	0.939	0.974	0.989	0.996	1	1	1	1	1	1								
0.48	0.927	0.967	0.988	0.995	1	1	1	1	1	1	1								
0.5	0.96	0.986	0.994	1	1	1	1	1	1	1	1								
0.55	0.995	0.999	1	1	1	1	1	1	1	1									

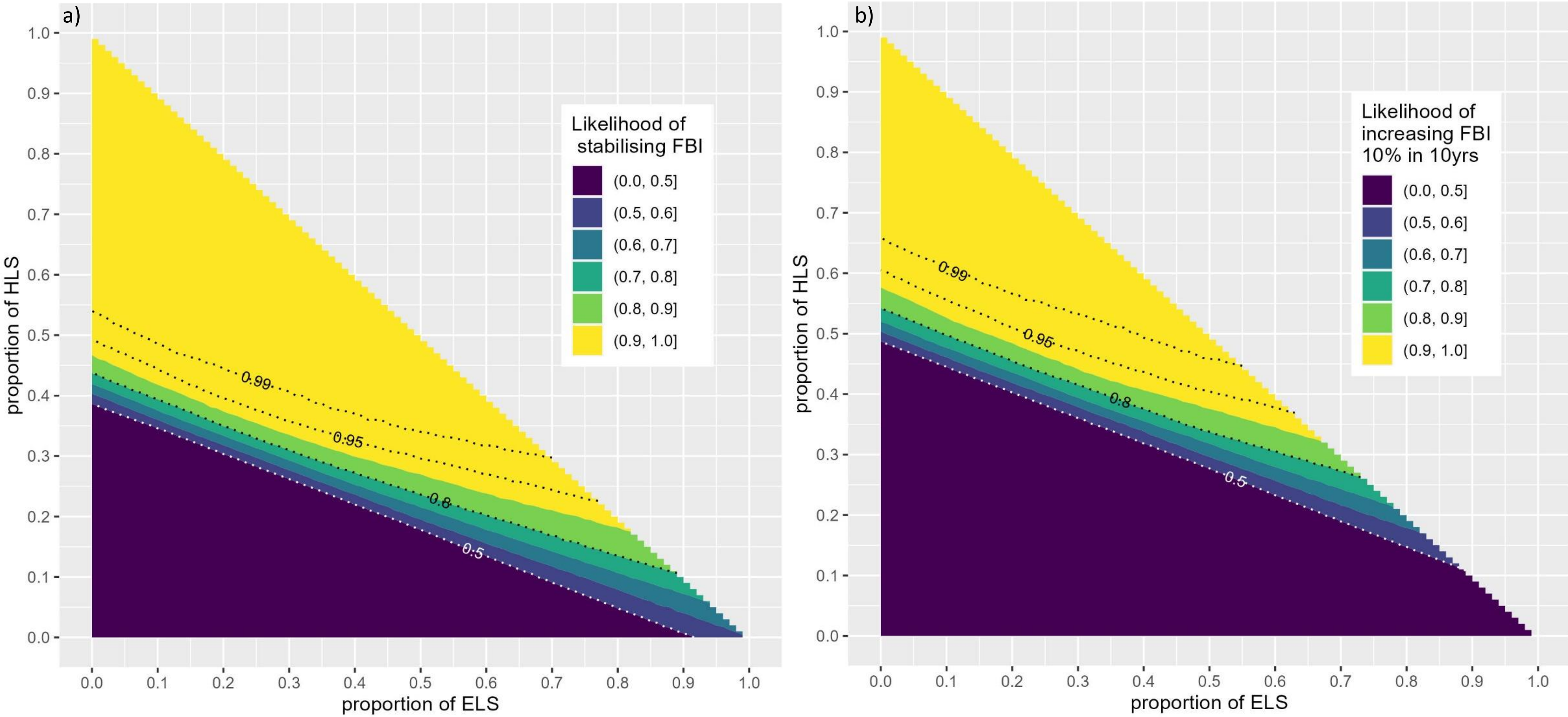

Figure S3: Omitting Turtle Dove and taking the AES impact in the mixed region as an average of the Arable and Pastoral regions, the likelihood of stabilising the FBI (FBI growth rate of >=1) (a) or increasing it by 10% in ten years (FBI growth rate >= 1.1^(1/10)) (b) for varying combinations of bird-friendly ELS and HLS. Likelihood of meeting the target is taken as the proportion of replicates meeting it in each case. HLS provision is the proportion of farms in our simulations, with e.g. 0.4 = 40% of the farms with 7% of their land given over to bird-friendly HLS. ELS provision is the proportion of farms in our simulations, with e.g., 0.4 = 40% of farms with 2-3% of their land given over to bird-friendly ELS.