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Evaluating terrestrial bird trends for Welsh Statement Areas

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Summary

National scale biodiversity monitoring schemes, such as the BTO/JNCC/RSPB Breeding Birds Survey (BBS), are designed to provide coverage of a broad range of common species, however, the implementation of conservation policy is increasingly devolved, creating a desire to repurpose data from national biodiversity monitoring schemes to provide information at smaller spatial scales, such as English Natural Character Areas or Welsh Statement Areas.

While BBS provides population trends for about 120 common and widespread bird species, sample sizes diminish in increasingly smaller areas, limiting species coverage. For example, Welsh BBS trends are reported for *c.* 60 species, but fewer than half of these, and fewer than 10% of Section 7 species (under the Environment (Wales) Act 2016), currently have sufficient sample sizes to produce trends per Area.

We compare the ability of three modelling approaches to derive area specific trends for the terrestrial Natural Resources Wales (NRW) Statement Areas. The Welsh BBS model is similar to the standard BBS model fitted to just Welsh data, and shares information across Areas. The GB BBS model uses GB-wide data to form a spatial map and incorporates habitat information; Area trends are "cookie-cuttered" from the overall map. The BBS-BirdTrack model supplements BBS counts with BirdTrack data (an opportunistic collection of list type data to create Area-specific trends; this maximises use of local information but is the most computationally challenging.

The three models produced broadly comparable trends for data-rich species, but for data-poor species (i.e. those observed at fewer than 20–30 BBS sites annually), the BBS-BirdTrack model had the potential to deliver more precise trends and to better discriminate region-specific trends. However, uncertainties were large in data-sparse regions as there was no pooling of information between Areas. The effectiveness of repurposing national monitoring schemes, however, will always be limited by the nature of the data available. No single modelling framework can provide a silver bullet when data are sparse, and these problems are exacerbated for species, such as those that occur in large flocks, whose counts do not conform to typical model assumptions.

Reporting on species trends at small spatial scales, particularly for many species of conservation concern, will likely require a combination of improved statistical methods and additional monitoring effort. Thus, effective delivery of monitoring priorities (whether these are single-species trends, or indicators of wider ecosystem processes/health) will require assessment of these two aspects in a coordinated way across species and regions.

We therefore make the following recommendations

- BBS squares can often be used for reporting small area trends where more than 20 squares contribute detections for a target species.
- BirdTrack records can supplement BBS data to produce integrated trends where fewer than 20 BBS squares with detections of a target species are available.
- An assessment needs to be undertaken as to which small area trends are of most use to fulfil policy goals.
- Monitoring improvements can be achieved by targeting either BBS or BirdTrack effort, but trade-offs between both modes of coverage differ on a species-specific basis.

Contents

1 Introduction

National scale biodiversity monitoring schemes such as the BTO/JNCC/RSPB Breeding Birds Survey (Harris *et al.* 2020) are designed to provide coverage of a broad range of common species over the UK, allowing the derivation of indicators of the state of nature to guide conservation legislation and policy while making the most of finite resources. However, the implementation of conservation policy on a legislative and executive level is increasingly devolved within the nations, resulting in diverging legislation and implementation approaches that are specific to England, Scotland, Wales, and Northern Ireland (Bainbridge 2014). There is also a shift from treating conservation and management as jurisdictional issues towards approaches focussed on the maintenance of healthy ecosystems and ecosystem services at the appropriate spatial scales (Kirsop-Taylor 2019). Within the UK such natural subdivisions are reflected, for example, in the National Character Areas in England (Natural England 2014) or the Area Statements in Wales (Welsh Government 2017).

The plethora of spatial units that arise from jurisdictional devolution and landscape-centric approaches, creates an increasing desire to repurpose data from national biodiversity monitoring schemes to provide information at smaller spatial scales, not addressed by national trends and indicators.

The Breeding Bird Survey (BBS) provides UK population trends for about 120 common and widespread bird species (Harris *et al.* 2020), but knowledge gaps remain for rare and cryptic species (approximately 220 species are regular breeders (Robinson 2010)). Country and region-specific trends are currently derived from these data by running trend analyses on discrete spatial subsets of the survey data. This generally limits the species coverage at the regional level as sample sizes diminish in increasingly smaller areas.

Opportunistic citizen science recording, for example. through BirdTrack (www.birdtrack.net; Baillie *et al.* (2006)), provides greater levels of coverage in space and time, but lacks the structured protocols and formal sampling design, leading to biases in site selection, visit timing, survey effort, and/or surveyor skill (Isaac & Pocock 2015; Johnston *et al.* 2020). A comparison of these two datasets showed that UK-scale annual reporting rate trends in BirdTrack were broadly consistent with BBS abundance trends for common species, and those exhibiting marked population changes (Boersch-Supan *et al.* 2019). However, the magnitude of reporting rate–abundance relationships were inconsistent across species, and agreement in trends for rarer species could not be ascertained, in part because of high uncertainty about population change in trends from both datasets. Integrating these two data sources may help overcome some of these issues, by combining the structure of survey data with the improved coverage of less structured schemes. This has the potential to improve the precision of model parameters and the resulting inferences (Isaac *et al.* 2019; Boersch-Supan & Robinson 2021), perhaps especially for species that are poorly covered by structured monitoring programmes.

As an example of estimating trends for regional (i.e. sub-country) areas, we here compare the ability of three modelling approaches to derive area specific trends for the terrestrial NRW Area Statements. All of our approaches aim to increase the effective sample size available for trend calculation, either by sharing information across spatial units, or by sharing information across data sources. However, it is important to note that modelling alone can rarely compensate for a lack of data, which is a particular issue for many species of conservation concern. It is therefore important that reporting targets (in terms of species and area coverage) are evaluated against data availability and model limitations to guide the allocation of additional monitoring effort.

2 Methods

2.1 Species selection

We attempted to derive area specific trends for each of the terrestrial NRW Area Statements for 61 species. This included all 60 species for which Welsh BBS trends are currently reported for at least one time interval, and additionally Pied Flycatcher, which falls just short of the country-level BBS reporting threshold. Of these species 14 are listed in Section 7 of the Environment (Wales) Act 2016: Bullfinch, Cuckoo, Curlew, Dunnock, House Sparrow, Lesser Redpoll, Linnet, Pied Flycatcher, Reed Bunting, Skylark, Song Thrush, Starling, Tree Pipit and Yellowhammer.

2.2 Trend models

Trends were derived using three different models:

(1) a hierarchical BBS trend model (Smith & Edwards 2021) based on Welsh data alone, further referred to as the **Welsh BBS model**;

(2) a spatially explicit predictive abundance model based on UK-wide BBS data and incorporating habitat information (Border & Gillings 2020), further referred to as the **GB BBS model**;

(3) an integrated trend model based on Welsh BBS and BirdTrack data (Boersch-Supan & Robinson 2021), further referred to as the **BBS-BirdTrack model**.

Full details of each model are given in the relevant literature source, but the important characteristics for each model are as follows.

The **Welsh BBS model** is most similar to the standard BBS model, in that it fits a smoothed site+year trend without any consideration of the spatial configuration of sites within regions, or any consideration of habitat or other environmental covariates. The model estimates a global trend (i.e. the country-specific trend for Wales), as well as NRW area specific trends in a hierarchical framework (i.e. the region-specific trends are random-effect smooths around the main country trend). The random-effects framework allows information about species trends to be shared among the regions.

This model was fitted as a hierarchical Poisson GAM (generalized linear model) (HGAM) using the `mgcv` package (Wood 2017) in R (3.6.3; R Core Team 2020). A GAM is a non-parametric extension of a general linear model, which can accommodate non-linear relationships by using additive smooth terms, allowing an interpretation similar to a traditional linear model. In `mgcv` smooths are implemented using penalised regression splines, the smoothness (or wiggliness) of which is estimated within the model fitting procedure. We used the “Model GS” parametrisation of Pedersen *et al.* (2019) to acount for the regional structure of the data by using a single common trend-smooth (i.e. at the Wales level), plus region-level smooths that all shared the same wiggliness. This model is a close analogue to a varying slopes GLMM: all groups (i.e. regions) have similar functional responses, but variation in the strength of the trends among regions is allowed.

The **GB BBS model** is a spatially explicit standard BBS model. It fits a spatio-temporally smooth abundance surface to BBS counts, taking habitat information into account, so that squares located close together will have more similar trends than those further apart. NRW-area specific trends are extracted from this model based on predictions that take the habitat-composition of each area into account. Because the model is fitted to a GB-wide dataset, information about species trends and species-habitat relationships is shared within the whole of GB (although the strongest influence on trends within Wales will come from English BBS squares close to the Welsh border).

The model was fitted as a Poisson GAM using the `mgcv` package (Wood 2017) and included a 2D thin-plate regression spline to model easting and northing (allowing bird abundance to vary spatially within regions), a smoothed year term and an interaction between the spatial and temporal smooths allowing the relationship between bird abundance and year to vary spatially. The model further included 11 environmental covariates largely based on the Centre for Ecology & Hydrology (CEH) Land Cover Map (LCM2007). The full model is described in Border and Gillings (2020). Regional trends were extracted for each Area Statement from the spatially and temporally explicit model predictions.

The **BBS-BirdTrack model** is the most computationally demanding one, especially over larger areas, and is therefore fitted to each NRW area separately. It uses a hierarchical state-space formulation to derive population trends that combine information from BBS and BirdTrack (Isaac *et al.* 2019; Mancini *et al.* 2022). Trends are smoothed through yearly random effects, which results in abundance indices that are of intermediate smoothness compared to either unsmoothed or smoothed BBS indices. Importantly, no information is shared among regions.

The model is hierarchical in that it incorporates an underlying state (the true population size), which is then observed imperfectly, with both state and observation process included in the model. The state process for this model assumes there is a population abundance $N_{j,t}$ at a site j in every time step t. $N_{j,t}$ changes between successive timesteps as a result of individuals that survive and remain at each site $S_{j,t}$, and those that are gained to a site by recruitment or immigration $G_{j,t}$. These sub-processes are expressed as

$$S_{j,t} \sim \mathrm{Bin}\left(N_{j,t-1}, \omega\right)$$

$$G_{j,t} \sim \mathrm{Pois}(\gamma)$$

where ω is the apparent annual survival probability of individuals, and γ is the expected number of individuals that are gained at site j by recruitment or immigration between $t-1$ and t.

For every time step $t > 1$ the total population abundance at site j is

$$N_{j,t} = S_{j,t} + G_{j,t}$$

For the first year ($t = 1$), the state process is initialized by modelling abundance at each site according to a Poisson distribution with an expected count λ

$$N_{j,1} \sim \mathrm{Pois}(\lambda)$$

The true population abundance $N_{j,t}$ in the survey area was linked to the recorded data according to two sampling processes ("observation models"), counts of individuals in the case of BBS data and detection of at least one individual or non-detection in the case of BirdTrack lists. In both cases repeat visits to a site between April and the end of June were treated as replicates, implying the assumption of a closed population over this period, which we deemed reasonable for the species covered as most individuals will have been tied to a breeding territory.

We assumed detection was imperfect for both sampling approaches(i.e. for count data the number of individuals encountered during a survey visit $n_{j,t,k} \leq N_{j,t}$ and similarly, an occurrence record $y_{j,t,k}$ could be a nondetection if none of the $N_{j,t}$ individuals were seen or heard during a site visit). We modelled the count data as arising from a binomial process:

$$n_{j,t,k} \sim \mathrm{Bin}\left(N_{j,t}, p\right)$$

with an individual detection probability p. Detection-nondetection data were modelled as arising from a Bernoulli trial:

$$y_{j,t,k} \sim \mathrm{Bern}\left(1 - (1 - p_{occ})^{N_{j,t}}\right)$$

with a separate detection probability p_{occ}, to take into account potential differences in survey methodology and/or observer skill between BBS and BirdTrack records.

Model parameters were estimated in a Bayesian framework using `JAGS` via the `jagsUI` package in `R` (Plummer 2003; Kellner 2018; R Core Team 2018). Markov-chain Monte Carlo (MCMC) estimation was run on four parallel chains until the Gelman-Rubin convergence diagnostic $\hat{R}$ indicated convergence, usually after 10,000–50,000 iterations.

2.3 Trend model comparisons

More detailed comparisons were undertaken between the Welsh BBS model and the integrated BBS-BirdTrack model to determine potential sample size thresholds affecting trend precision and discrimination of trends among regions. To assess nominal precision of the integrated BBS-BirdTrack model we estimated the relationship between average annual sample sizes and integrated trend precision (CI width) using a log-link Gamma GLM. Relative nominal precision was compared between the two model types by regressing the ratio of CI widths against sample size using a GAM. Lastly, regional trend discrimination was assessed by comparing region-specific trends for each species using a time-series similarity method based on dynamic time warping (DTW) dissimilarities (Giorgino 2009). This metric measures how much a time-series needs to be distorted to achieve the same trajectory as a reference time-series. Values closer to zero indicate more similar time-series and increasingly large values indicate increasing dissimilarity. For each species-region combination the mean DTW dissimilarity to trends for the same species in other regions was calculated using the `IncDTW` package (Leodolter 2020), and mean dissimilarities were regressed against sample sizes using a GAM.

3 Results

3.1 BBS coverage and reporting in Wales

The most recent full BBS report (i.e. prior to survey restrictions caused by COVID-19) reports breeding bird trends for 60 species in Wales using BBS data (Harris *et al.* 2020). Fewer than half of these species, and fewer than 10% of species listed in Section 7, have achieved the necessary sample sizes for 5-year Area Statements Trends using the standard BBS model and reporting thresholds. As in most other areas of the UK, BBS survey coverage has increased across Wales since the inception of the monitoring scheme in 1994, so species coverage for longer-term trends (i.e. relying on more historical data) is even sparser.

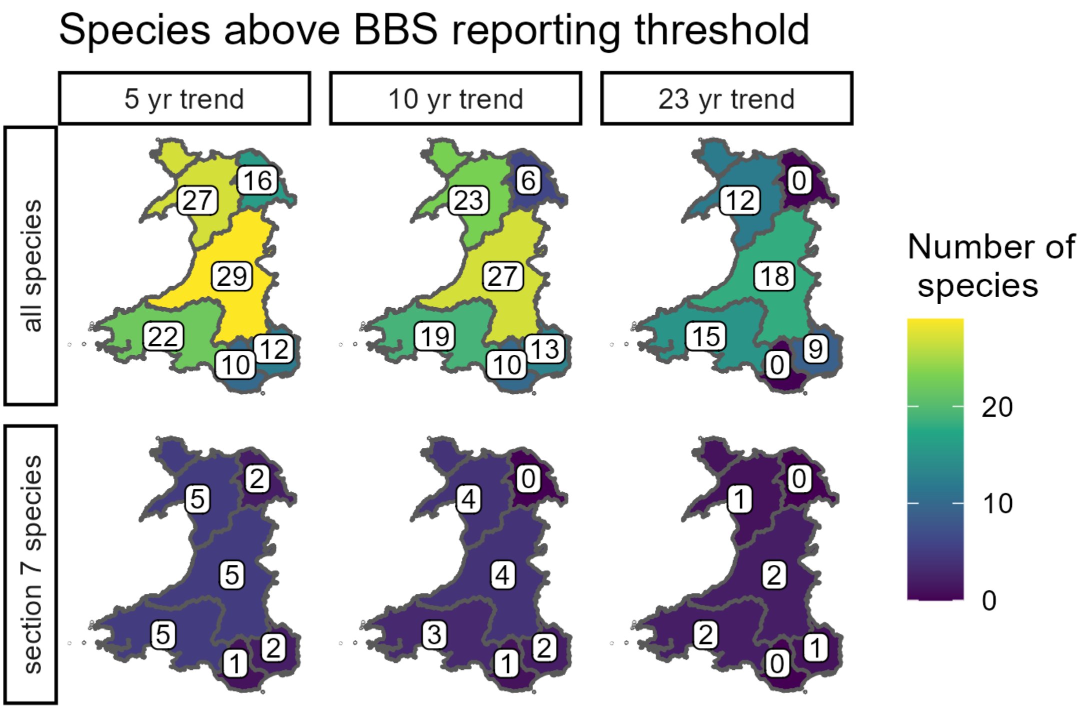

Figure 1. Fewer than half of the species for which Welsh BBS trends are reported, and fewer than 10% of Section 7 species, have the necessary sample sizes for Statement Area Trends using the standard BBS model and reporting thresholds.

3.2 Regional trend-model fits

Regional trends could be derived in principle for all 61 species using the Welsh BBS model or the GB BBS model. The BBS-BirdTrack model failed to yield trends for 49 of the 366 (13%) possible species-area combinations. This affected 18 species across all NRW areas (Figure 8). Not all Areas hold ecologically meaningful populations of the assessed species though (Table 2), and as such region-specific reporting priorities should be defined. All fitted trends are presented in Appendix 3.

Agreement among the three methods was reasonable when looking at end-to-end 10-year trends (Figure 2), with trends from the BBS-BirdTrack models generally skewing somewhat more positive, and trends from the GB BBS model skewing somewhat more negative compared to the Welsh BBS model.

However, at shorter timescales it was apparent that the GB BBS model smooths comparatively heavily and fails to reflect population fluctuations on the scale of 3–5 years, both in data-rich and data-poor species (Figures 3,4).

For data-poor species, the pooling of information in the GB BBS and Welsh BBS models effectively results in the estimation of a Wales-wide trend only, with little differentiation among regional trends estimated (e.g. for Pied Flycatcher (Figure 4)). The integrated BBS-BirdTrack model delivered more discrimination among regions when there were fewer than about 30 BBS sites with detections for a species (Figure 5), as it could draw on supplementary BirdTrack records. However, the lack of information sharing across regions meant that uncertainties around integrated BBS-BirdTrack trends were large in those regions where both data sources have low coverage with respect to a target species.

In fact, the number of BBS sites with presences strongly influenced the overall trend precision in the integrated model, with a CV of 0.1 generally achieved with about 25 sites/year (Figure 6A & B). When there are few BBS sites in the model, adding sites with BirdTrack detections improves the model prediction. However, gains from integration diminished with increasing BBS coverage. Beyond *c*. 25 BBS sites/year the addition of BirdTrack records resulted on average in worse precision, although the meta-analysis model was poorly constrained by data for these conditions (Figure 6A).

The hierarchical Welsh BBS models (HGAM) generally had higher nominal precision of regional trends, with CIs on average *c*. 75% as wide as the corresponding estimates from the integrated model. This is unsurprising as the hierarchical model always drew on a larger sample (i.e. the total data available for Wales). The potential for precision gains from data integration was largest for species-region combinations with fewer than *c*. 20 annual BBS detections, especially when 50 or more locations with BirdTrack data were available (Figure 6). Under these circumstances the integrated model could be up to 1.75 times more precise than the hierarchical model based on Welsh BBS data alone.

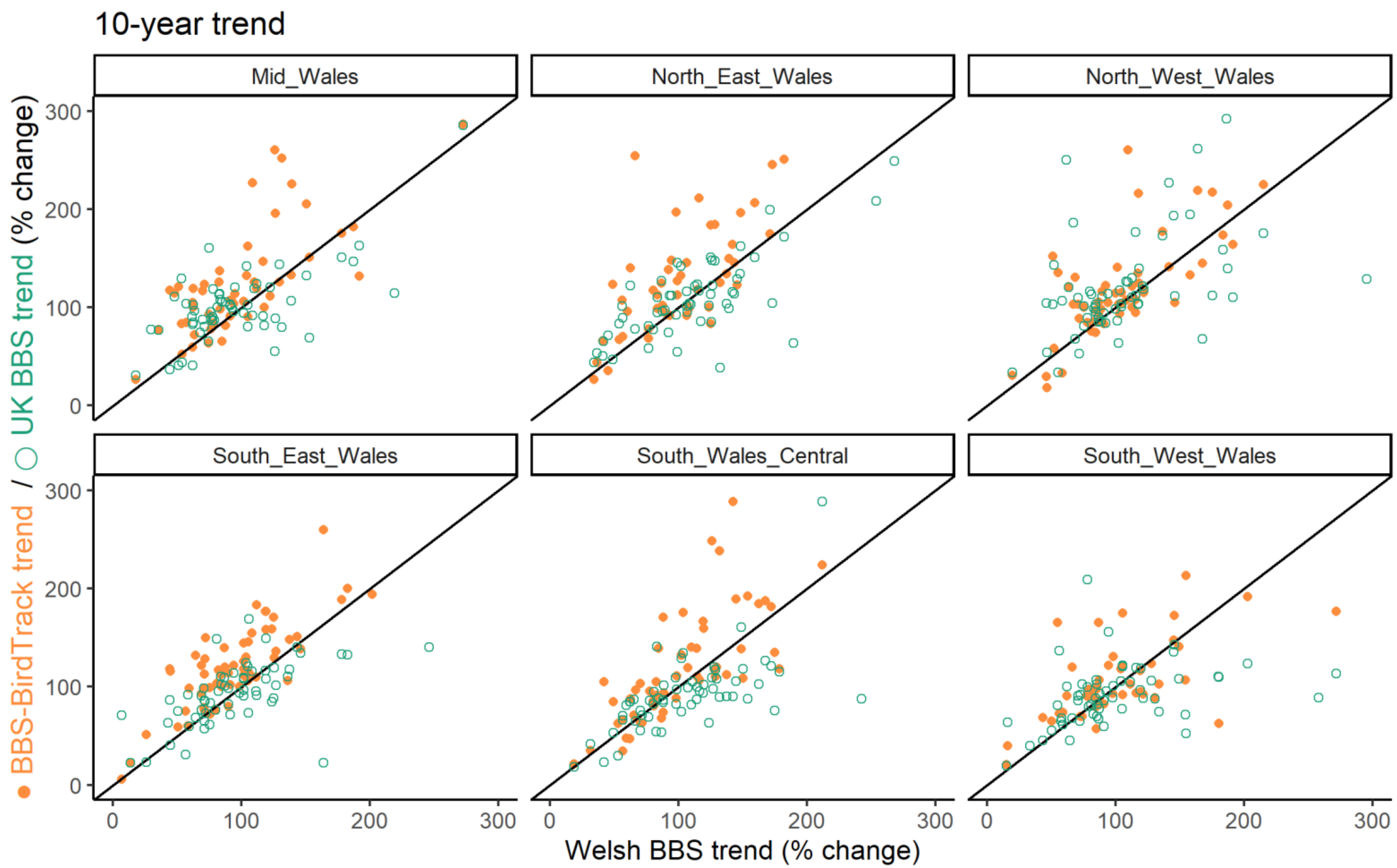

Figure 2. Across the 61 investigated species there was reasonable agreement between 10-year trend estimates (% change) by the three methods. BBS-BirdTrack trends (closed symbols) tended to be more optimistic than those from the Welsh BBS model, and trends from the GB BBS model (open symbols) tended to be more pessimistic than those from the Welsh BBS model. Solid lines indicate the 1:1 line of equivalence.

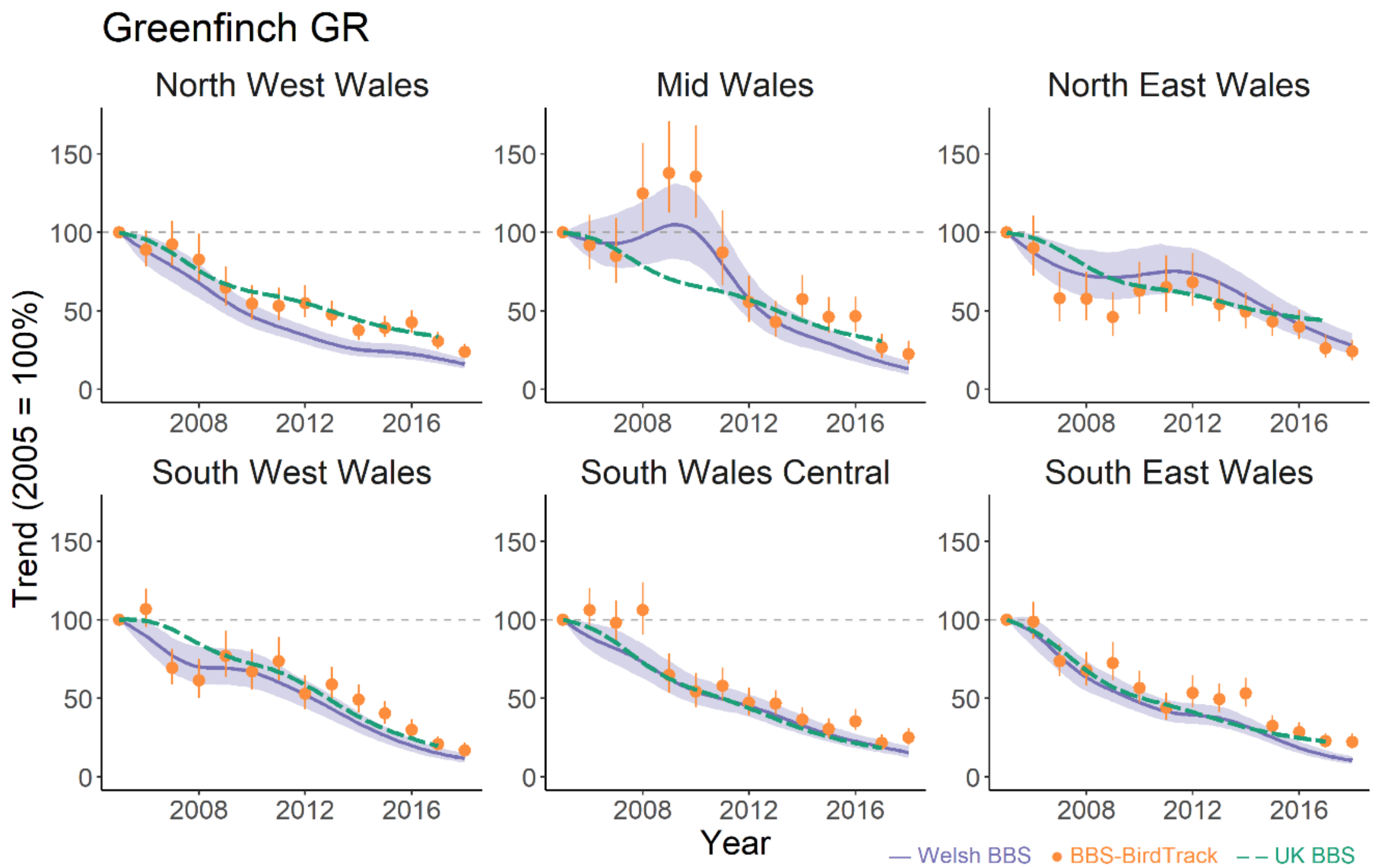

Figure 3. Regional trend estimates for Greenfinch illustrate some features of the three methods when applied to a data-rich species: The three methods generally agree well over longer time spans, but the GB BBS model (dashed line) tends to smooth out shorter fluctuations. Uncertainty estimates are generally in good agreement between the Welsh BBS model (solid line) and the BBS-BirdTrack model (points). Error bars and shading indicate the 95% credible interval. No uncertainty estimates were available for the GB BBS model.

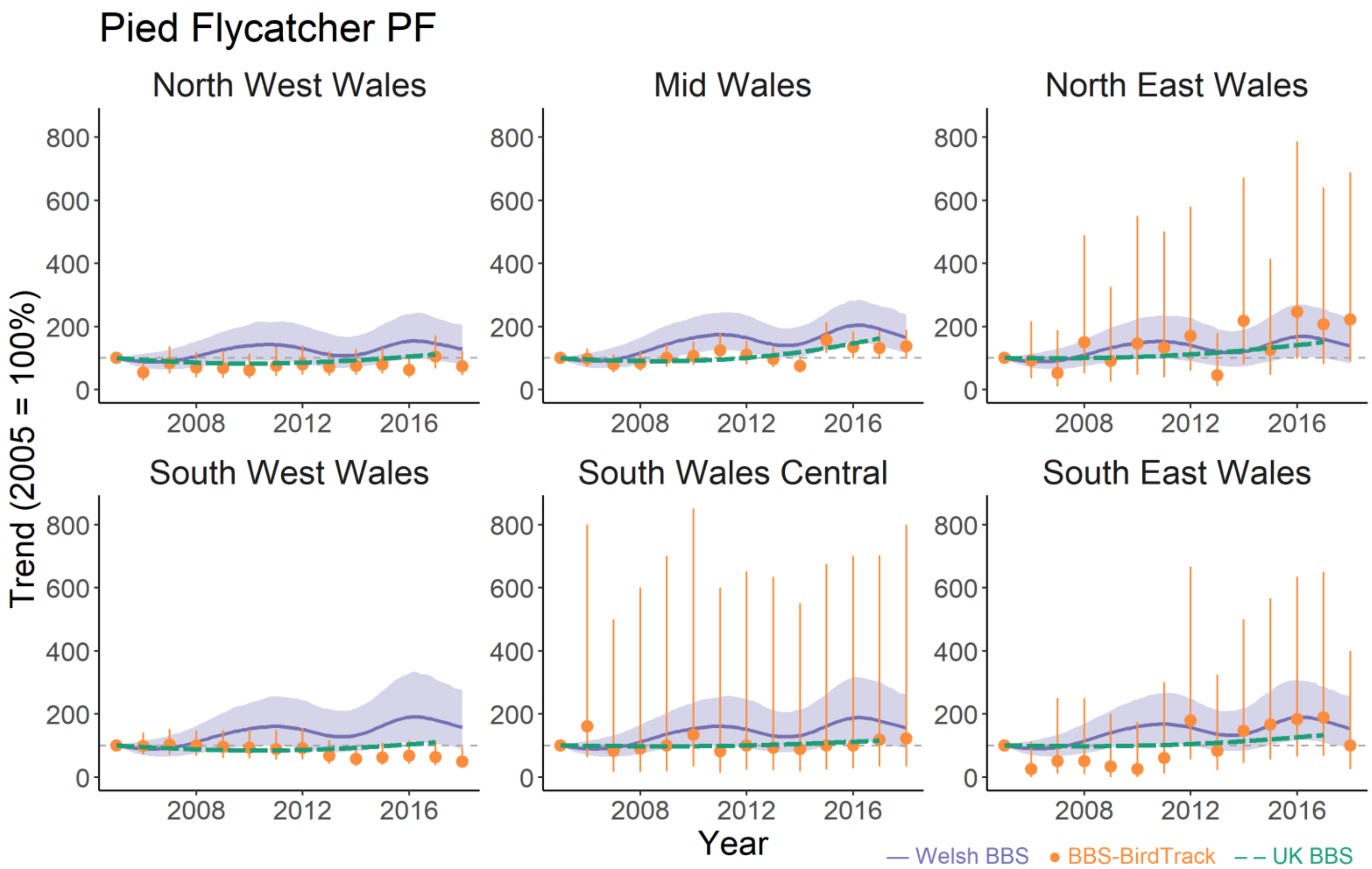

Figure 4. Regional trend estimates for Pied Flycatcher illustrate some features of the three methods when applied to a data-poor species: Mean trend estimates are not always in agreement between the three methods. There is little differentiation between the regional estimates from the GB BBS (dashed lines) and Welsh BBS models (solid lines), and the pooling of information across regions also means that uncertainty estimates are comparable between regions. The BBS-BirdTrack model (points) delivers more precise trends in regions with higher record densities (e.g. North West and mid-Wales) and emphasises the large uncertainty in the data-poorest regions (e.g. South Wales Central). Error bars and shading indicate the 95% credible interval. No uncertainty estimates were available for the GB BBS model.

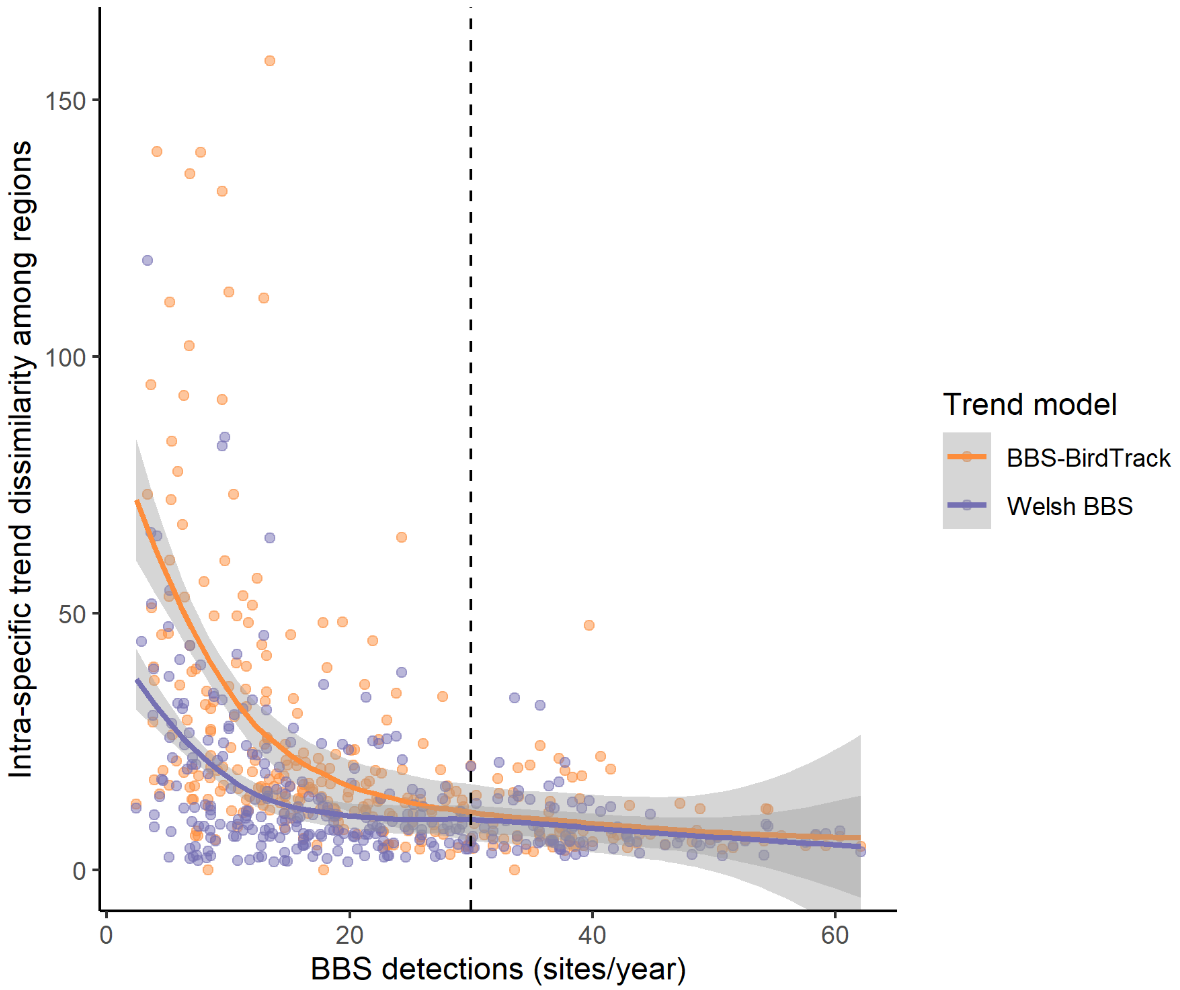

Figure 5. For sample sizes below *c.* 30 annual BBS detections (sites/year; dashed vertical line) trends based on Hierarchical BBS models (HGAM) generally were more similar among regions than trends derived for each region using the integrated BBS-BirdTrack model. Lines shows spline interpolation.

Table 1. Model estimates for the relationship between average annual sample sizes and integrated trend precision.

Predictors	Estimates (Risk ratio)	95% CI	P value
(Intercept)	0.414	0.361 – 0.476	< 0.001
BBS sites	0.945	0.938 – 0.951	< 0.001
BirdTrack sites	0.989	0.985 – 0.993	< 0.001
BBS sites*BirdTrack sites	1.000	1.000 – 1.001	< 0.001
Observations	315	n/a	n/a
R^2	0.745	n/a	n/a

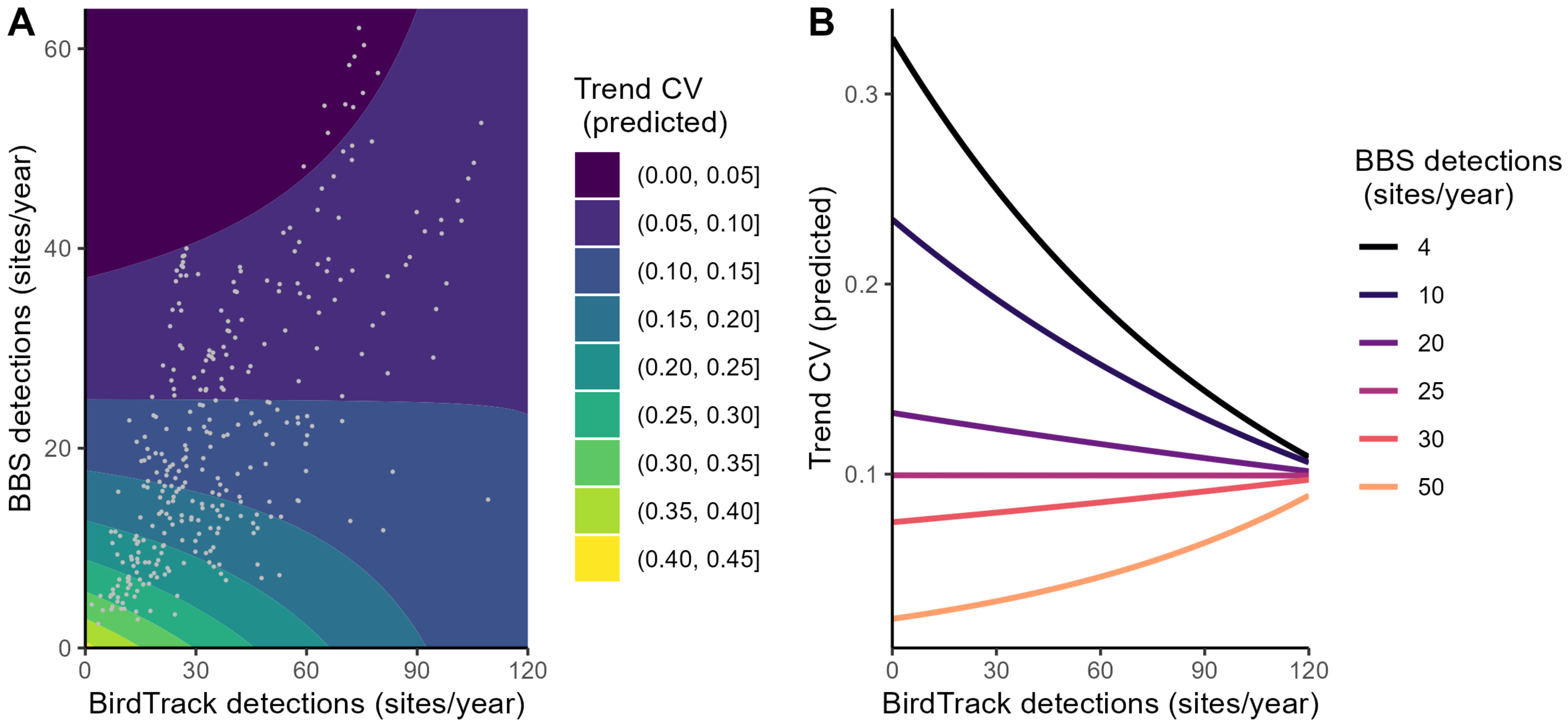

Figure 6. The addition of BirdTrack sites (A) results in better nominal precision (lighter colours; measured using the coefficient of variation, CV) of integrated trends when there are few BBS data available, but (B) gains from integration diminish for species well surveyed by the BBS. For very well sampled species trend precision of the integrated model can decrease with the addition of BirdTrack data (lighter coloured lines). A: points represent fitted integrated trends for each species and region (n = 366).

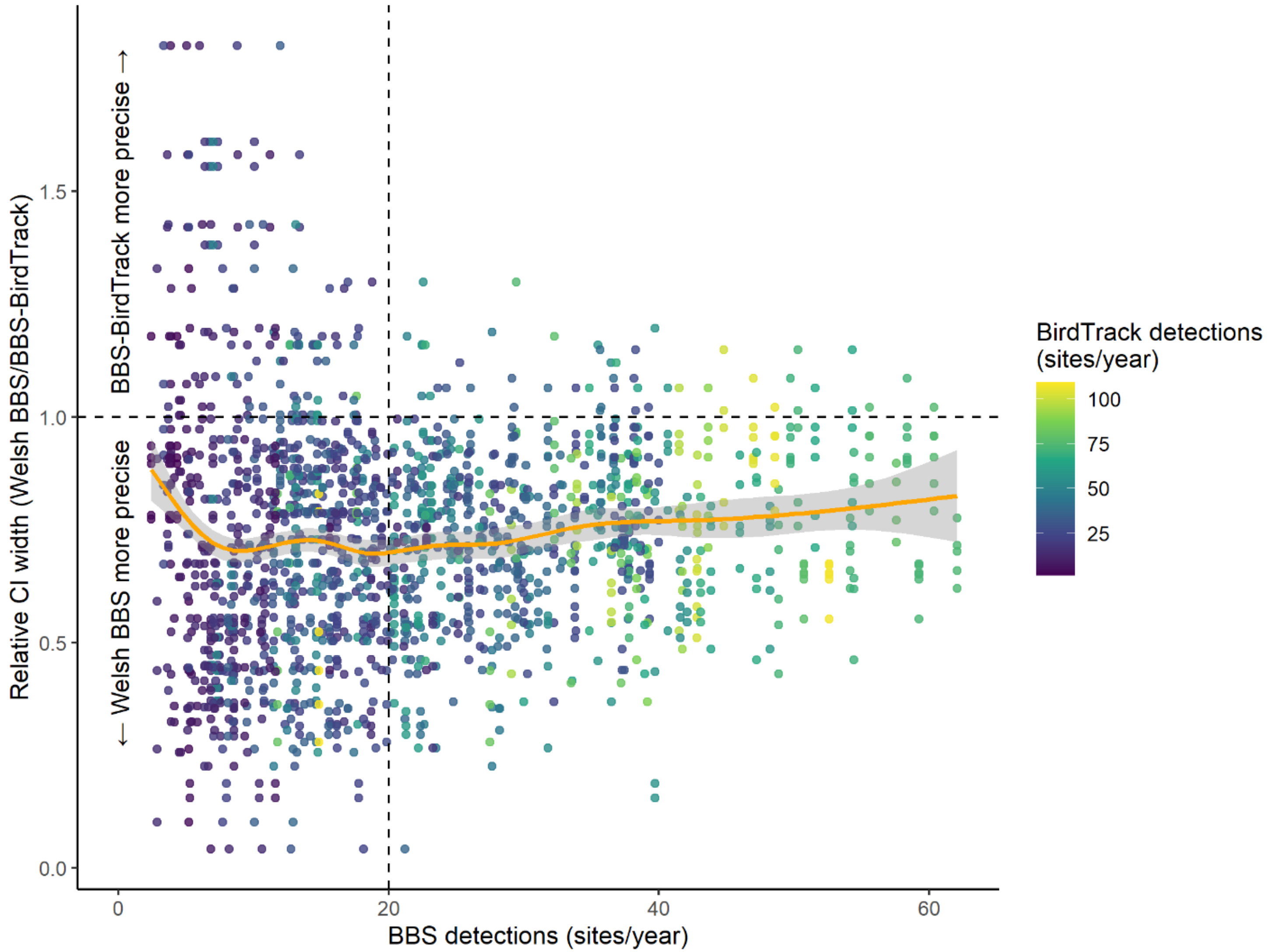

Figure 7. Hierarchical Welsh BBS models generally had higher nominal precision of regional trends compared to regional BBS-BirdTrack models as they always drew on the data available for all Welsh regions. The potential for precision gains from data integration was largest for species-region combinations with fewer than *c.* 20 annual BBS detections (vertical dashed line). The unbroken line shows spline interpolation.

4 Discussion

4.1 BBS models

Both “BBS-only” modelling frameworks investigated here provide a natural extension of existing analysis framework, and – in principle – allow for finer-scale trend assessment, particularly for data-rich species, that is species with detections at more than 30 BBS sites per year on average in the area of interest. The non-spatial models following the approach of Smith & Edwards (2021) are methodologically closest to the currently reported UK-level and Wales-level BBS trends (Harris *et al.* 2020) and are the computationally most efficient method evaluated in this study. However, because the models are non-spatial some information is discarded. Region-specific performance (i.e. reflection of the “true trend”) may be unclear in data-poor regions, because regional trend estimates will be pulled towards the global mean trend (i.e. the Welsh national trend). This became particularly apparent for trends based on detections from fewer than *c.* 30 BBS sites per year when compared to the integrated model. Distinguishing trend synchrony across regions, from lack of power to detect regional trend differences is a challenge whenever there is little real deviation between the global trend estimate and the region-specific ones. Further these models require a priori region definitions, which means trends for custom (sub-)regions cannot be extracted post-hoc.

Abundance maps, as provided by Border and Gillings (2020), on the other hand, are an elegant solution to provide trends for arbitrary regions by exploiting species-habitat relationships across the training dataset. However, in the case of the NRW areas, the UK-wide models often appear to oversmooth regional trends apparent in both other methods, which may be a consequence of species-habitat relationships and/or trends in England dominating the predictions. This is likely a consequence of a relatively simple model being fitted to UK-scale data. Refitting this class of model to data from Wales alone and/or allowing for finer-scale interactions between species abundance trends and habitat variables may ameliorate this situation, but even then, data-rich regions within Wales will, potentially unduly, influence trend predictions in data-poor regions.

4.2 BBS-BirdTrack models

Where BirdTrack sample sizes are sufficient, data integration between BBS and BirdTrack has great potential to improve precision and better quantify uncertainty for regional bird trends. The results here show that the greatest potential benefit from data integration is for species-region combinations that are presently covered by fewer than 20 BBS sites per year, which is more likely in remote areas in the North and West of the UK (Border *et al.* 2019). However, the modelling framework used is computationally costly and requires specialist knowledge to operationalize across species and regions. Fitting this model failed for *c.* 13% of species-area combinations and further work is needed to assess whether these failures can be overcome through technical refinements, or whether they reflect fundamental limitations of the modelling framework and/or data structures. In particular, the model is challenging to fit to flocking species with overdispersed counts, and additional statistical development may be necessary to obtain robust results for such species - and would likely be crucial if this approach were to be applied to datasets other than BBS and BirdTrack (e.g. to also include counts from WeBS). Expanding the model to include a hierarchical structure which allows the sharing of information among regions would likely benefit estimation of trends for the rarest species.

4.3 Scheme design and engagement

No single modelling framework can provide a silver bullet when data are sparse. As such the desire to report on species trends at small spatial scales will likely require improved statistical methods as well as additional monitoring effort, in particular for many species of conservation concern, which by definition are usually rare. It is therefore important that reporting targets (in terms of species and area coverage) are evaluated against data availability and local importance (e.g. Appendix 2). Where policy needs are not met by existing survey effort, additional resourcing for monitoring is required for successful policy implementation, for example through paid fieldwork or increased engagement effort targeted at volunteer recorders. The results here show that BBS and BirdTrack effort are generally correlated (points in Figure 6A), with regions and species that are poorly covered by BBS also receiving fewer BirdTrack records. These species-region combinations have the greatest potential to benefit from improved coverage, although increasing BBS coverage will generally have greater impact on model precision and discrimination than increasing BirdTrack coverage.

4.4 Summary and recommendations

In this report we demonstrate the feasibility of generating regional trends from BBS data and/or combinations of BBS data and BirdTrack. For common species (detections at more than 20 BBS sites per year), a hierarchical trend model (referred to as the Welsh BBS model in this report), appears to offer a good compromise between ease of implementation and both statistical accuracy and ecological interpretability of results. For data-poor species the integration of BBS and BirdTrack has great potential in regions where there is reasonable coverage of both schemes. Under such conditions the integrated model can outperform BBS-only models in delivering precise local trends. It is important to stress here that the thresholds for BBS coverage discussed here are squares *with detections* of a focal species (i.e. whether or not a threshold is met in a certain region is species-specific). The addition of BBS squares following the standard BBS allocation method (i.e. using random locations) will improves matters on average across species, but is not necessarily suitable to provide coverage improvements for specific species (e.g. those of conservation concern). Targeted coverage could in these cases be achieved by encouraging BirdTrack recording in the range of the target species, or by establishing survey squares that employ BBS protocol in predefined locations. The latter would have the benefit of delivering consistent count data, but because of their non-random locations the survey data may need to be excluded from general BBS reporting.

However, for many species of conservation concern data are sparse. The trends estimated in this report cover only about one quarter of the bird species listed in Section 7 of the Environment (Wales) Act 2016. Trends for additional species may be possible to derive for selected regions, but even when combining BBS and BirdTrack observations, estimated trends may have large associated uncertainties. Furthermore, not all Areas hold ecologically meaningful populations of the assessed species (Table 2), and as such region-specific reporting priorities should be established. In these cases, expert judgement will be necessary to decide whether it is ecologically sensible to pool information among regions and/or additional data sources, or even extrapolate information from regions outside of the target areas (here, Wales) to obtain trend estimates if such trends are desired from a policy or management perspective. In many cases robust inferences about the local status and trend of a species may require additional survey effort, with additional BBS surveys having higher impact on trend quality.

We therefore make the following recommendations:

- BBS squares can often be used for reporting small area trends where more than 20 squares contribute detections for a target species.

- BirdTrack records can supplement BBS data to produce integrated trends where fewer than 20 BBS squares with detections of a target species are available. Quality control of integrated trends is crucial to ensure model assumptions are met.

- An assessment needs to be undertaken as to which small area trends are of most use – for example Section 7 species (of conservation concern), at least where these occur in meaningful numbers in a region, or trends of commoner species to contribute to indicator measures of ecosystem health.

- Monitoring coverage improvements can be achieved by increasing either or both schemes. Additional BBS squares will improve trend precision at a faster rate than additional BirdTrack locations, but trade-offs between both modes of coverage need to be considered on a species-specific basis.

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Appendix 1: Integrated BBS-BirdTrack models

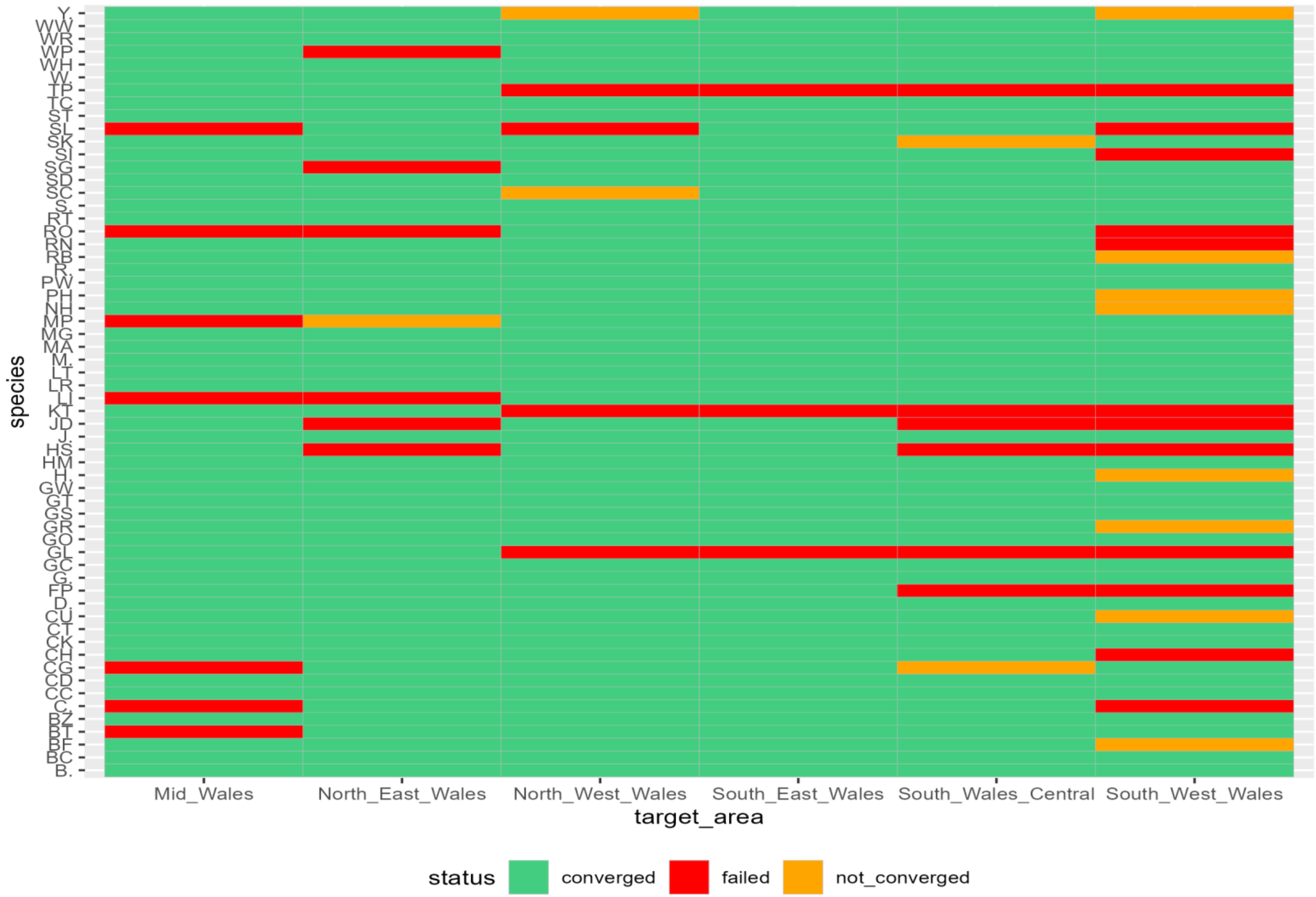


Figure 8. Integrated BBS-BirdTrack models could be successfully fitted to 315 of the possible 366 species-area combinations, but either failed completely (38 combinations) or failed to converge (13 combinations) for the remainder. Each row represents a species identified by BTO two-letter code.

Appendix 2: Relative abundances

Table 2. Relative share of the estimated total Welsh population (%) for each modelled species in each terrestrial NRW Area. Population size estimates are based on Bird Atlas 2007–11 data. Percentages in column headers give relative land area for each Statement Area. Population share values are bold (with *) whenever the population share of a species exceeds the relative land area by at least 10%.

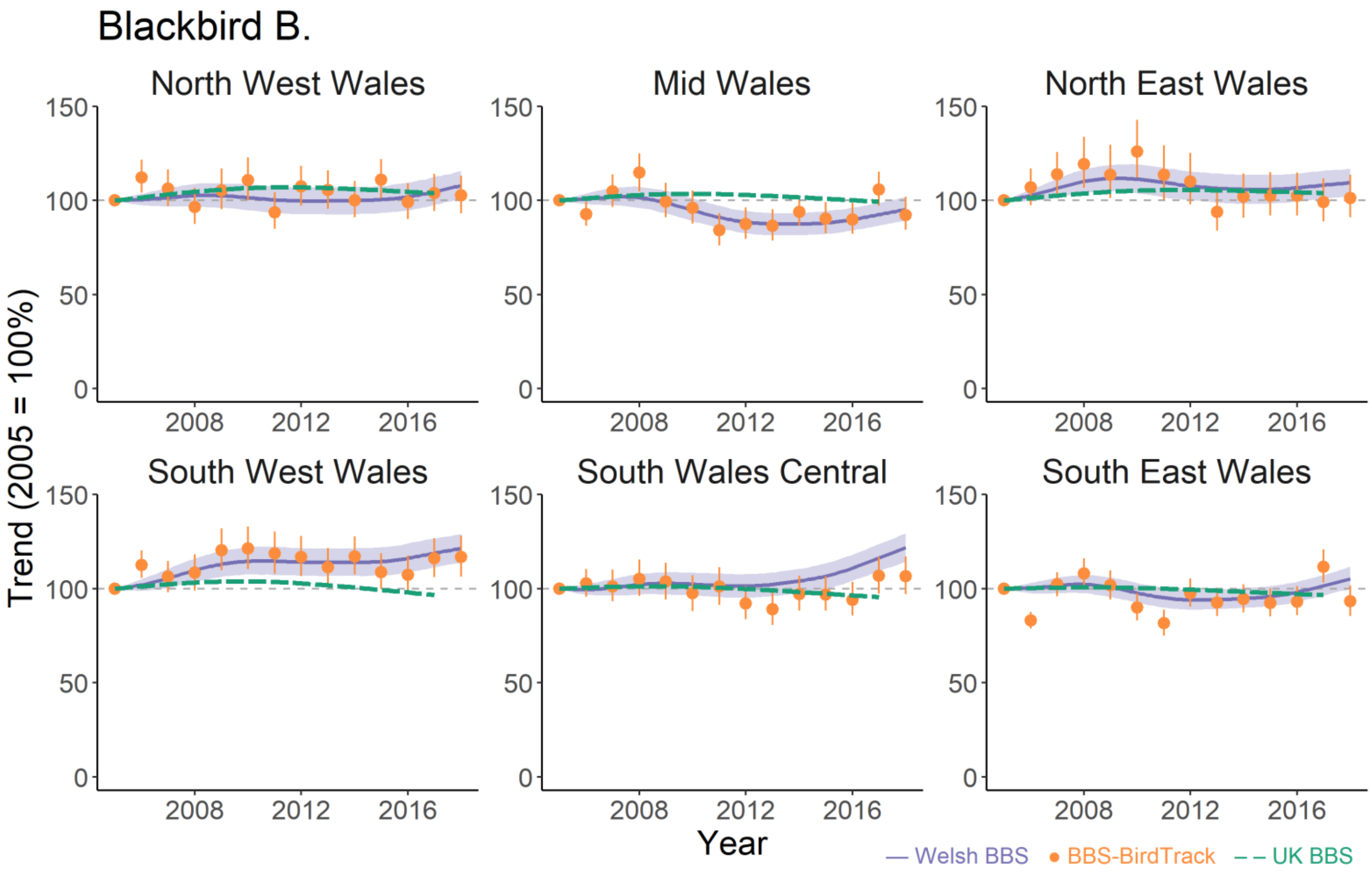
Species	English name	Mid Wales (33.0%)	North East Wales (8.7%)	North West Wales (21.3%)	South East Wales (7.6%)	South Wales Central (6.0%)	South West Wales (23.4%)
BC	Blackcap	26.7	5.1	11.8	**11.9***	**8.4***	**36.1***
BF	Bullfinch	29.5	7.1	12.9	7.1	**8.2***	**35.3***
BT	Blue Tit	32.3	8.5	16.1	**8.9***	6.4	**27.8***
BZ	Buzzard	**40.6***	7.6	18.1	7.7	4.9	21.0
CC	Chiffchaff	27.1	7.7	12.9	**9.8***	6.1	**36.4***
CD	Collared Dove	16.6	**11.4***	18.3	**10.3***	**9.5***	**33.8***
CG	Canada Goose	31.1	**13.1***	22.5	8.1	5.3	19.9
CH	Chaffinch	35.0	8.8	21.1	6.3	4.7	24.1
CK	Cuckoo	**36.5***	5.4	**24.4***	**8.6***	6.2	18.9
CT	Coal Tit	**36.5***	6.5	19.8	6.9	**7.9***	22.4
CU	Curlew	24.7	**16.8***	**39.4***	5.6	0.4	13.0
GC	Goldcrest	**36.6***	5.4	17.7	6.3	5.8	**28.2***
GL	Grey Wagtail	33.5	8.3	19.5	7.2	**7.1***	24.4
GO	Goldfinch	29.6	**10.0***	16.4	**8.8***	6.5	**28.7***
GR	Greenfinch	22.6	8.7	17.0	**11.3***	**10.2***	**30.1***
GS	Great Spotted Woodpecker	35.5	8.4	14.7	**10.3***	6.0	25.2
GT	Great Tit	31.8	9.3	15.4	**10.0***	**7.3***	**26.2***
GW	Garden Warbler	**49.5***	3.9	14.1	4.7	3.2	24.5
HM	House Martin	30.3	9.3	15.1	**10.2***	6.3	**28.8***
HS	House Sparrow	26.0	9.1	17.0	**9.8***	**7.9***	**30.1***

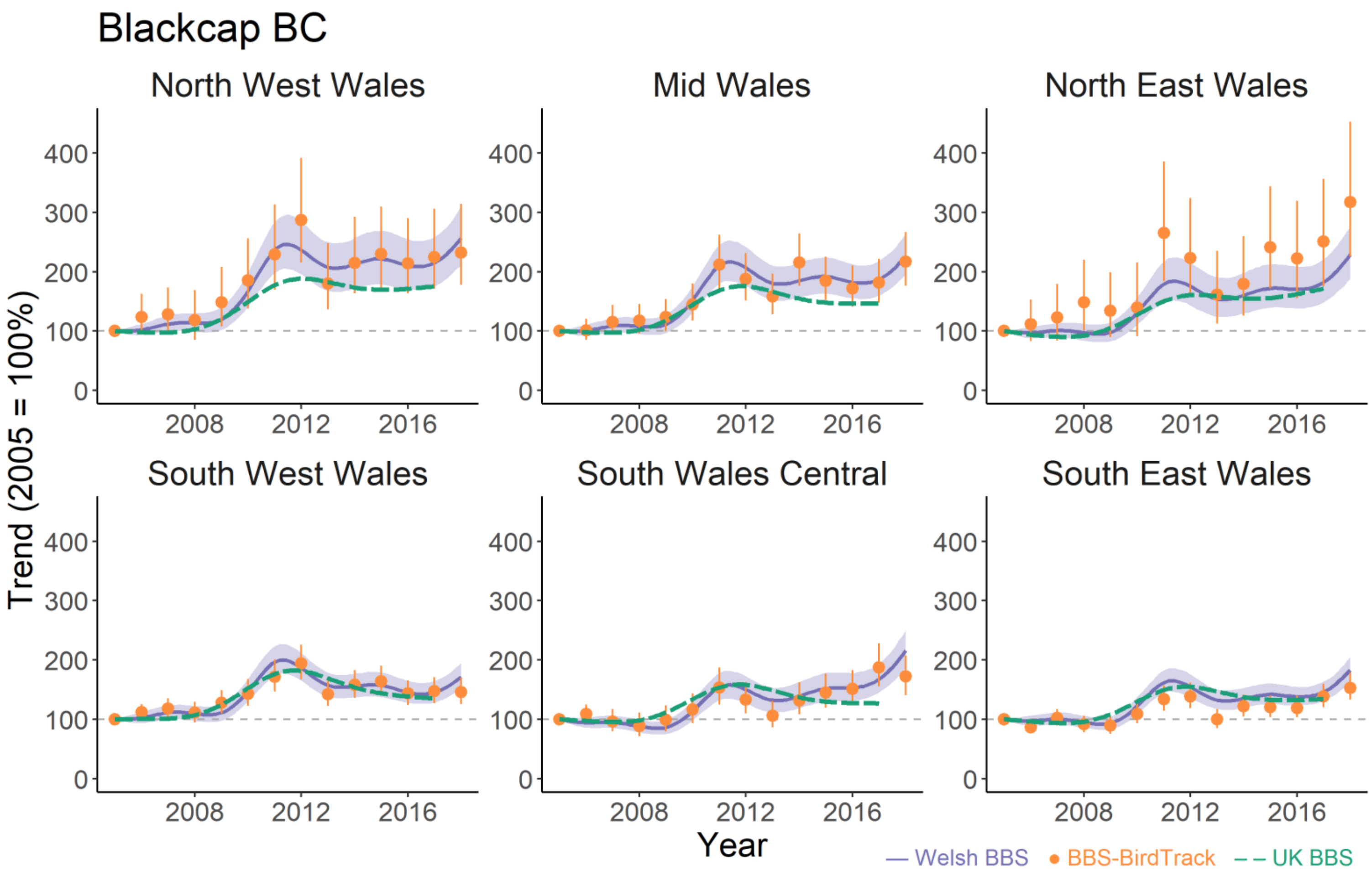
Species	English name	Mid Wales (33.0%)	North East Wales (8.7%)	North West Wales (21.3%)	South East Wales (7.6%)	South Wales Central (6.0%)	South West Wales (23.4%)
JD	Jackdaw	24.5	9.2	17.3	**9.0***	**8.2***	**31.8***
KT	Red Kite	**69.6***	0.6	5.4	0.6	0.8	23.0
LI	Linnet	25.8	5.4	19.2	7.6	6.4	**35.6***
LR	Lesser Redpoll	**45.6***	4.7	**29.5***	2.3	5.2	12.6
LT	Long-tailed Tit	24.8	**11.9***	11.5	**13.1***	**11.0***	**27.8***
MA	Mallard	21.5	**14.0***	18.7	**15.9***	**10.0***	19.8
MG	Magpie	27.2	**9.6***	16.7	**9.7***	**9.2***	**27.7***
MP	Meadow Pipit	**43.1***	5.5	**31.2***	4.4	4.1	11.7
NH	Nuthatch	**39.3***	6.3	13.3	6.7	**7.4***	**27.0***
PF	Pied Flycatcher	**59.5***	3.3	20.2	0.6	1.0	15.4
PH	Pheasant	31.2	**15.4***	21.9	**9.0***	4.9	17.6
PW	Pied/White Wagtail	33.9	6.8	**25.5***	5.7	4.7	23.5
RB	Reed Bunting	30.8	8.3	22.1	7.1	**6.9***	24.8
RN	Raven	**43.6***	5.2	**24.5***	6.5	3.5	16.7
RO	Rook	25.7	**11.4***	18.5	7.3	4.2	**32.9***
RT	Redstart	**61.5***	3.7	17.3	3.8	2.0	11.6
SC	Stonechat	28.7	4.6	**29.2***	4.6	6.4	**26.5***
SD	Stock Dove	**40.9***	**15.0***	4.9	**14.6***	5.4	19.2
SG	Starling	10.3	**15.3***	18.0	**18.3***	**15.1***	23.0
SI	Swift	25.3	**11.5***	15.1	**12.8***	**12.9***	22.3
SK	Siskin	**41.7***	4.2	**26.2***	3.1	6.3	18.6
SL	Swallow	27.8	8.9	20.1	7.3	5.2	**30.7***
ST	Song Thrush	29.4	6.9	15.3	**10.8***	**8.2***	**29.4***
TC	Treecreeper	**39.8***	5.3	14.0	5.9	5.7	**29.2***
TP	Tree Pipit	**50.0***	3.5	19.1	4.8	6.1	16.4

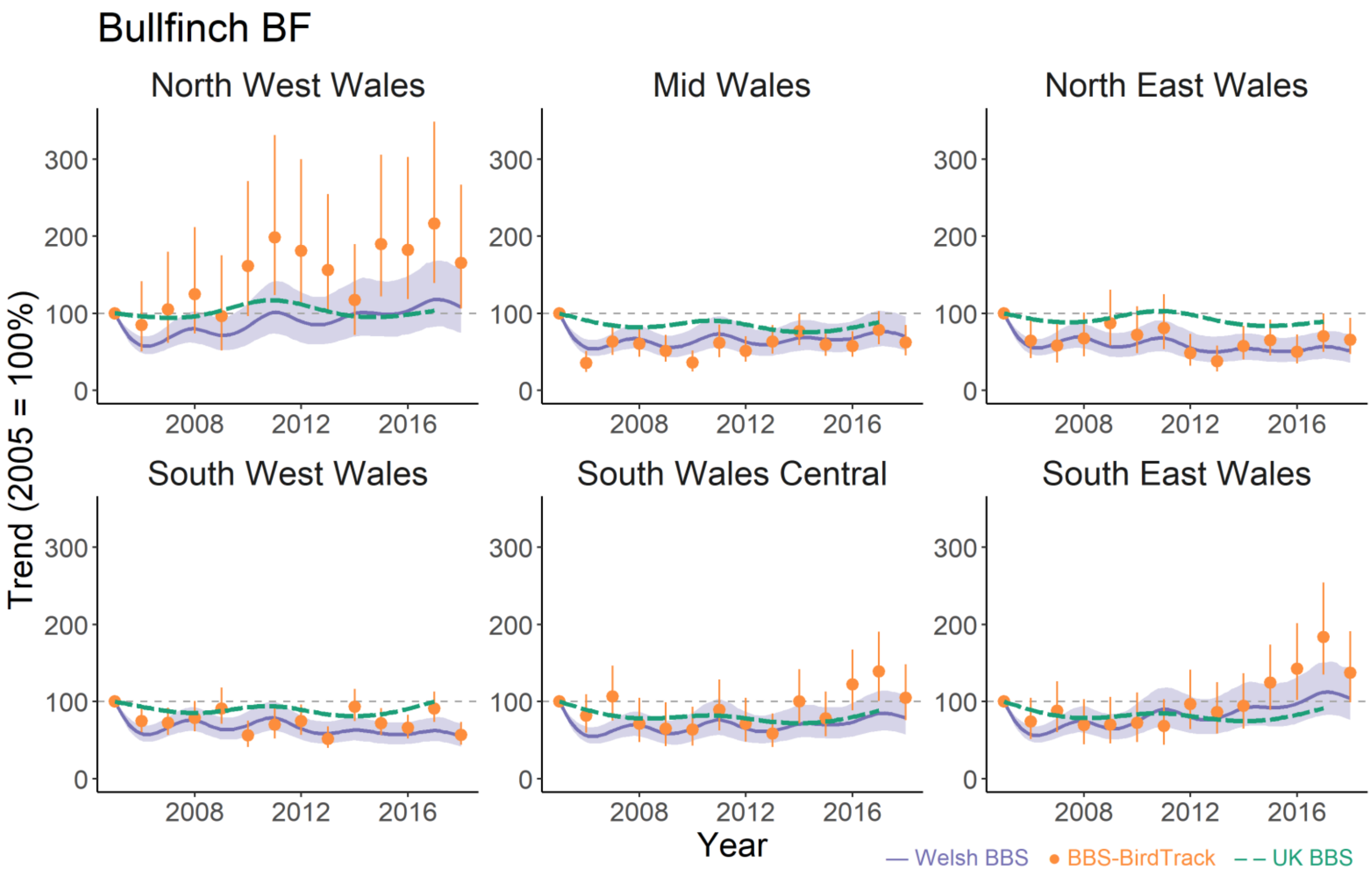
Species	English name	Mid Wales (33.0%)	North East Wales (8.7%)	North West Wales (21.3%)	South East Wales (7.6%)	South Wales Central (6.0%)	South West Wales (23.4%)
WH	Whitethroat	13.7	6.8	18.4	7.6	**8.0***	**45.6***
WP	Woodpigeon	27.1	**15.0***	13.3	**12.0***	**7.8***	24.7
WR	Wren	27.4	7.6	18.9	**9.0***	**7.5***	**29.7***
WW	Willow Warbler	**38.7***	5.8	**25.8***	4.1	5.3	20.3

Appendix 3: Species trends

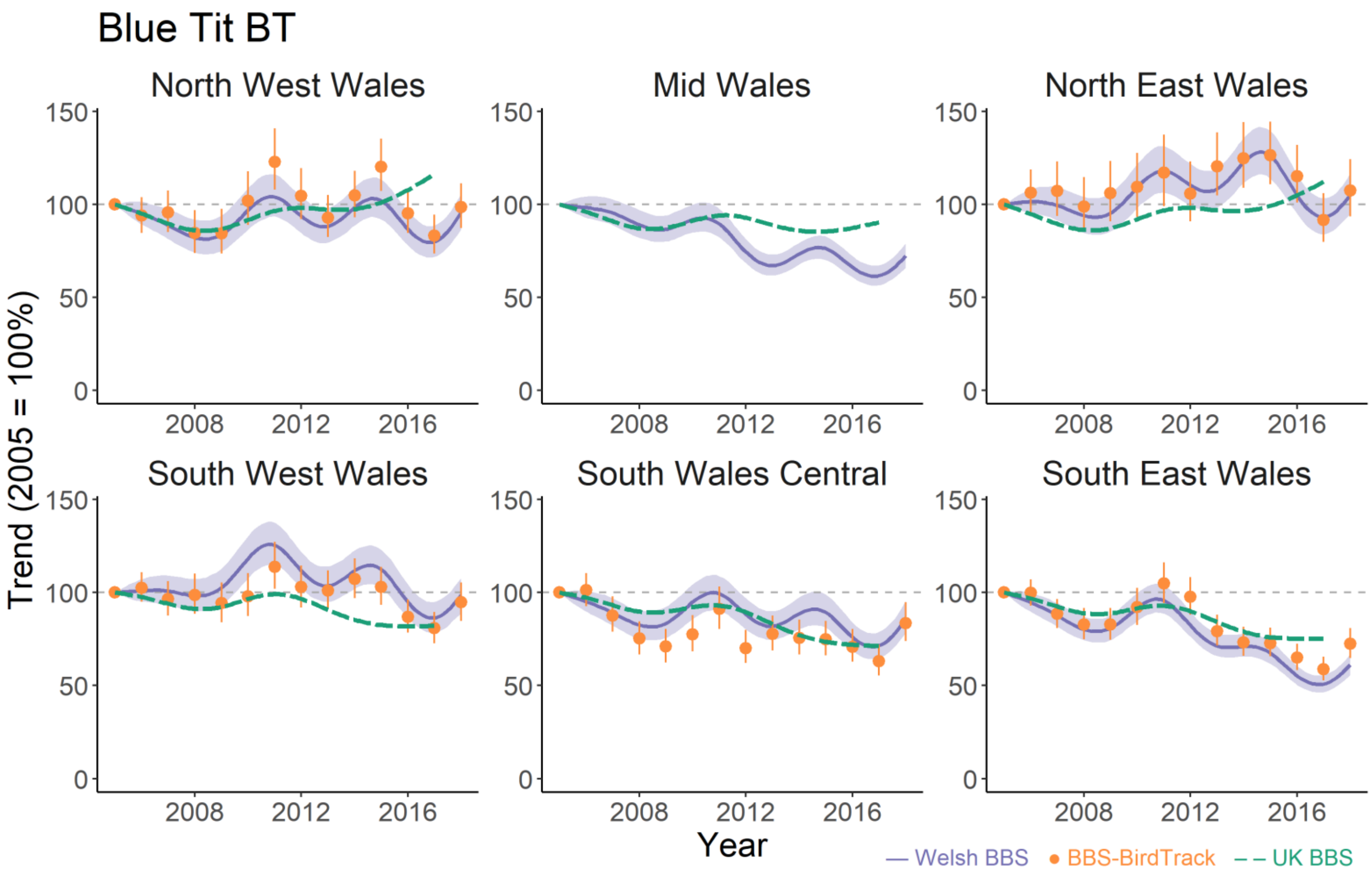
Graphs showing regional species trends for the species listed in Environment (Wales) Act 2016, Section 7. Trends for Welsh BBS, UK BBS and BBS-BirdTrack are given, for the following regions: North West Wales, Mid Wales, North East Wales, South West Wales, South Wales Central, and South East Wales.

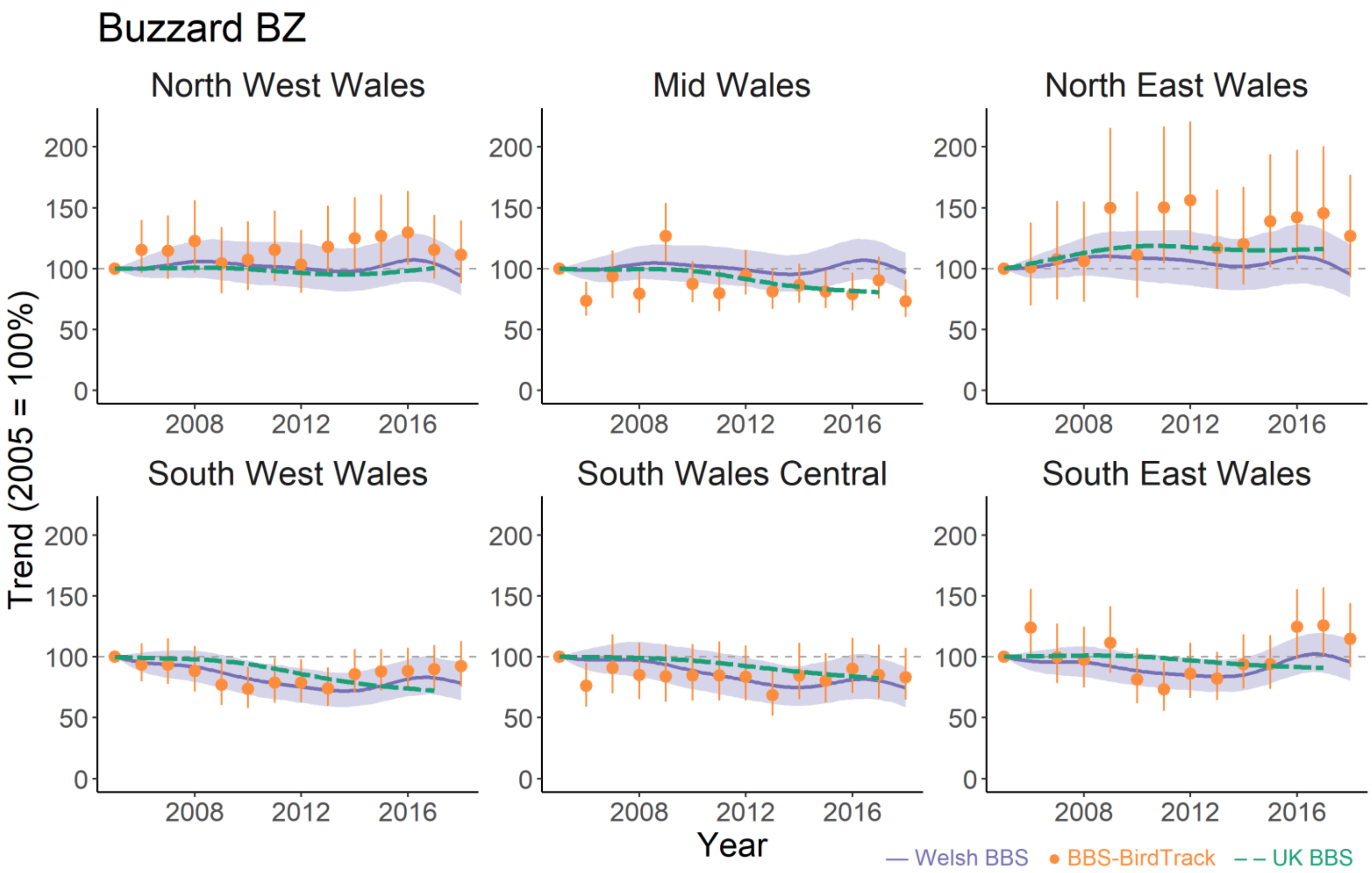


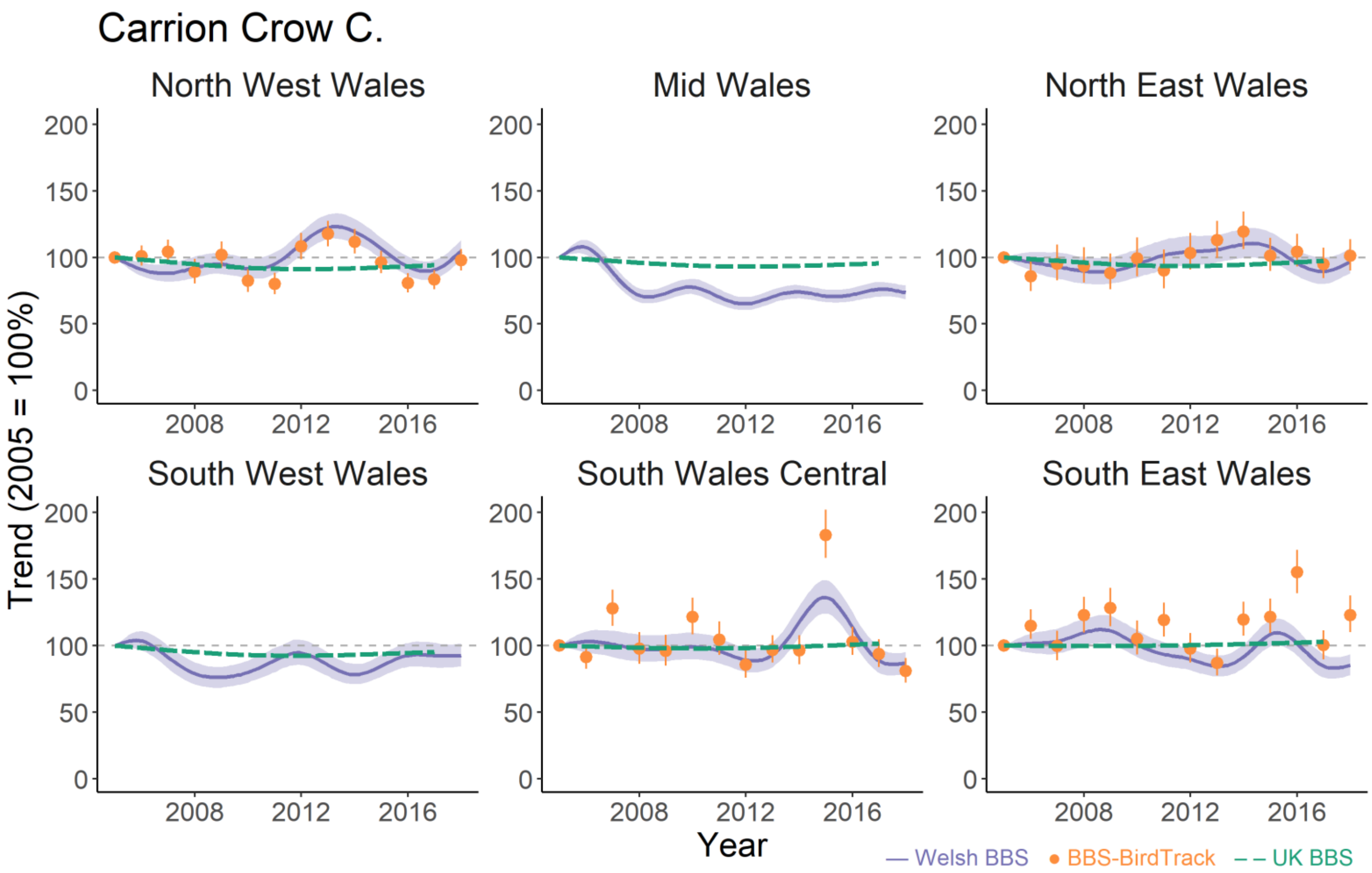

Blackcap BC
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
400
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS



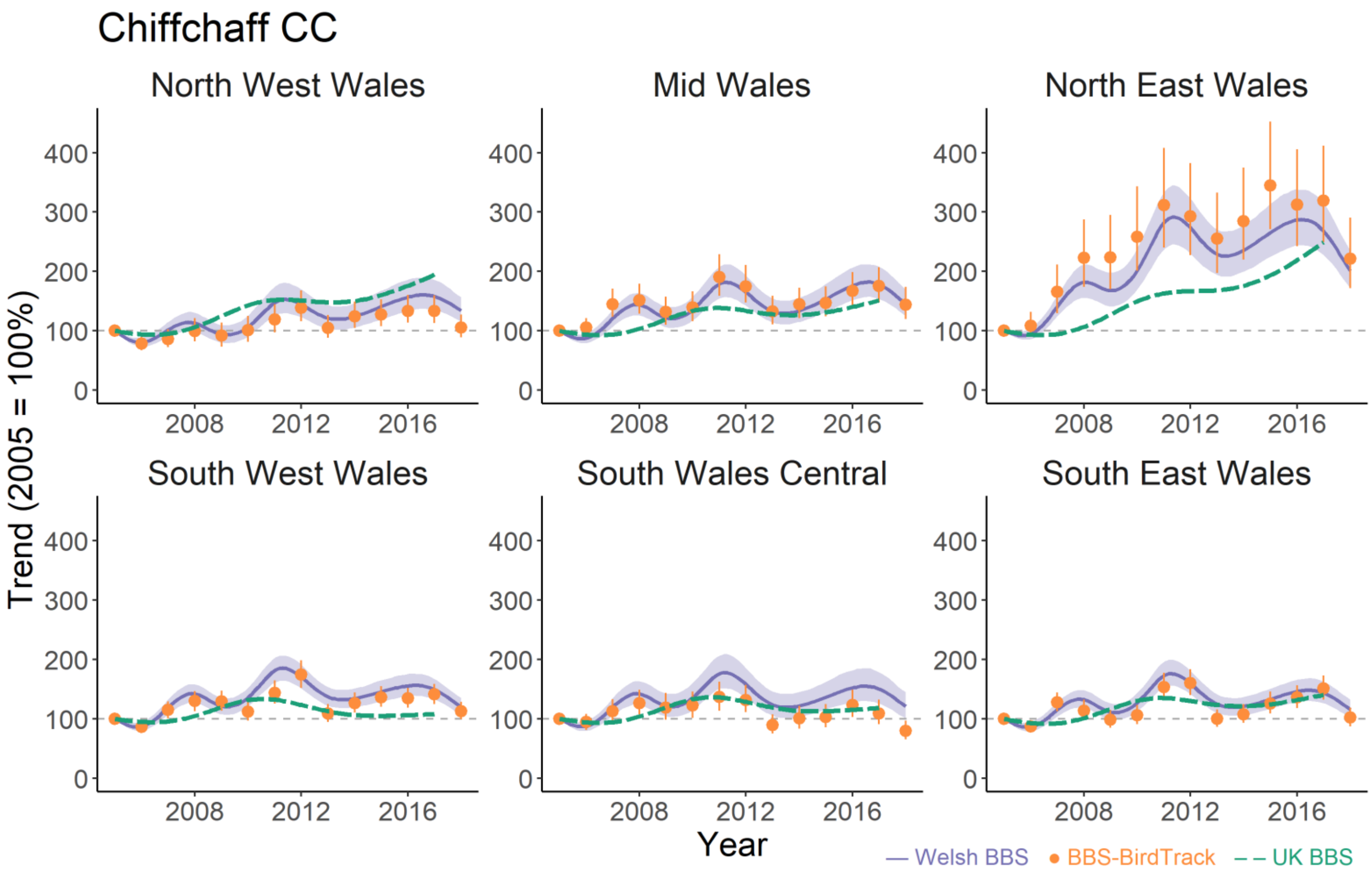
Bullfinch BF
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
300
200
100
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS


Blue Tit BT
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
50
100
150
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

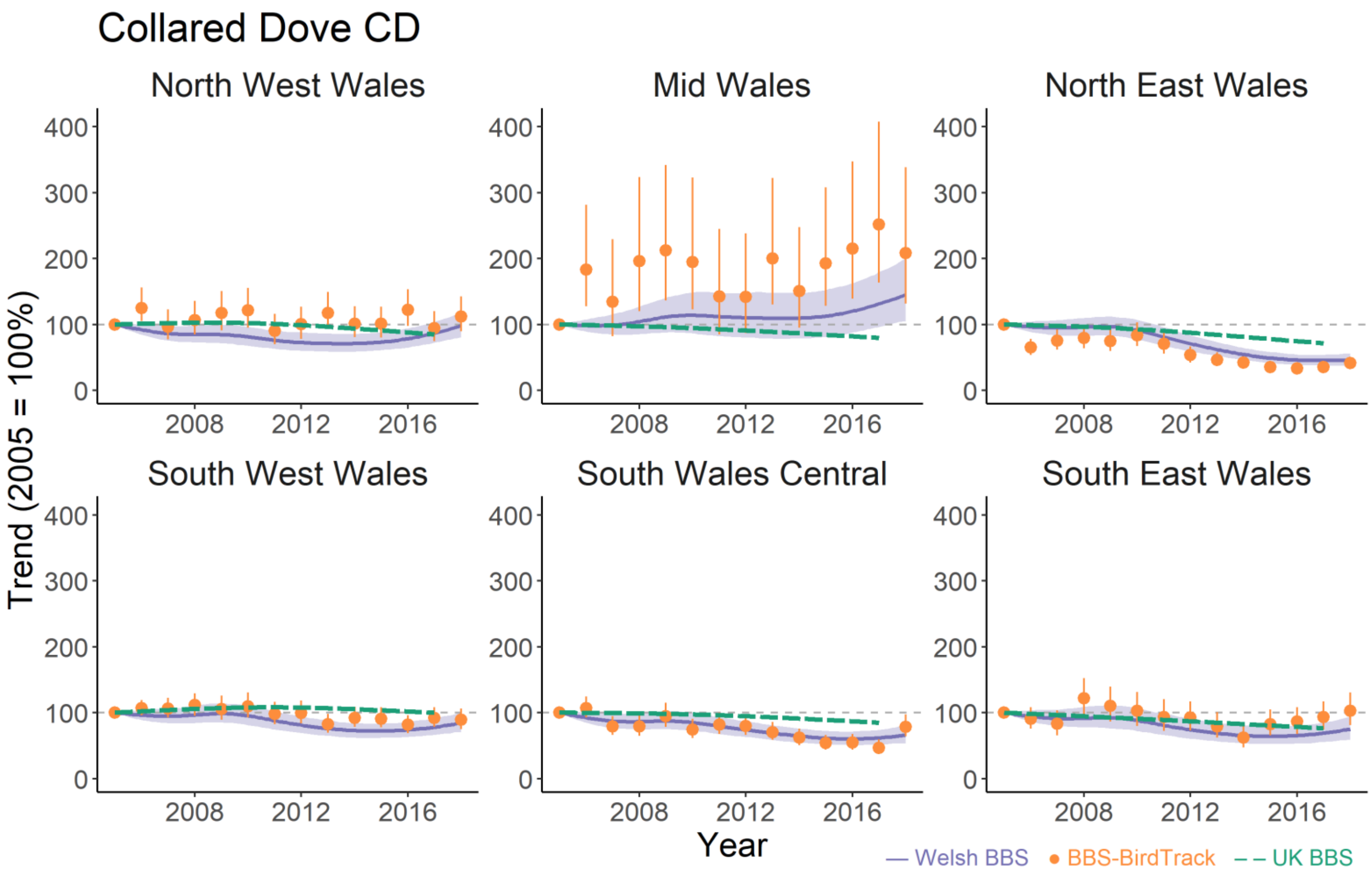

Buzzard BZ
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
50
100
150
200
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

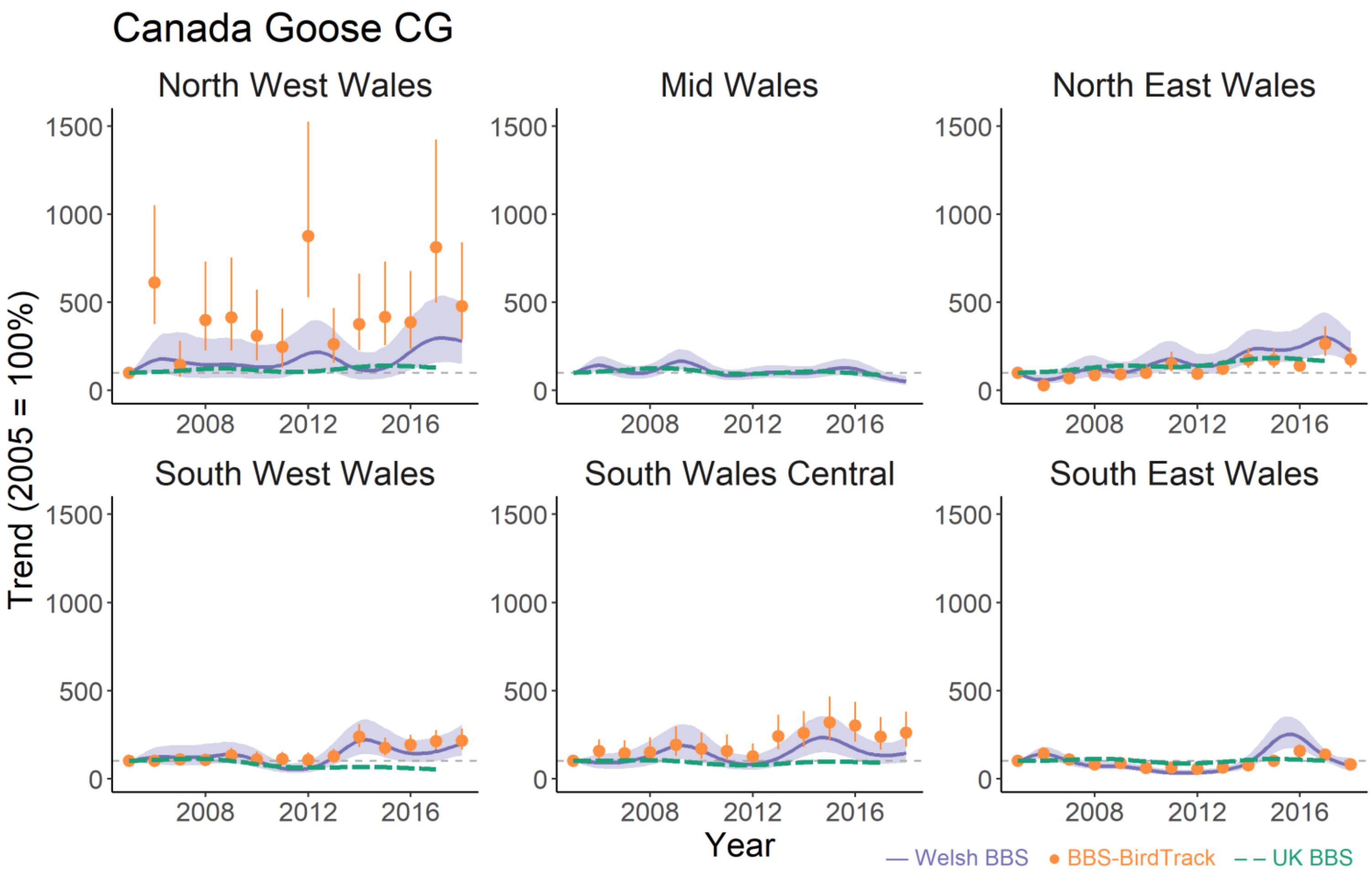


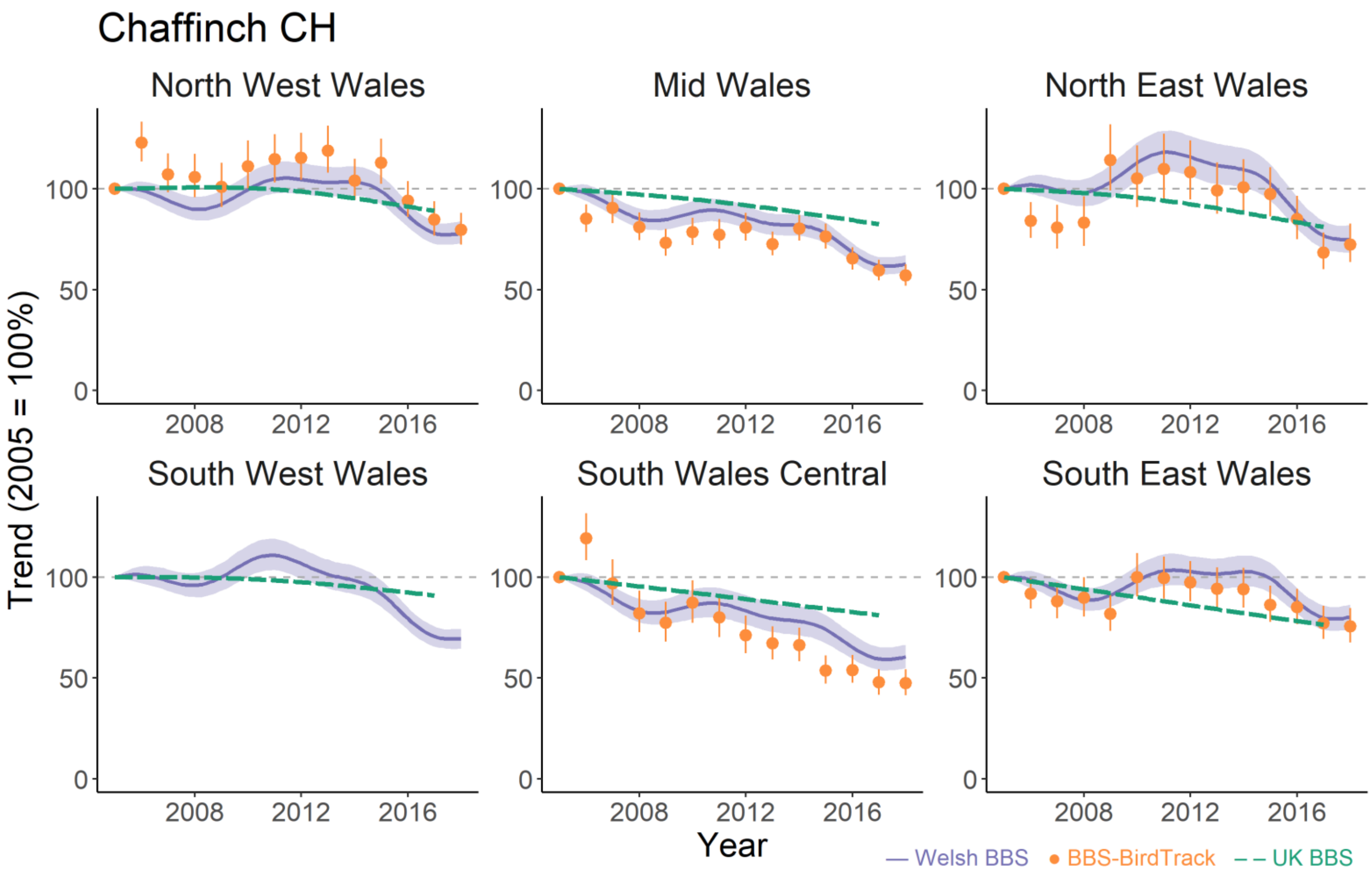
Carrion Crow C.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
50
100
150
200
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS



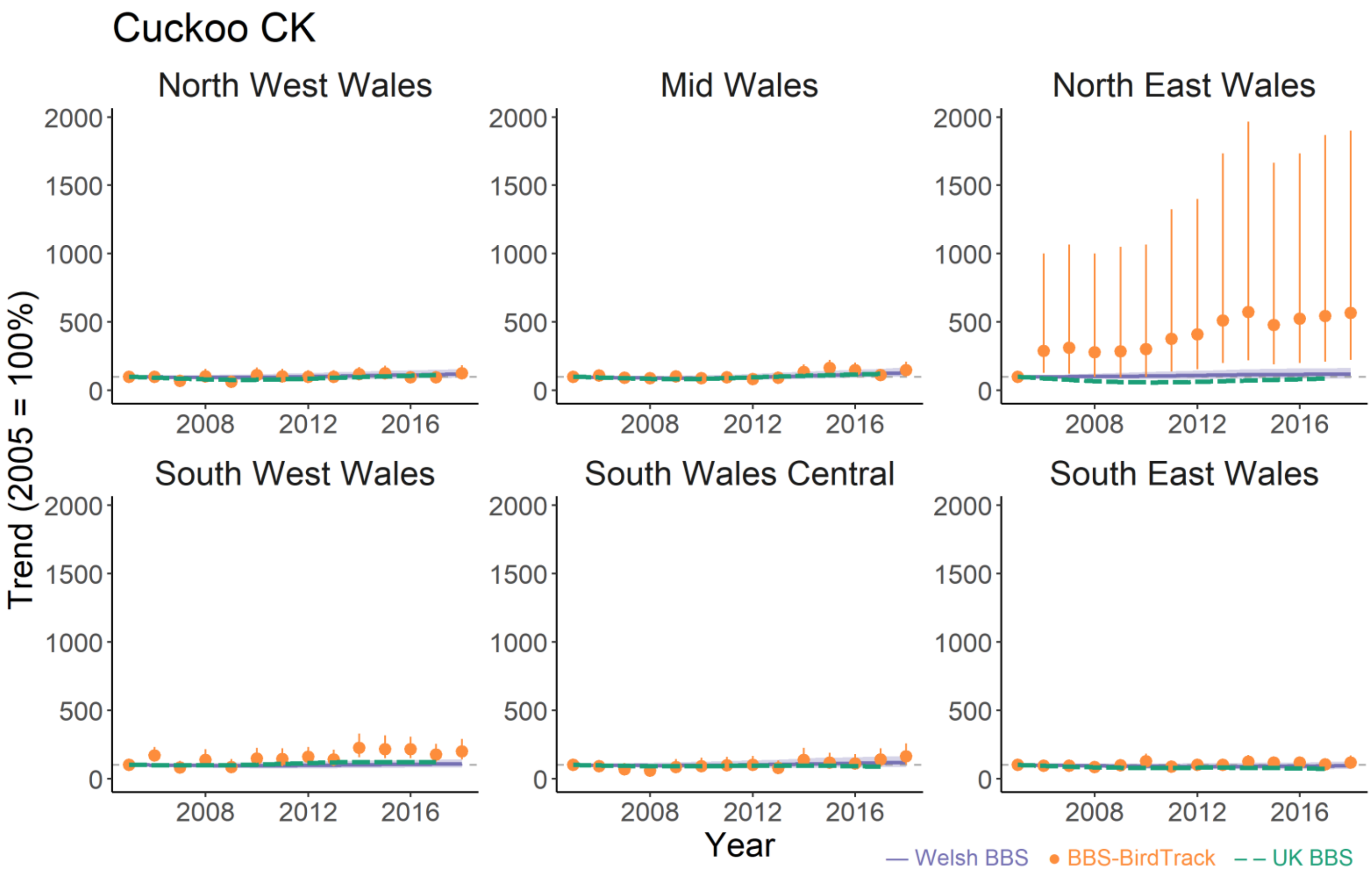
Chiffchaff CC
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
400
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

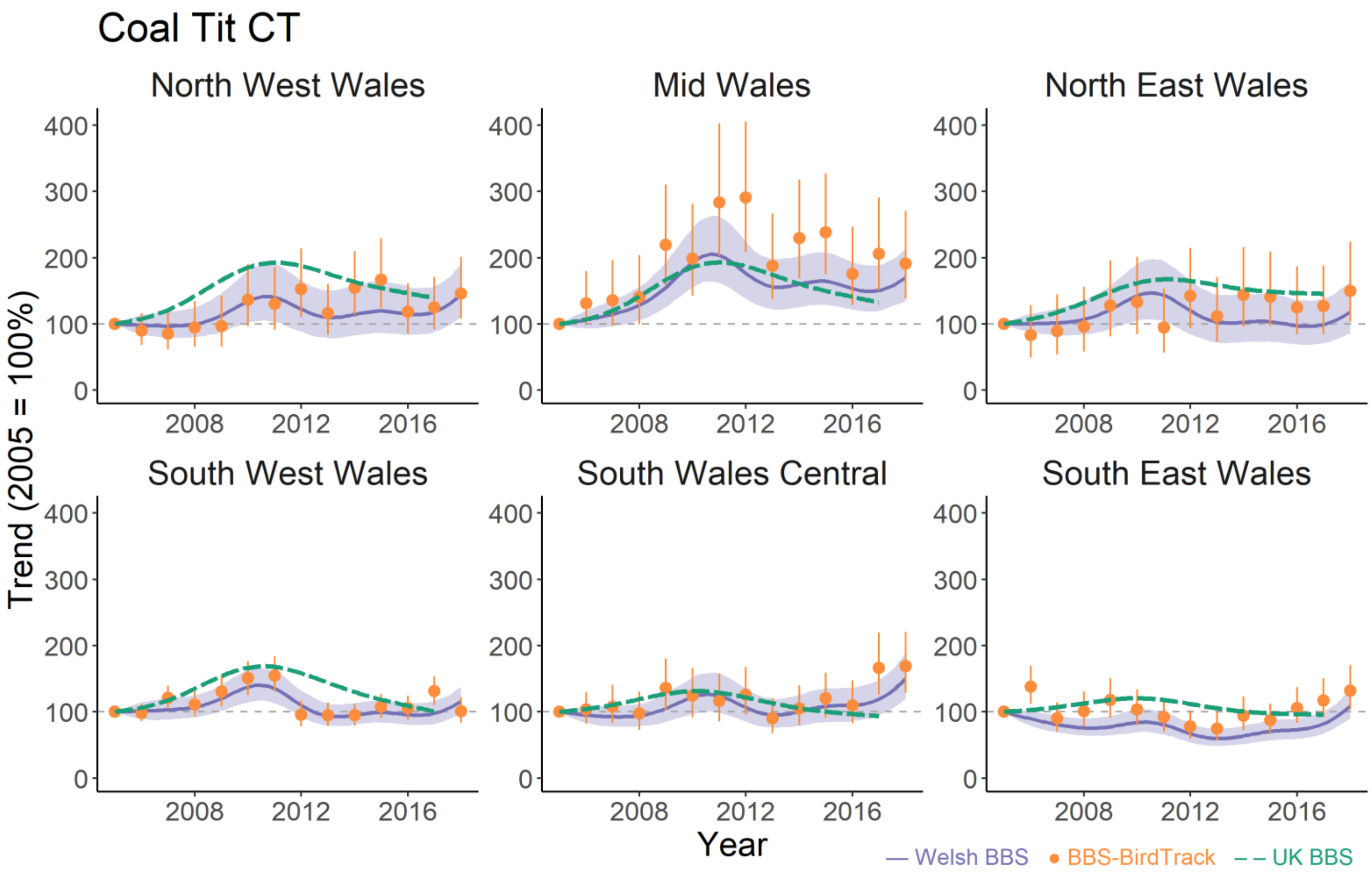

Collared Dove CD
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
Year
400
300
200
100
0
2008
2012
2016
— Welsh BBS
● BBS-BirdTrack
– – UK BBS

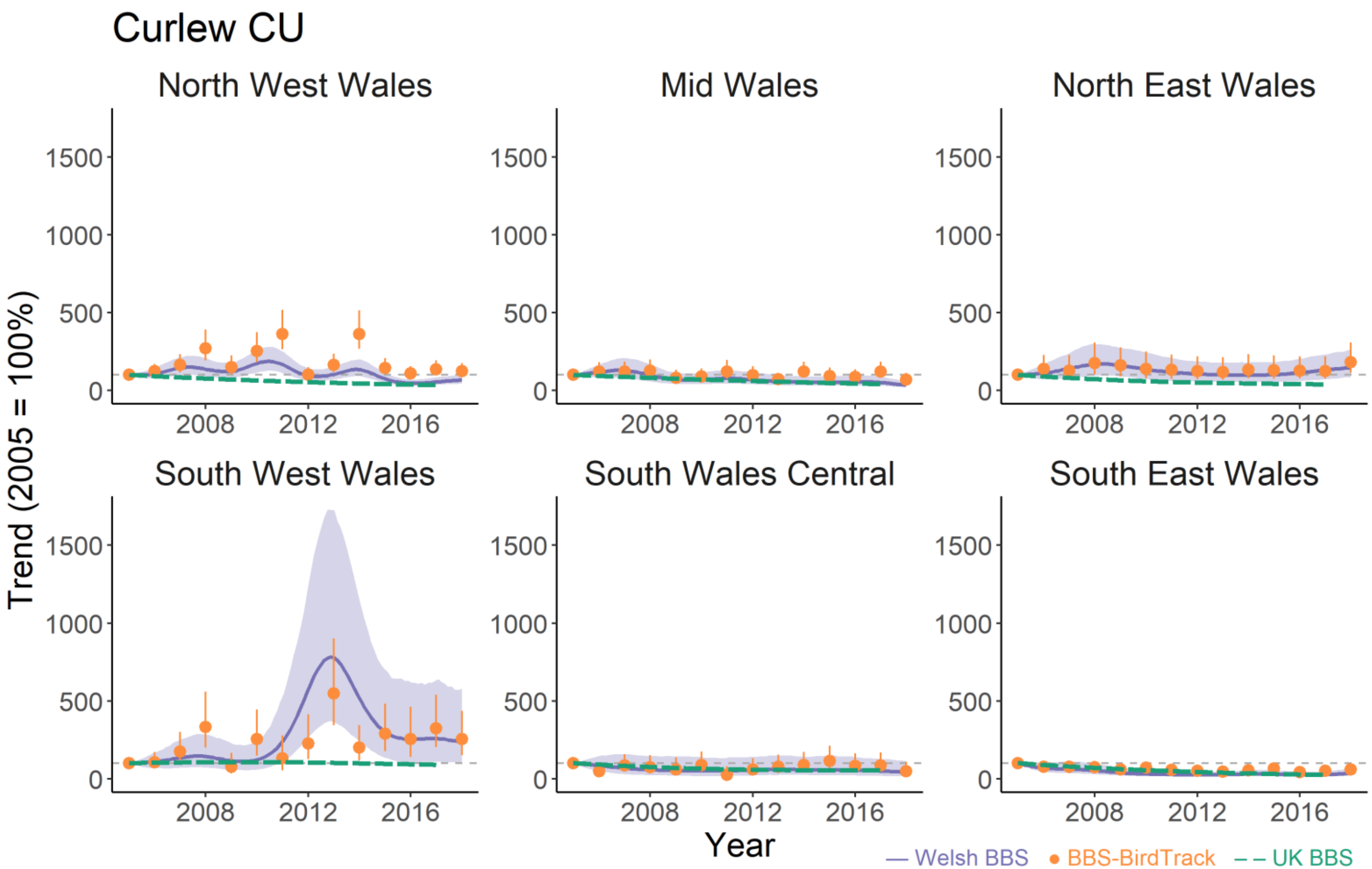

Canada Goose CG
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
1500
1000
500
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

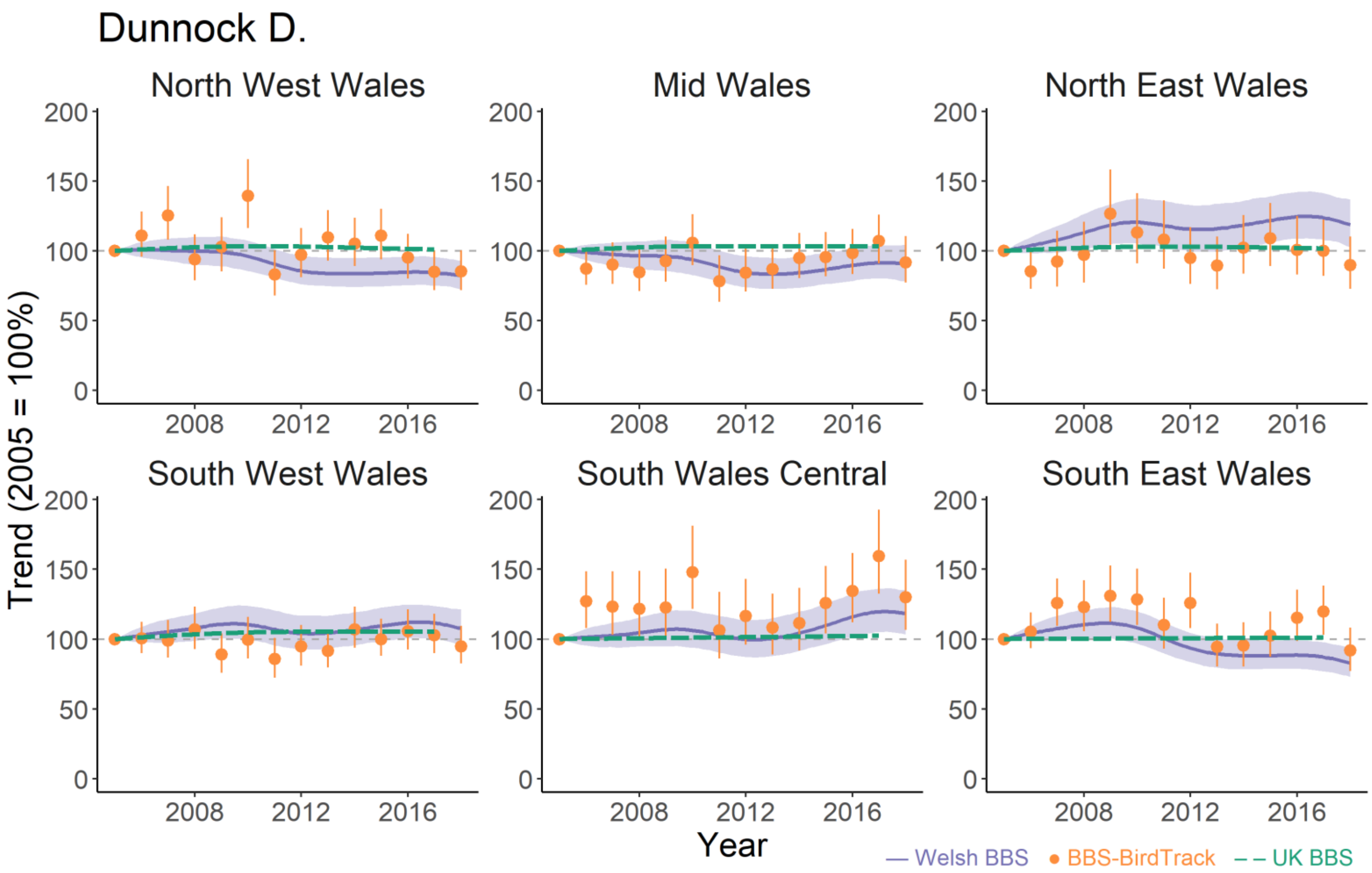


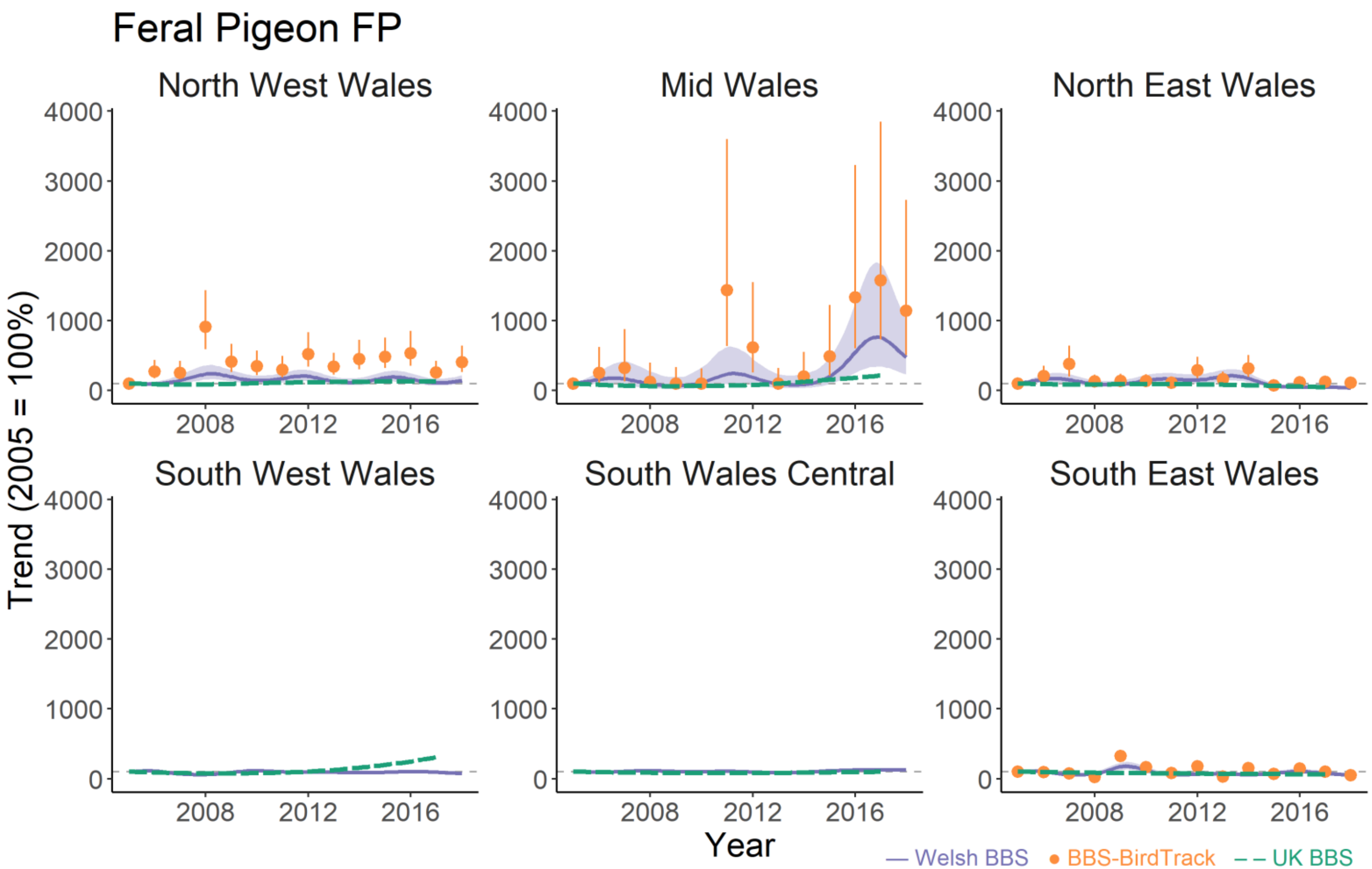
Chaffinch CH
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
50
100
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS


Cuckoo CK
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
2000
1500
1000
500
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

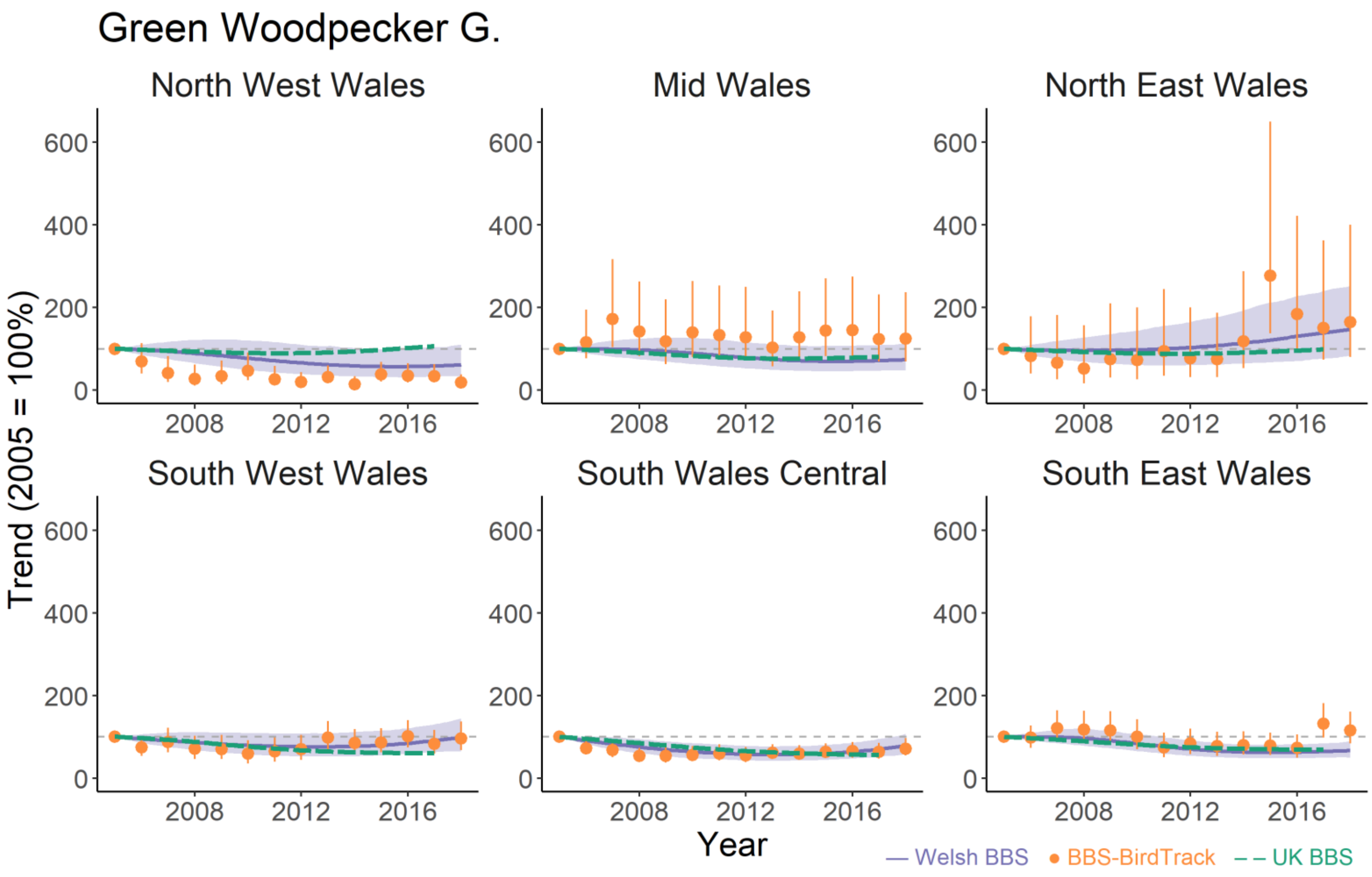

Coal Tit CT
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
400
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

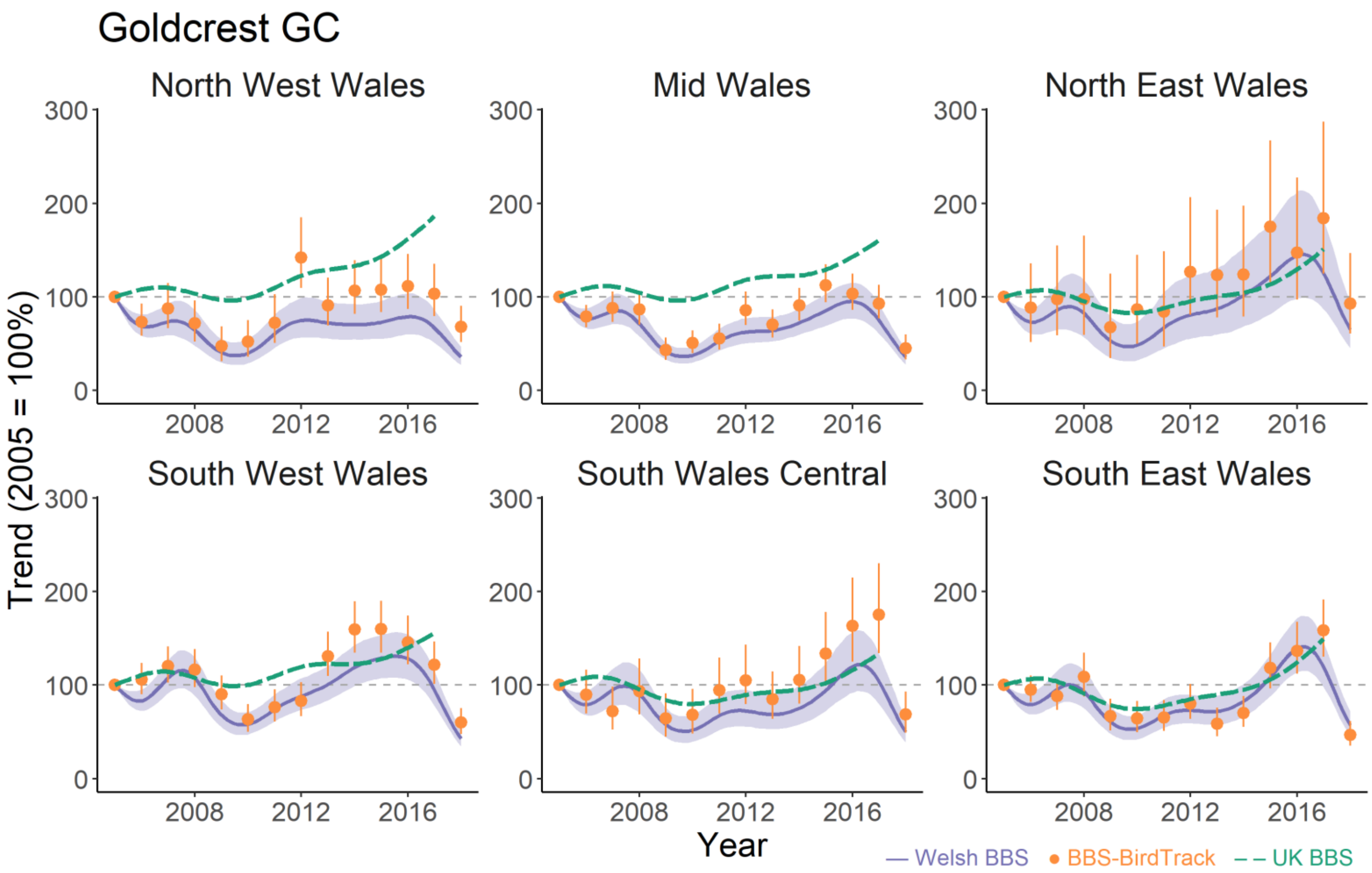

Curlew CU
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
1500
1000
500
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

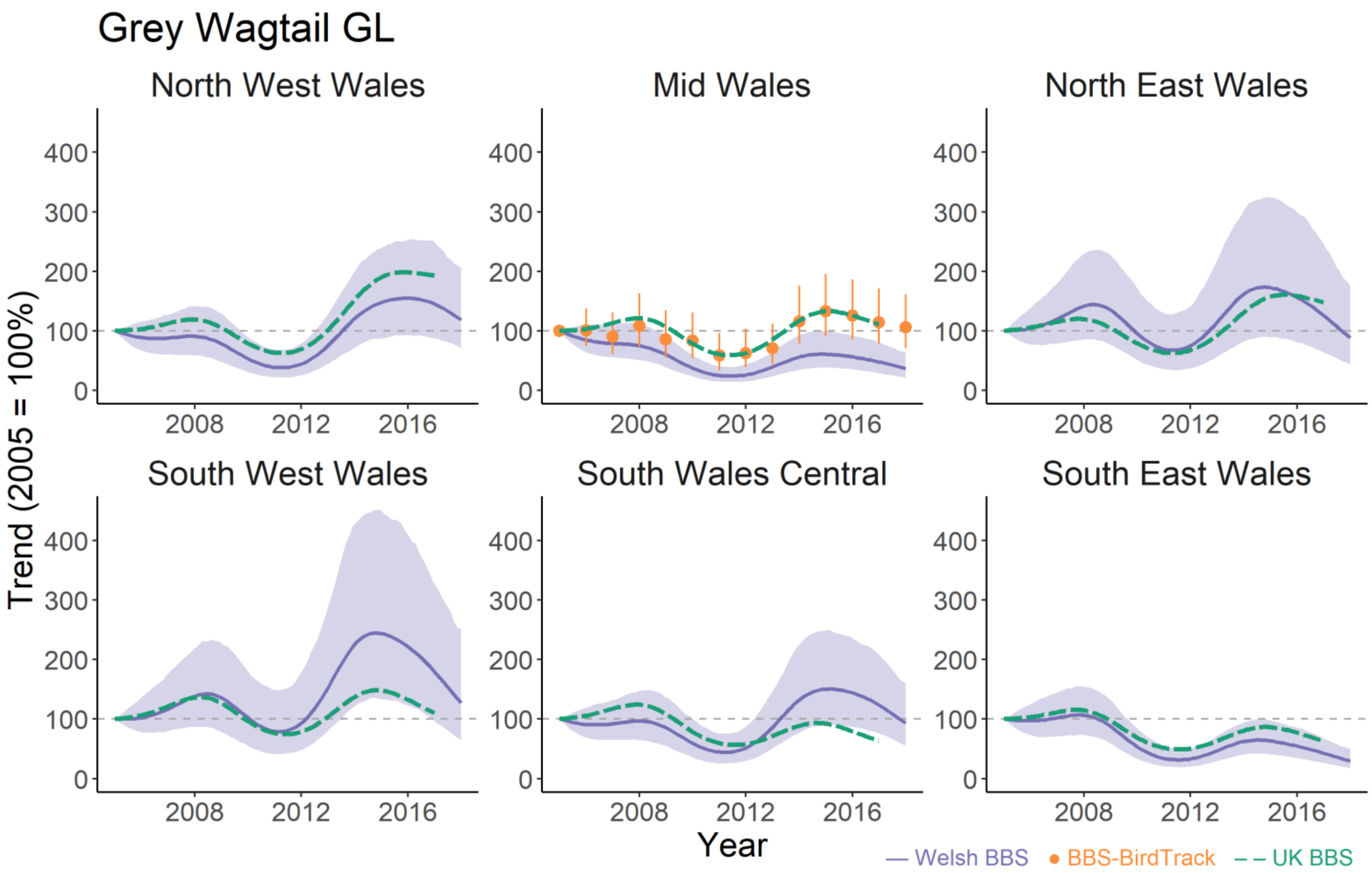

Dunnock D.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
200
150
100
50
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

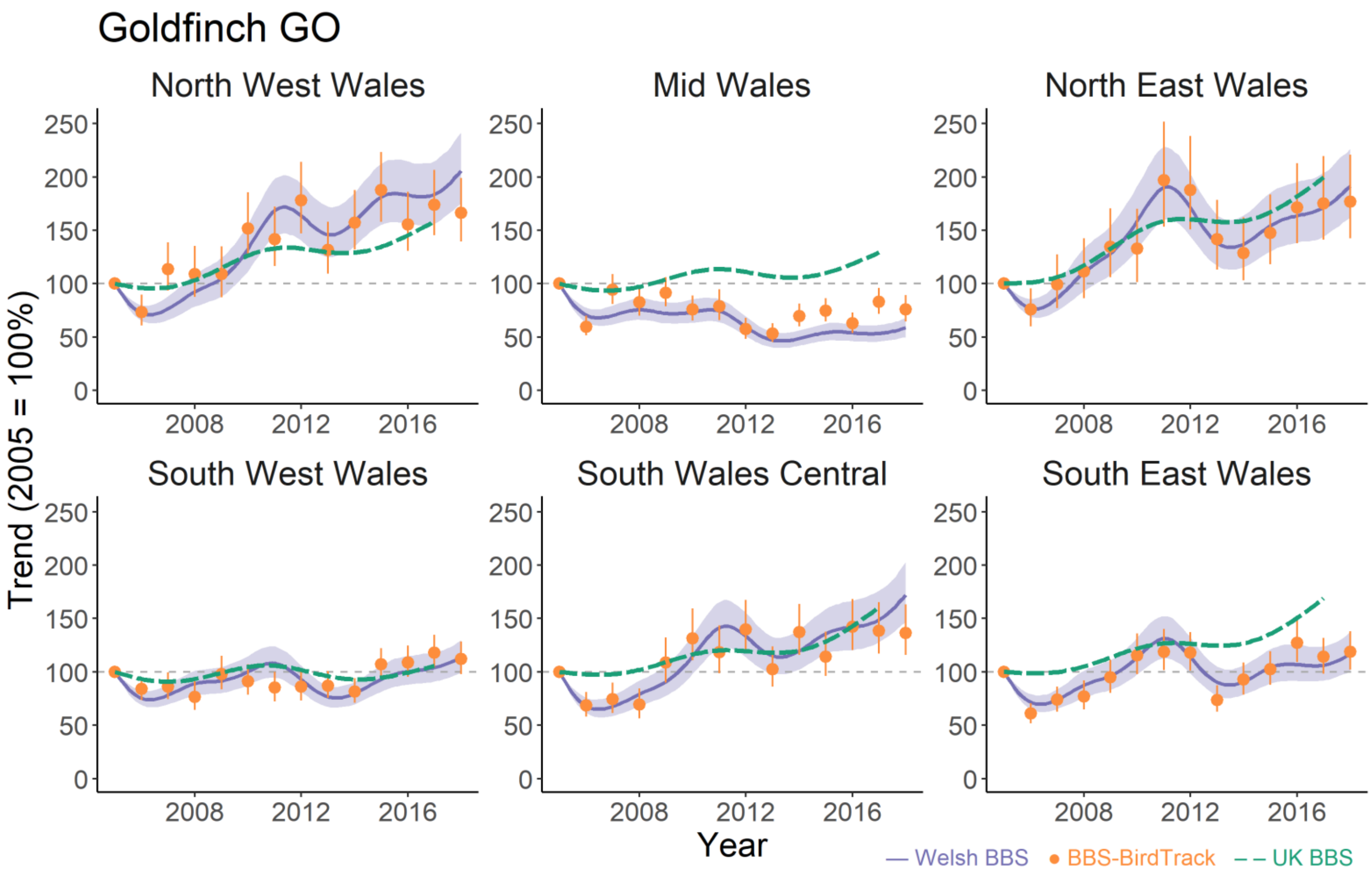


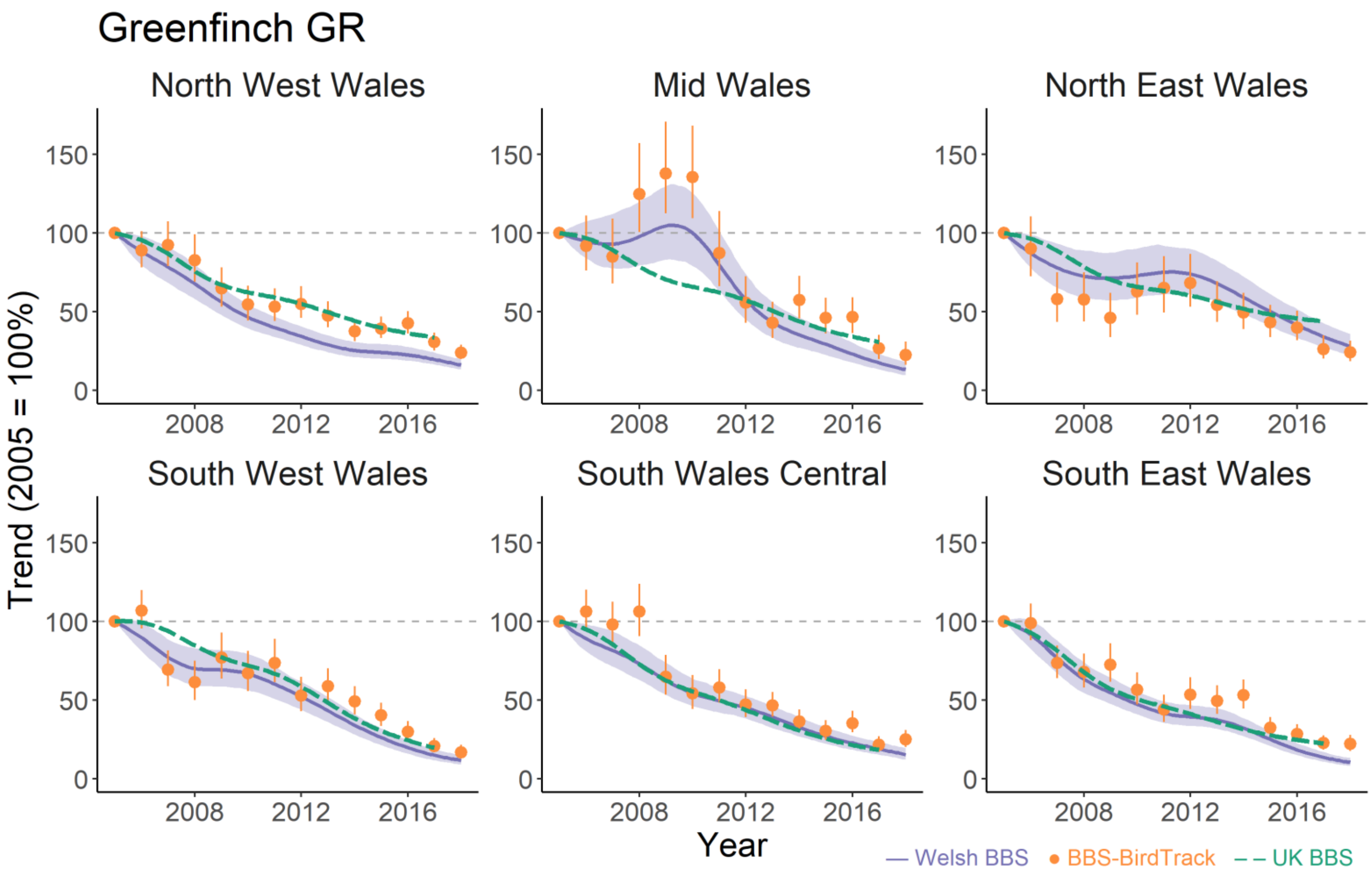
Feral Pigeon FP
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
1000
2000
3000
4000
2008
2012
2016
Year
— Welsh BBS
● BBS-BirdTrack
-- UK BBS


Green Woodpecker G.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
600
400
200
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

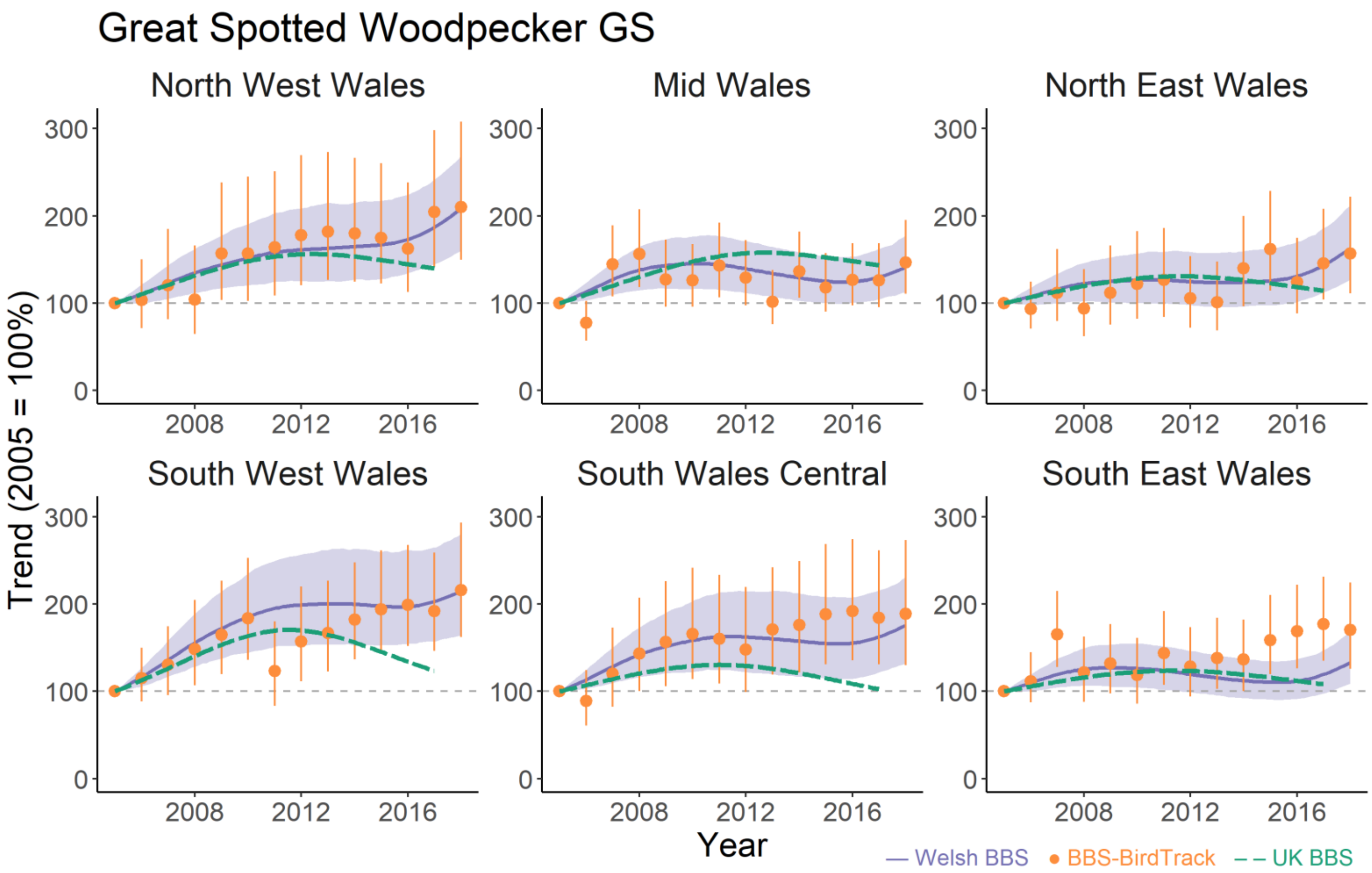

Goldcrest GC
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
300
200
100
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

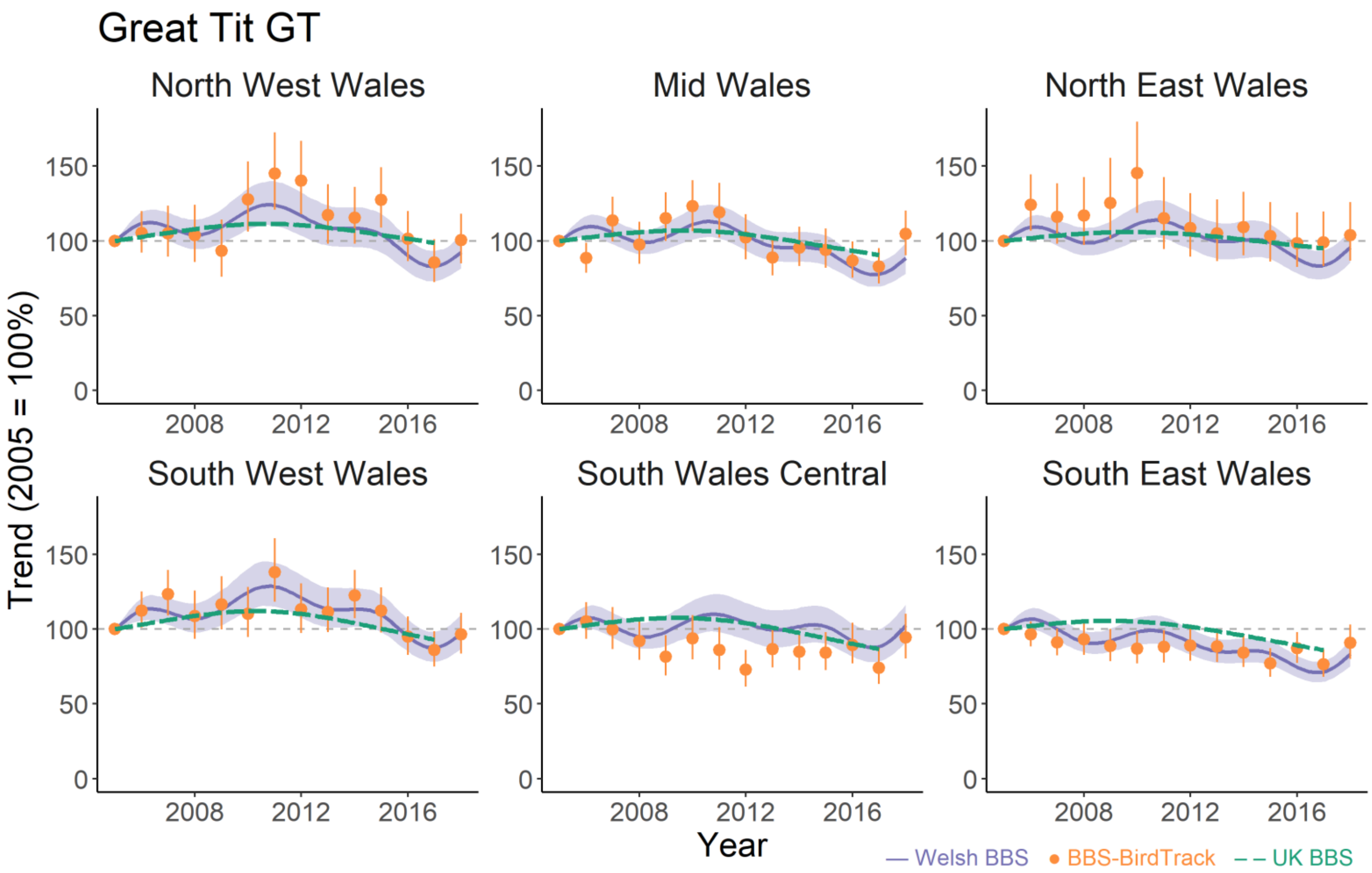

Grey Wagtail GL
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
400
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

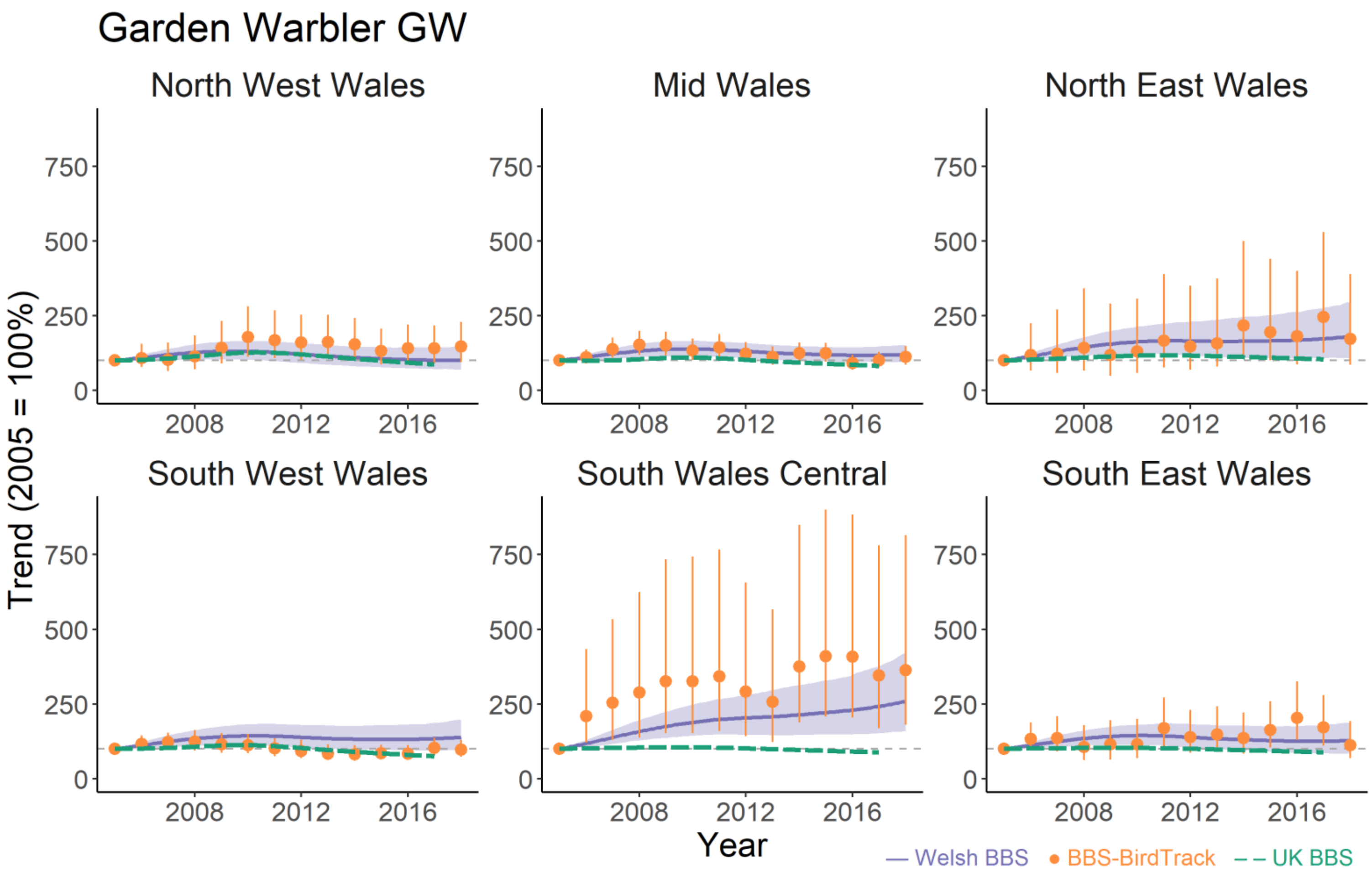

Goldfinch GO
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
250
200
150
100
50
0
2008
2012
2016
Year
— Welsh BBS
● BBS-BirdTrack
– – UK BBS

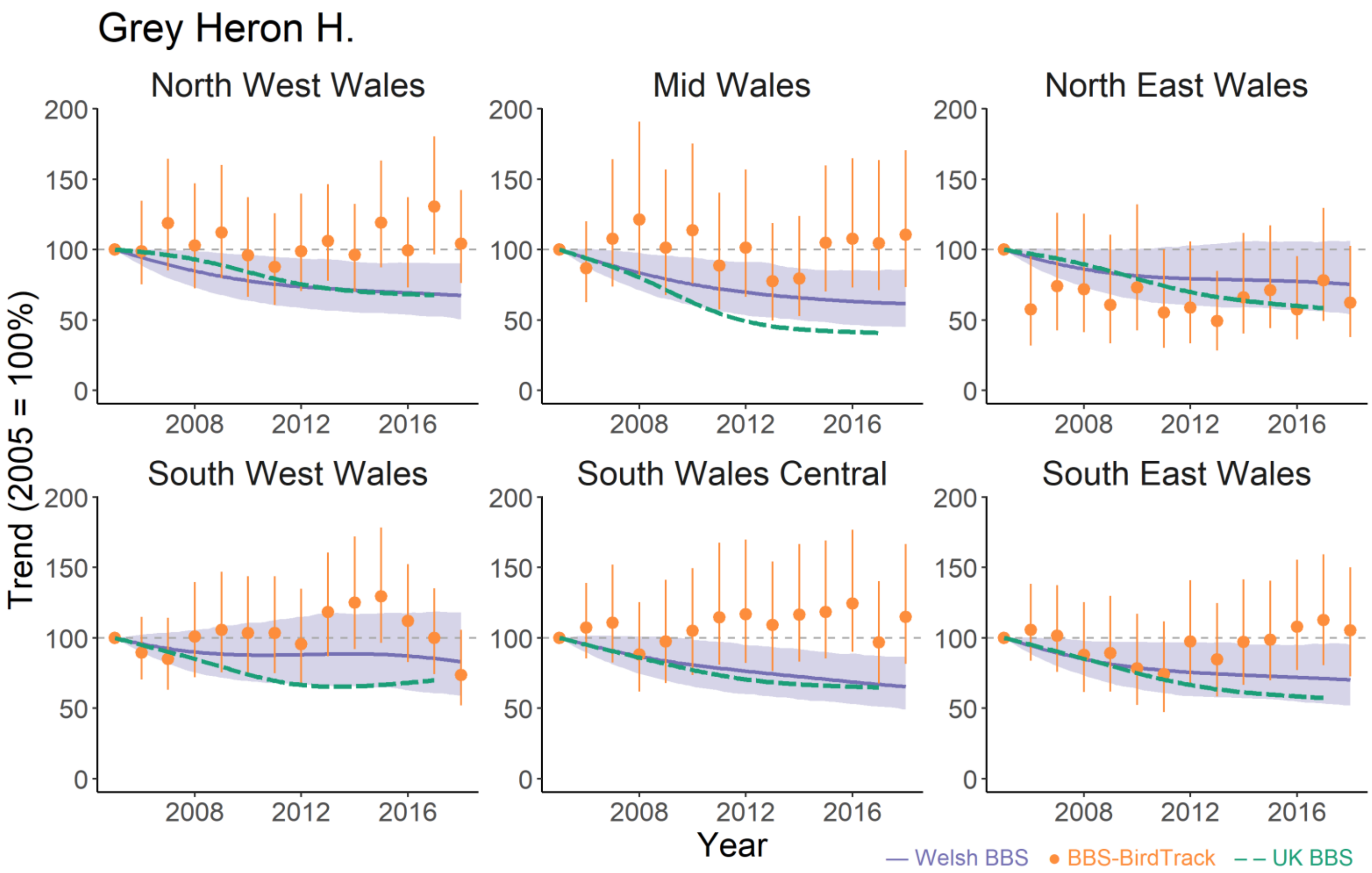


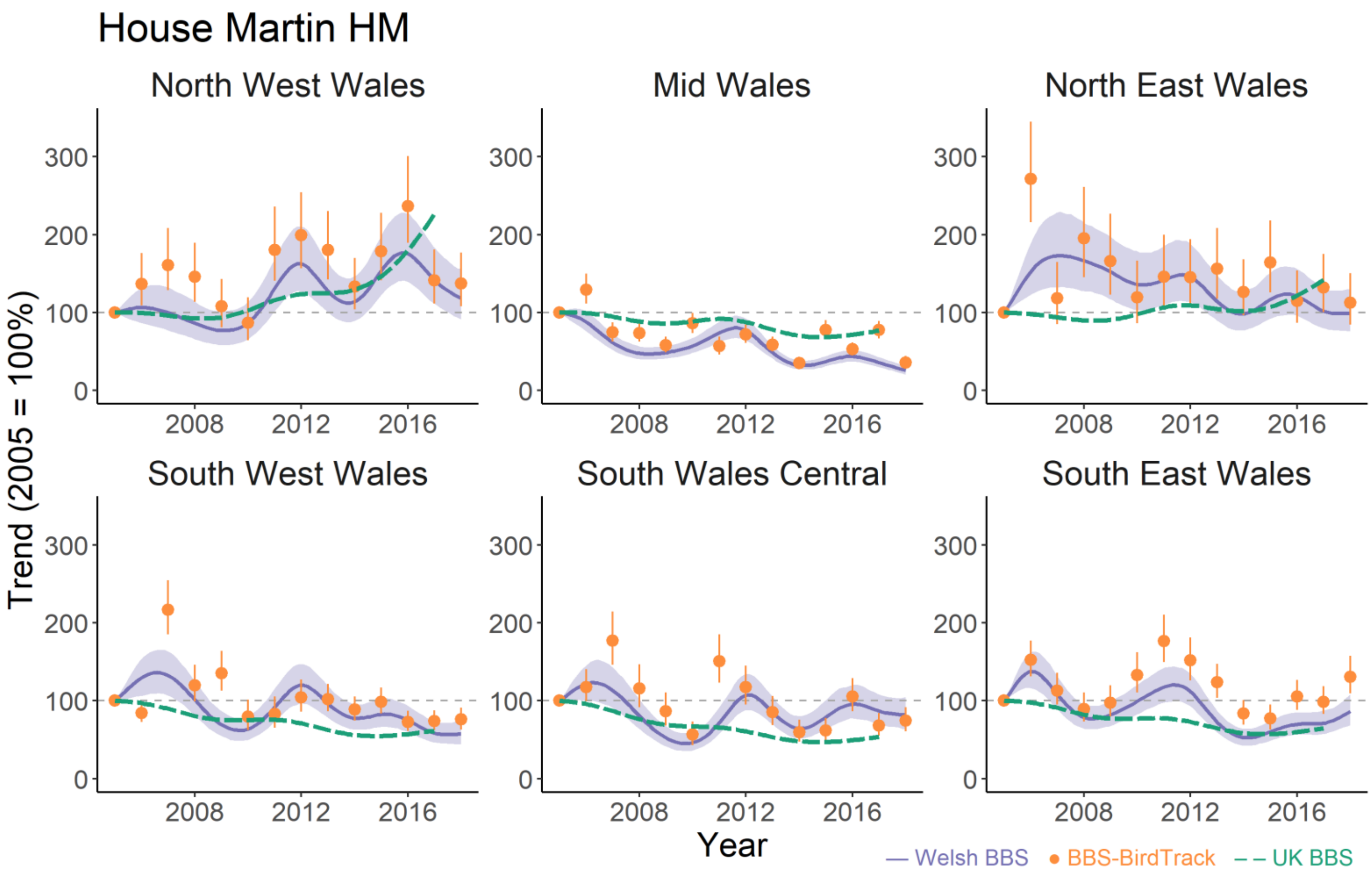
Greenfinch GR
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
50
100
150
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

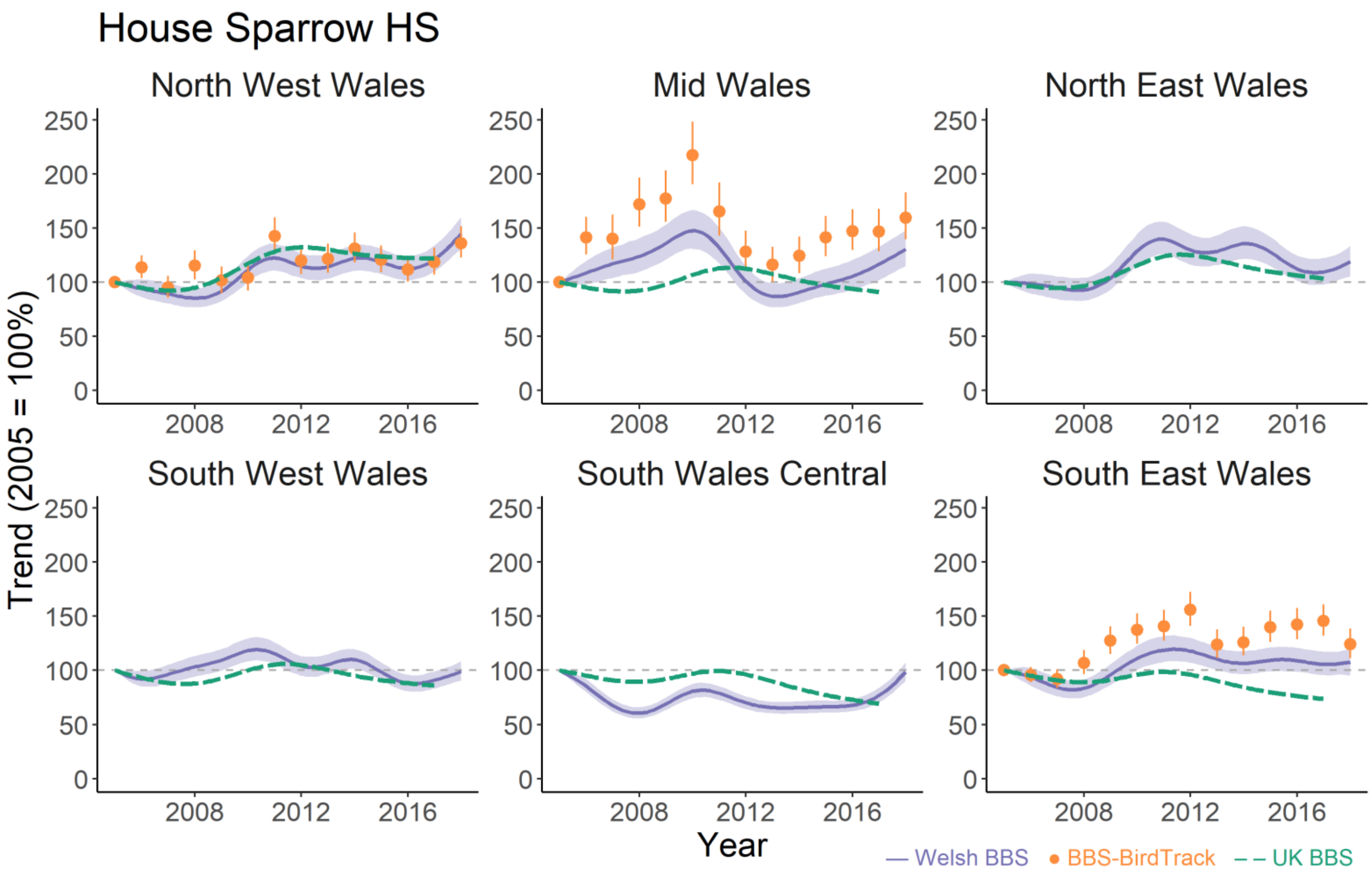

Great Spotted Woodpecker GS
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
Year
0
100
200
300
2008
2012
2016
— Welsh BBS
• BBS-BirdTrack
– – UK BBS

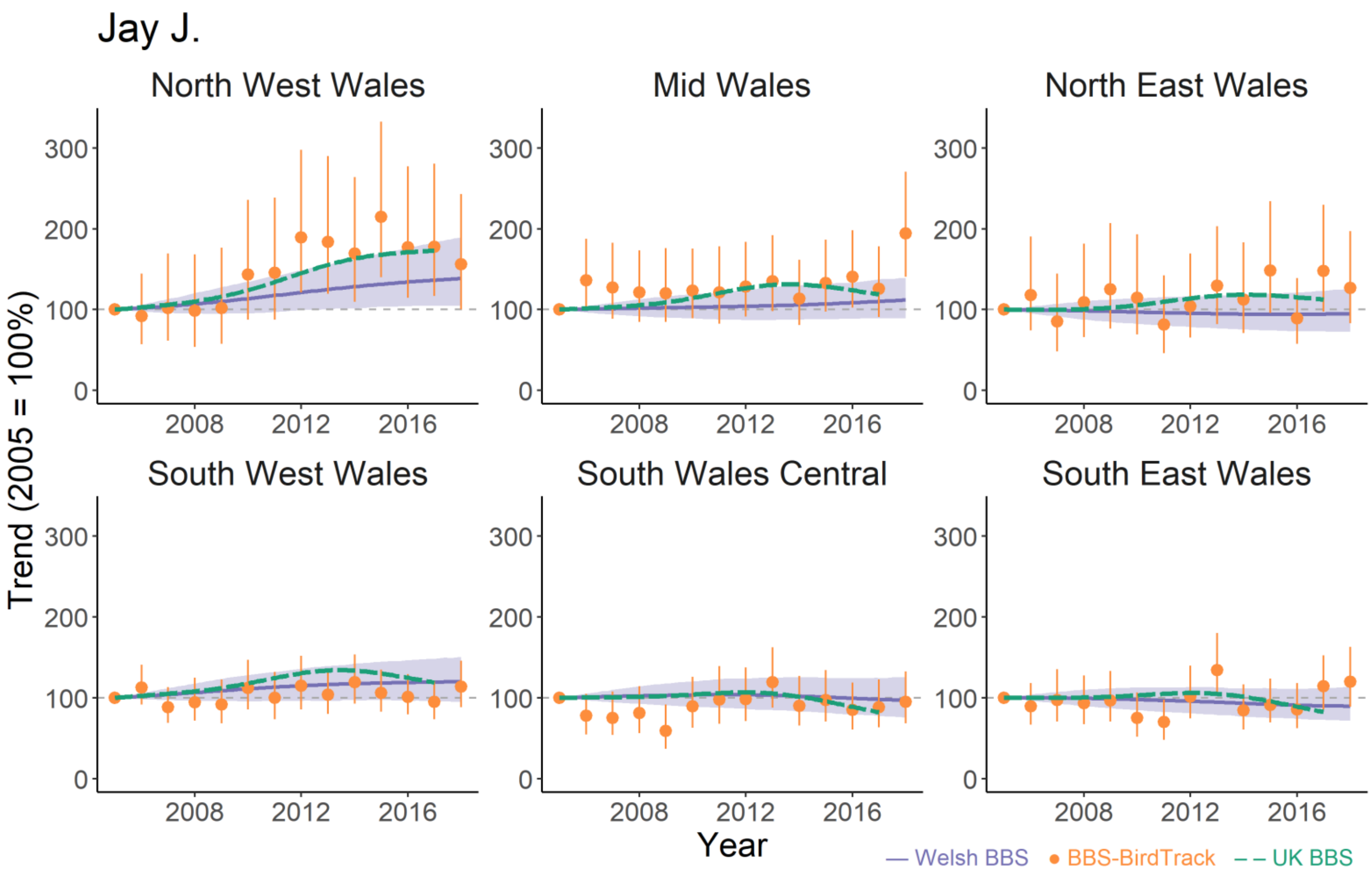

Great Tit GT
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
150
100
50
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

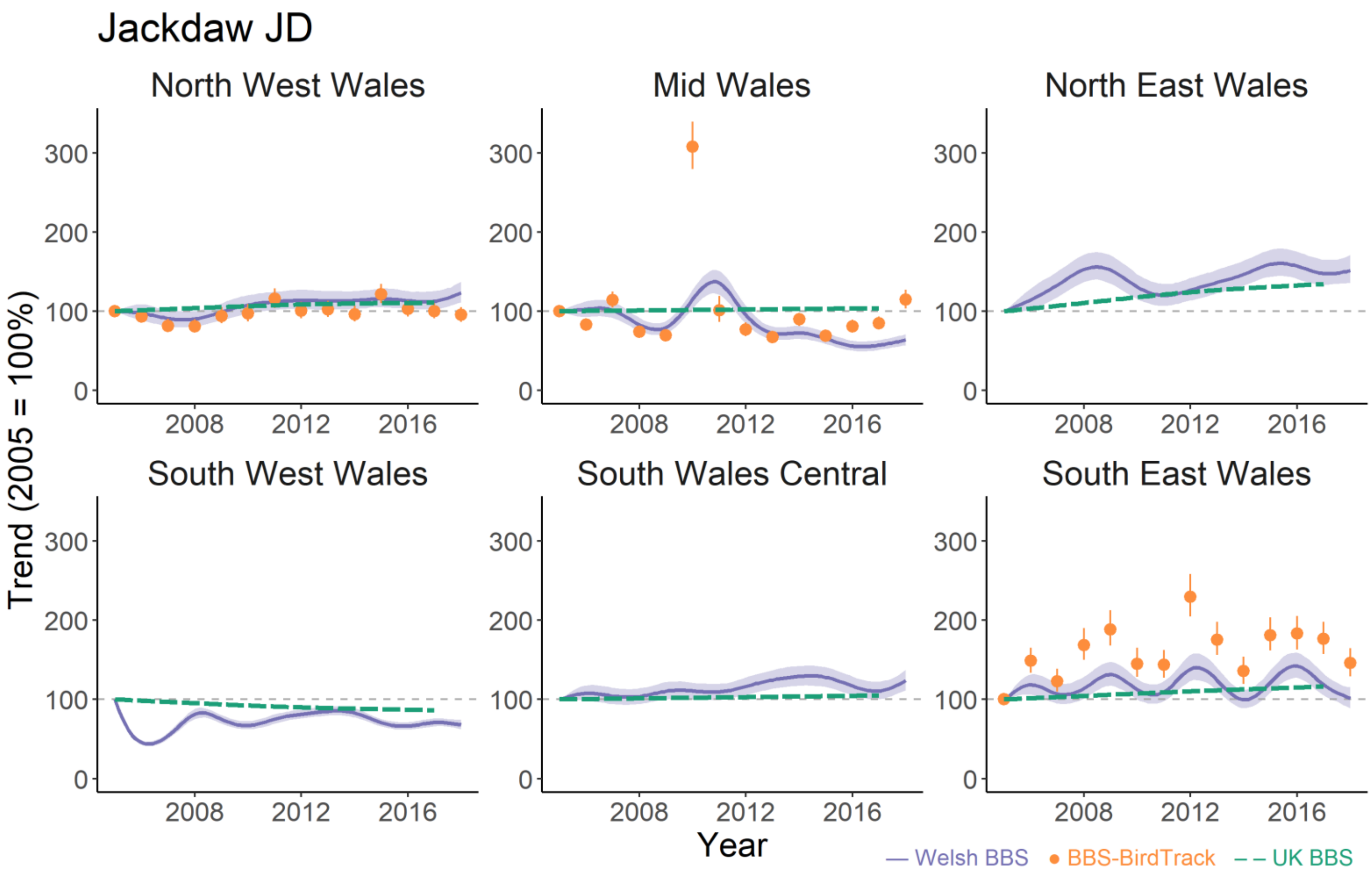

Garden Warbler GW
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
750
500
250
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

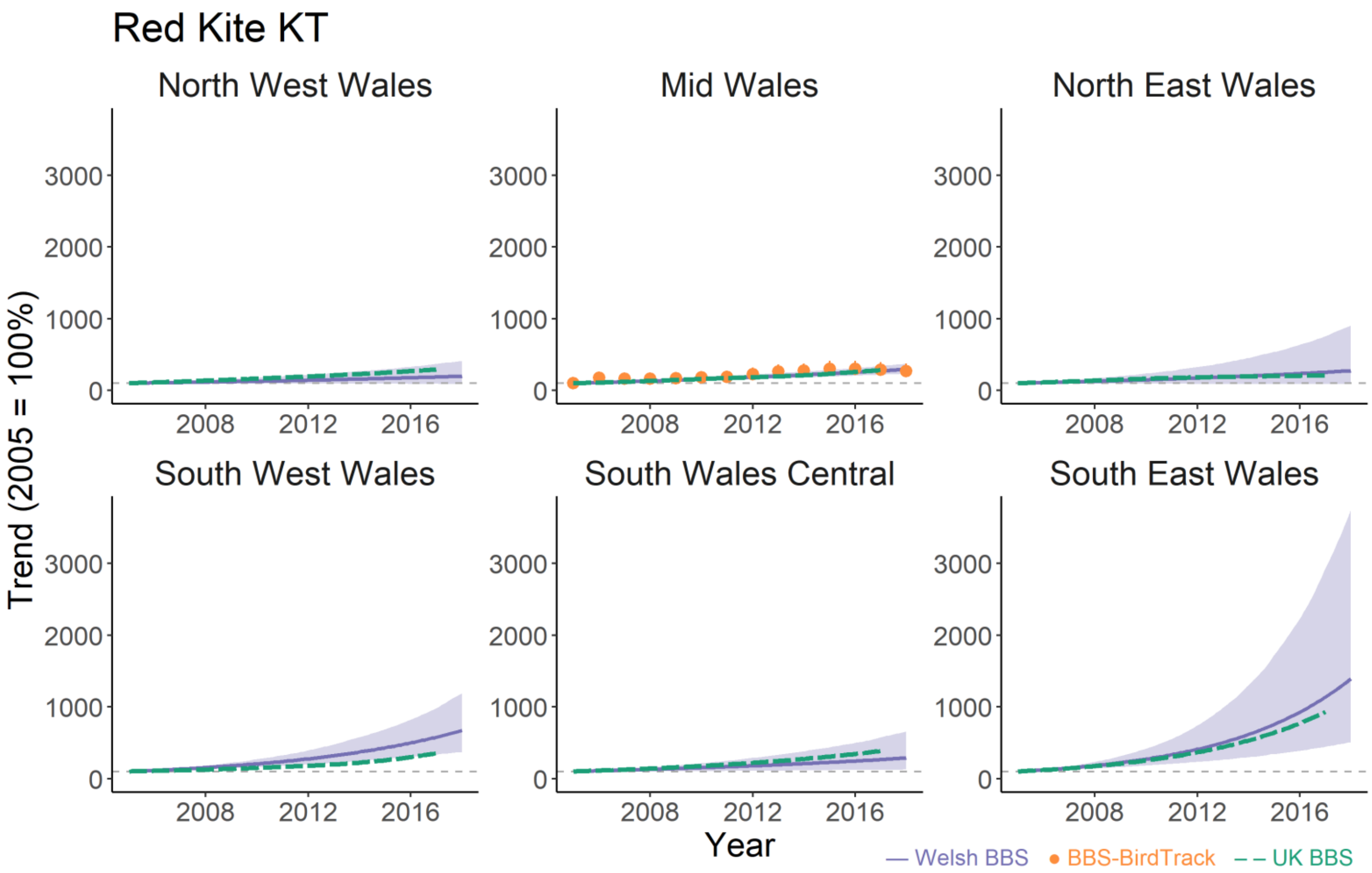

Grey Heron H.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
200
150
100
50
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

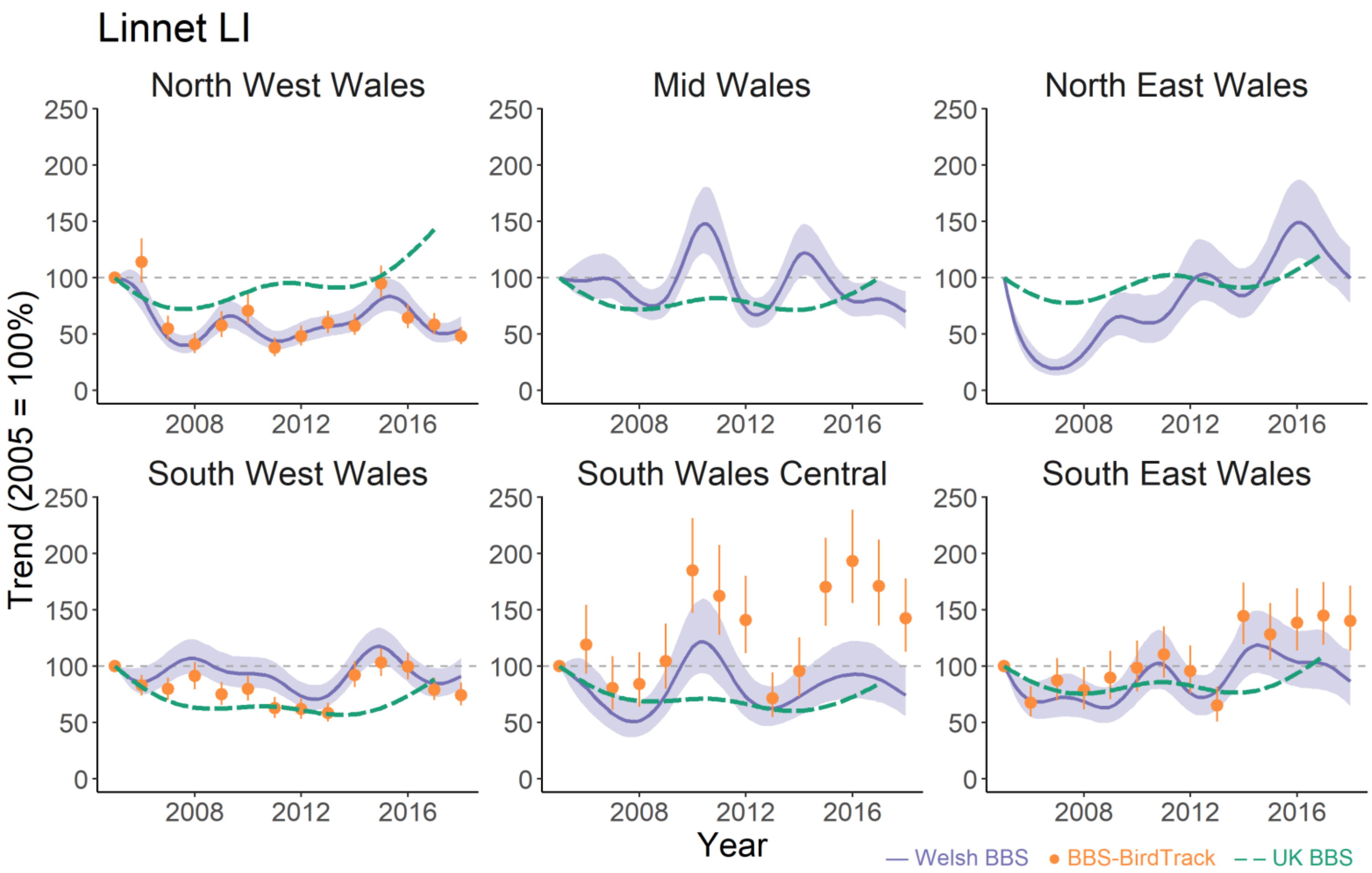

House Martin HM
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
300
200
100
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

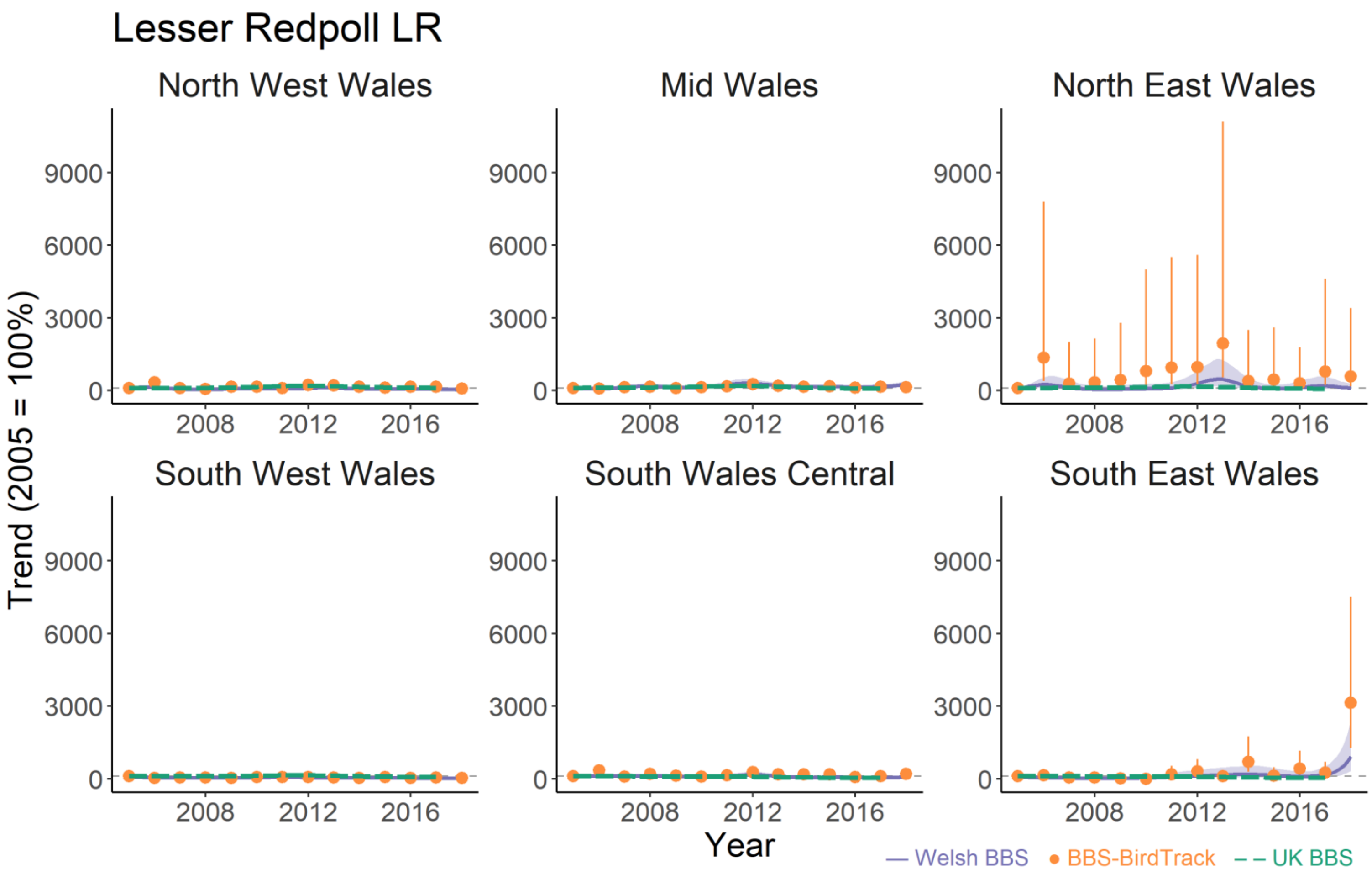

House Sparrow HS
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
50
100
150
200
250
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

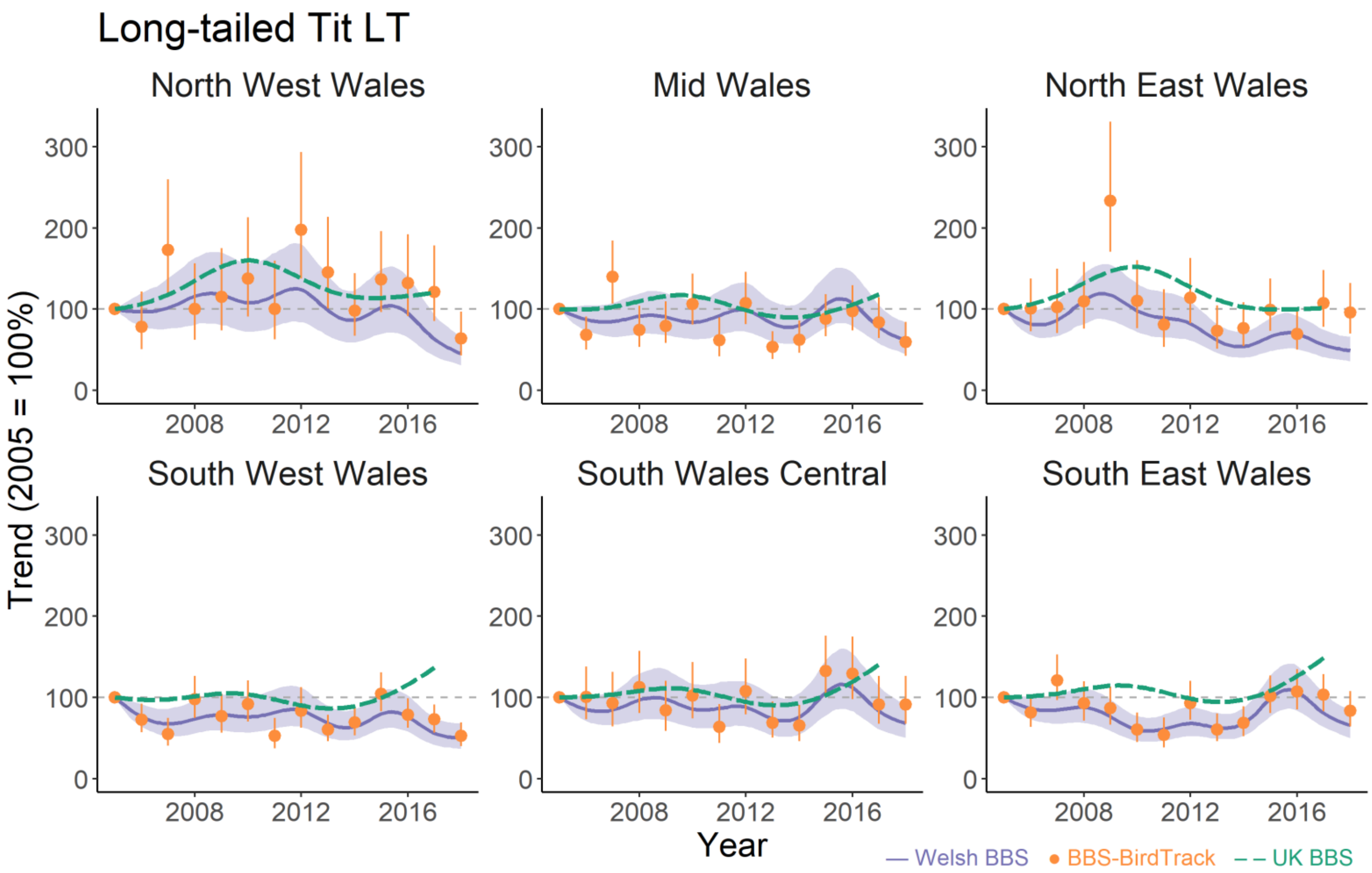

Jay J.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

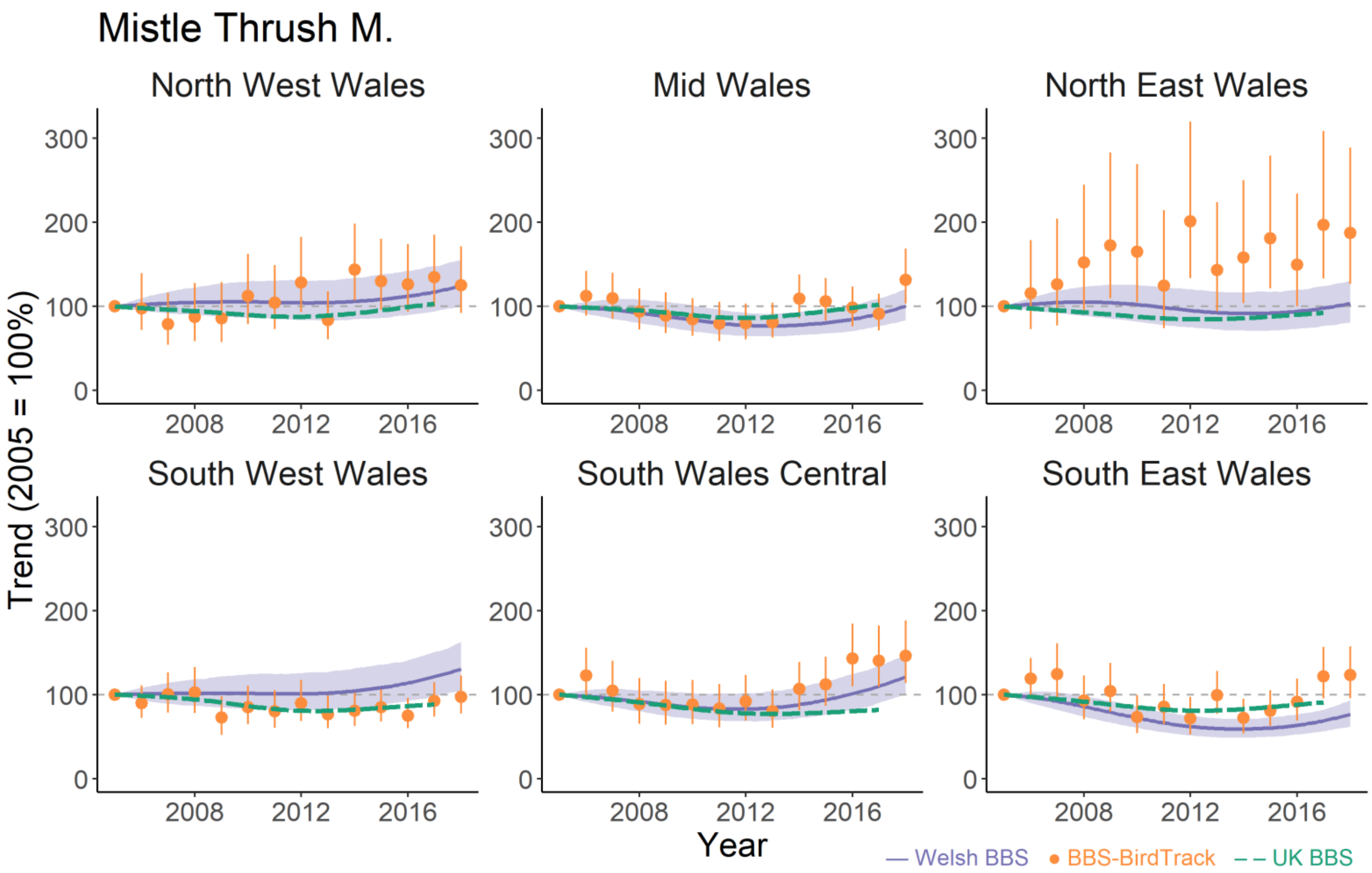

Jackdaw JD
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

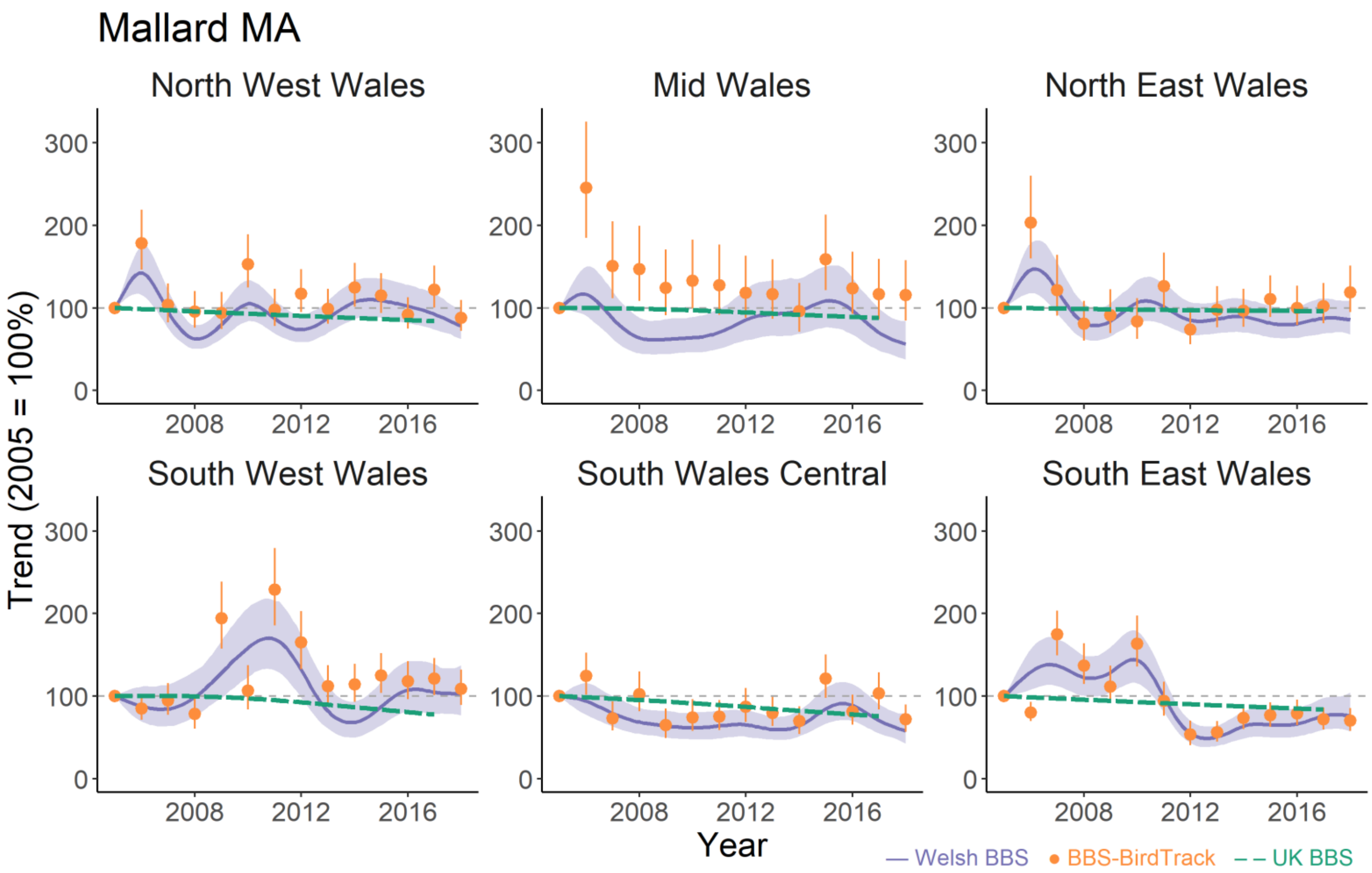

Red Kite KT
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
3000
2000
1000
0
2008
2012
2016
Year
— Welsh BBS
● BBS-BirdTrack
– – UK BBS

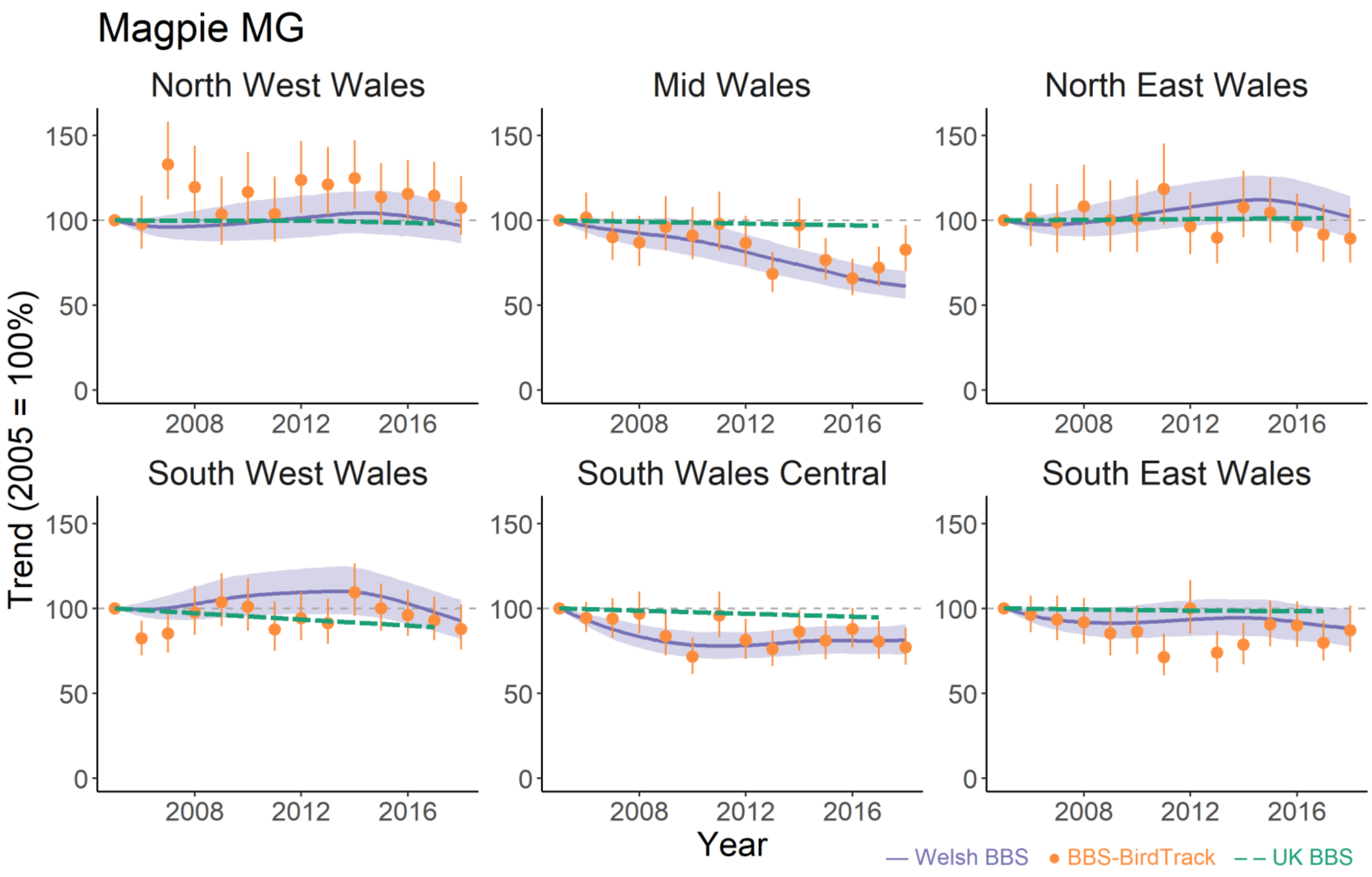

Linnet LI
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
250
200
150
100
50
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

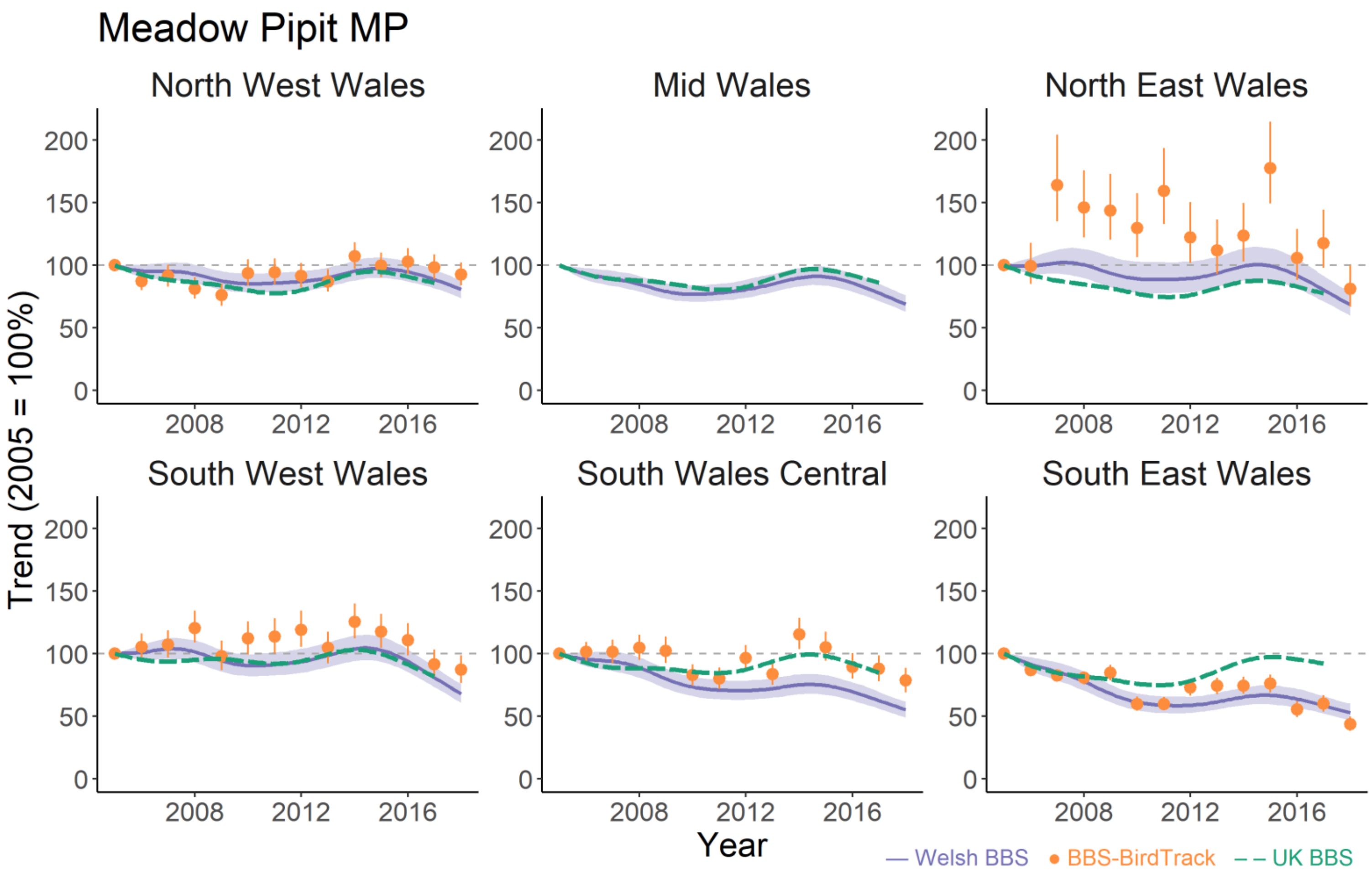

Lesser Redpoll LR
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
9000
6000
3000
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

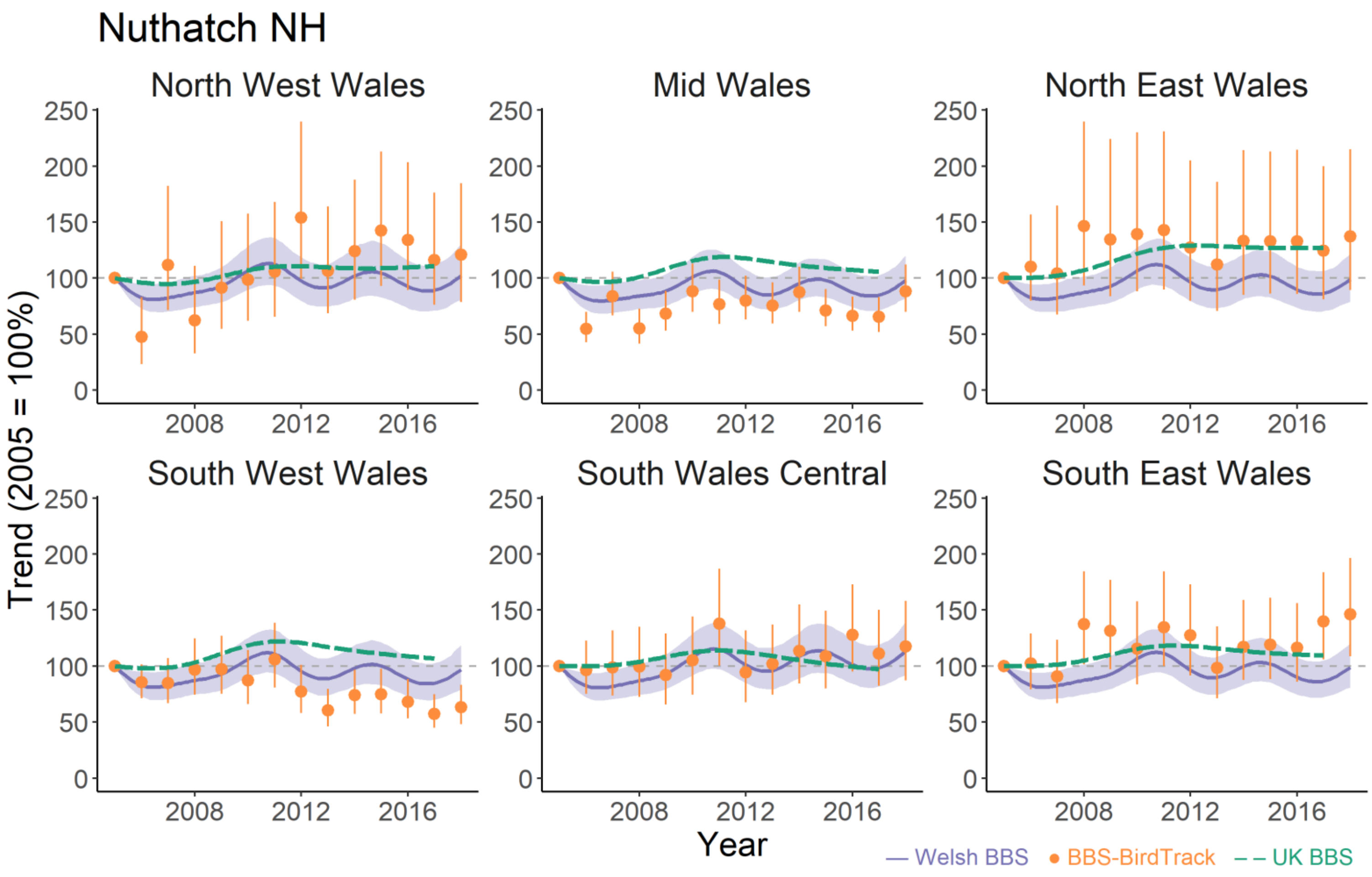

Long-tailed Tit LT
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

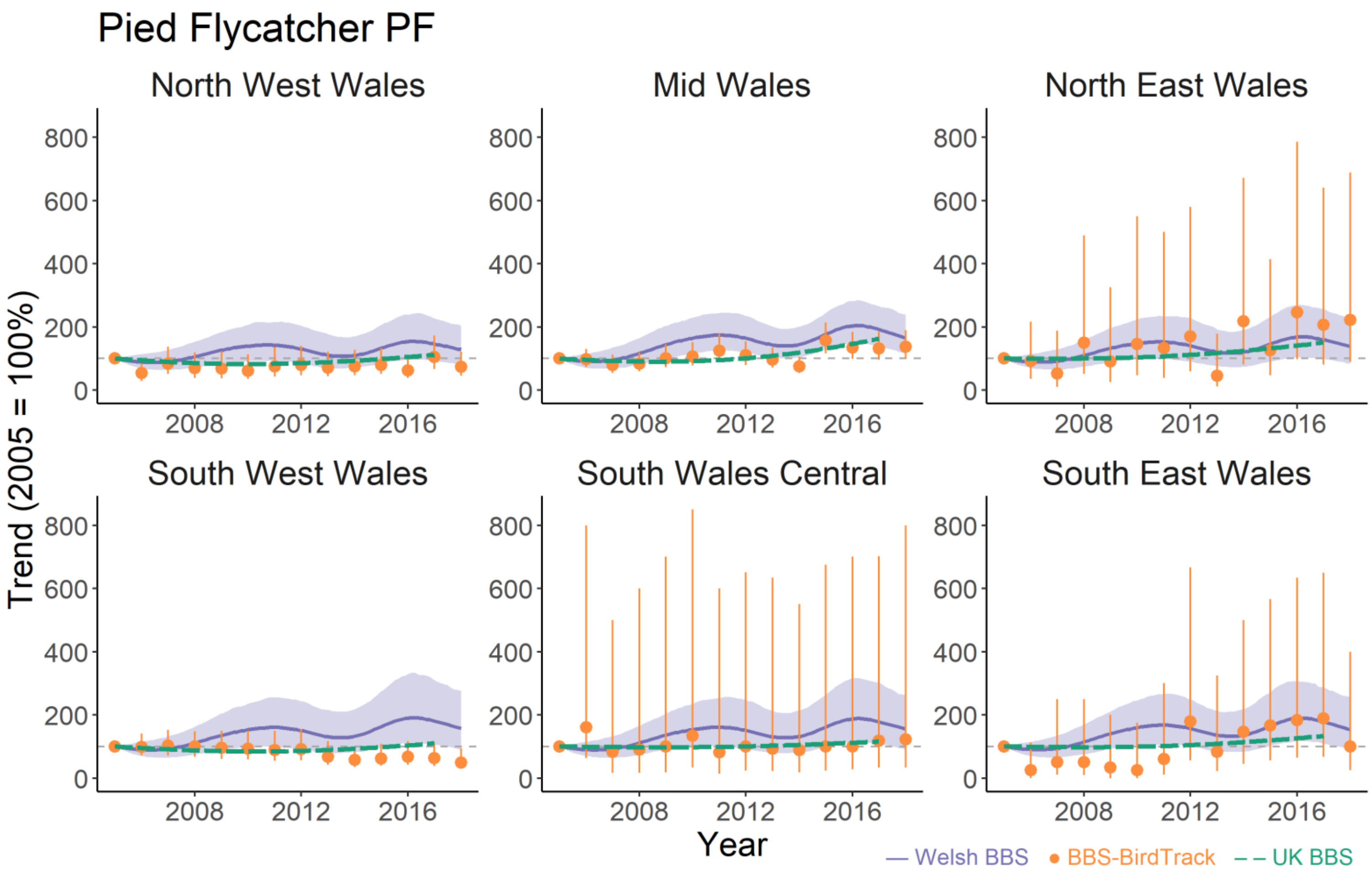

Mistle Thrush M.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

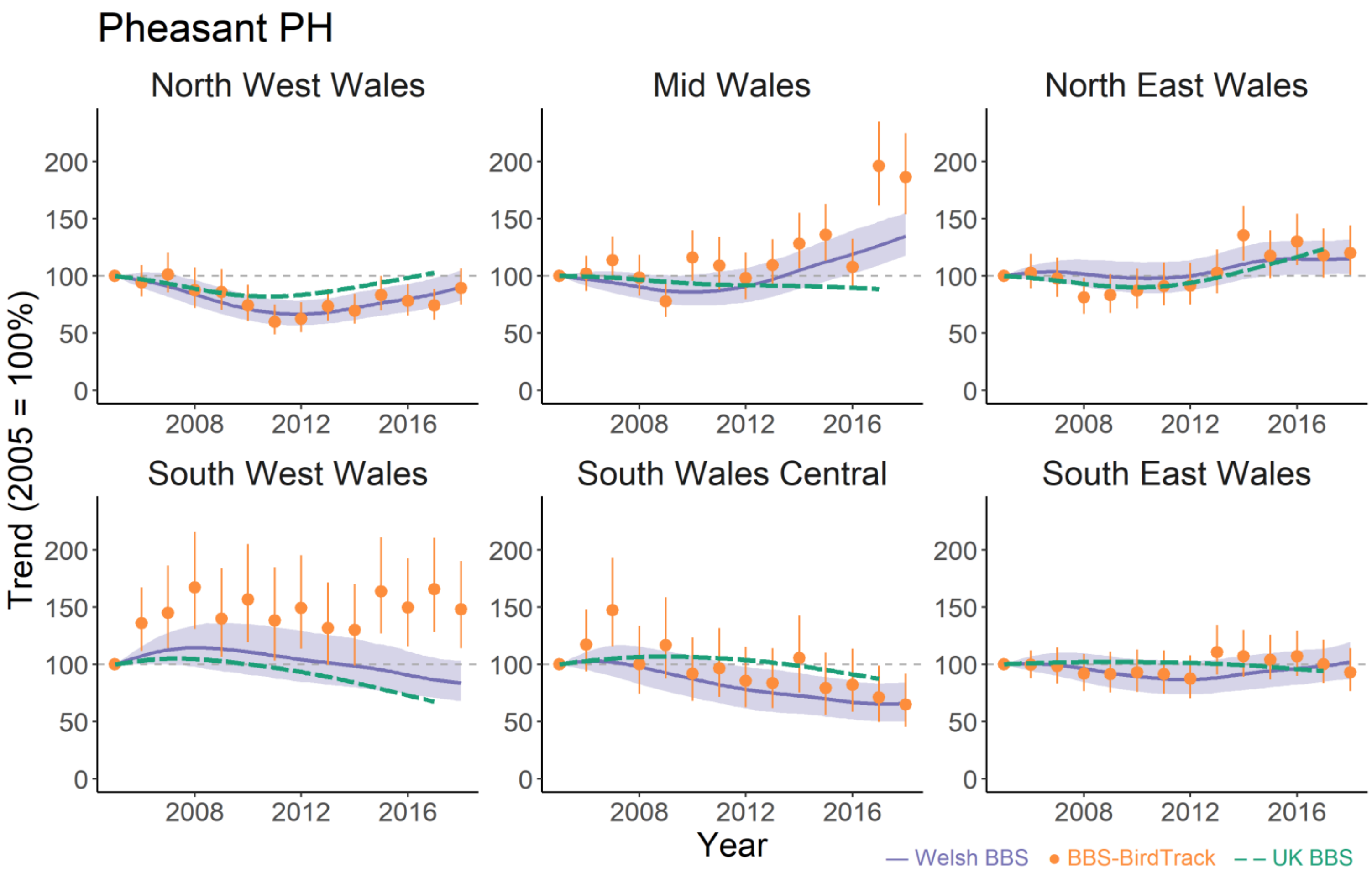

Mallard MA
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

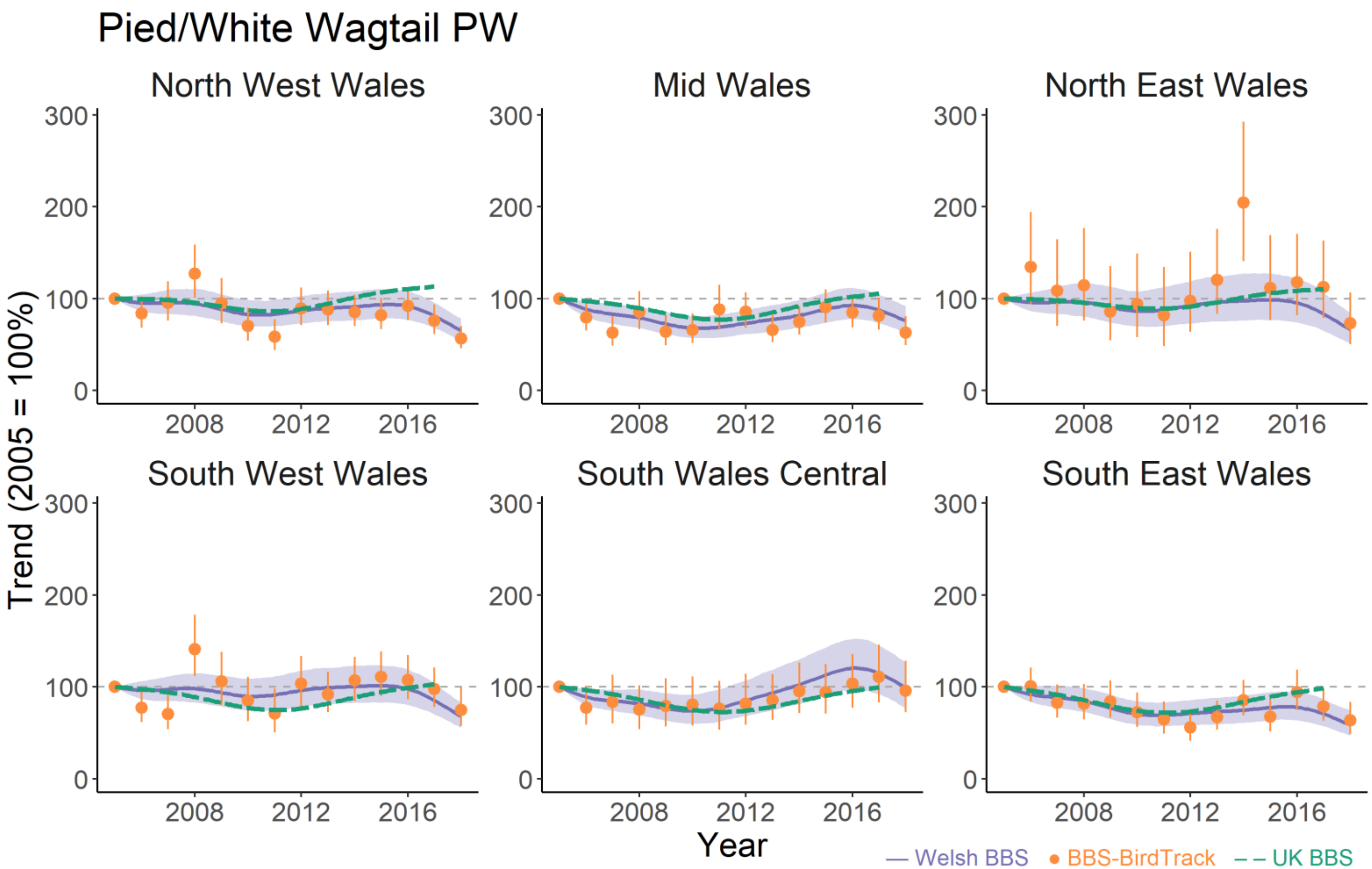

Magpie MG
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
Year
0
50
100
150
2008
2012
2016
— Welsh BBS
● BBS-BirdTrack
– – UK BBS

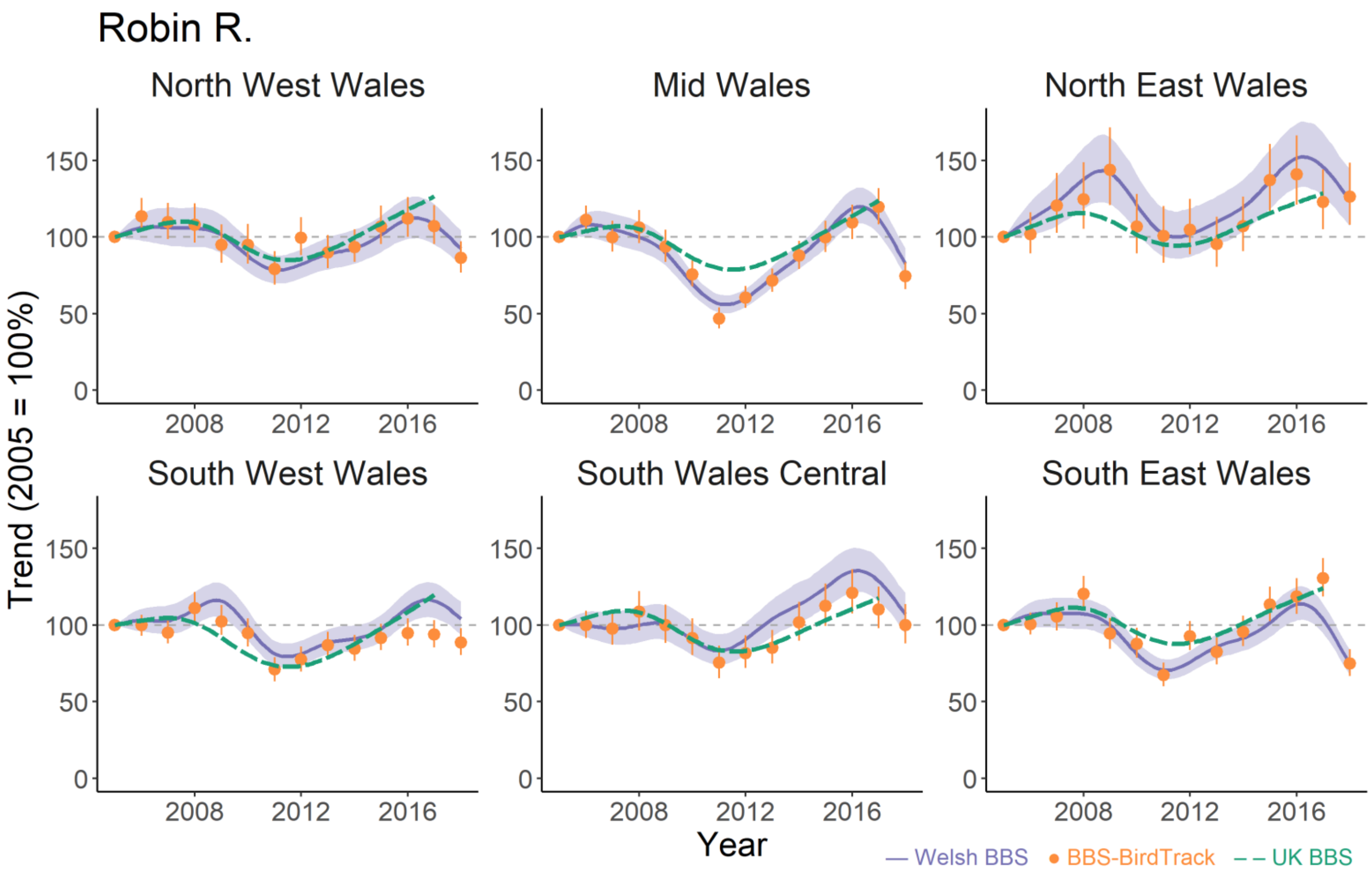

Meadow Pipit MP
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
50
100
150
200
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

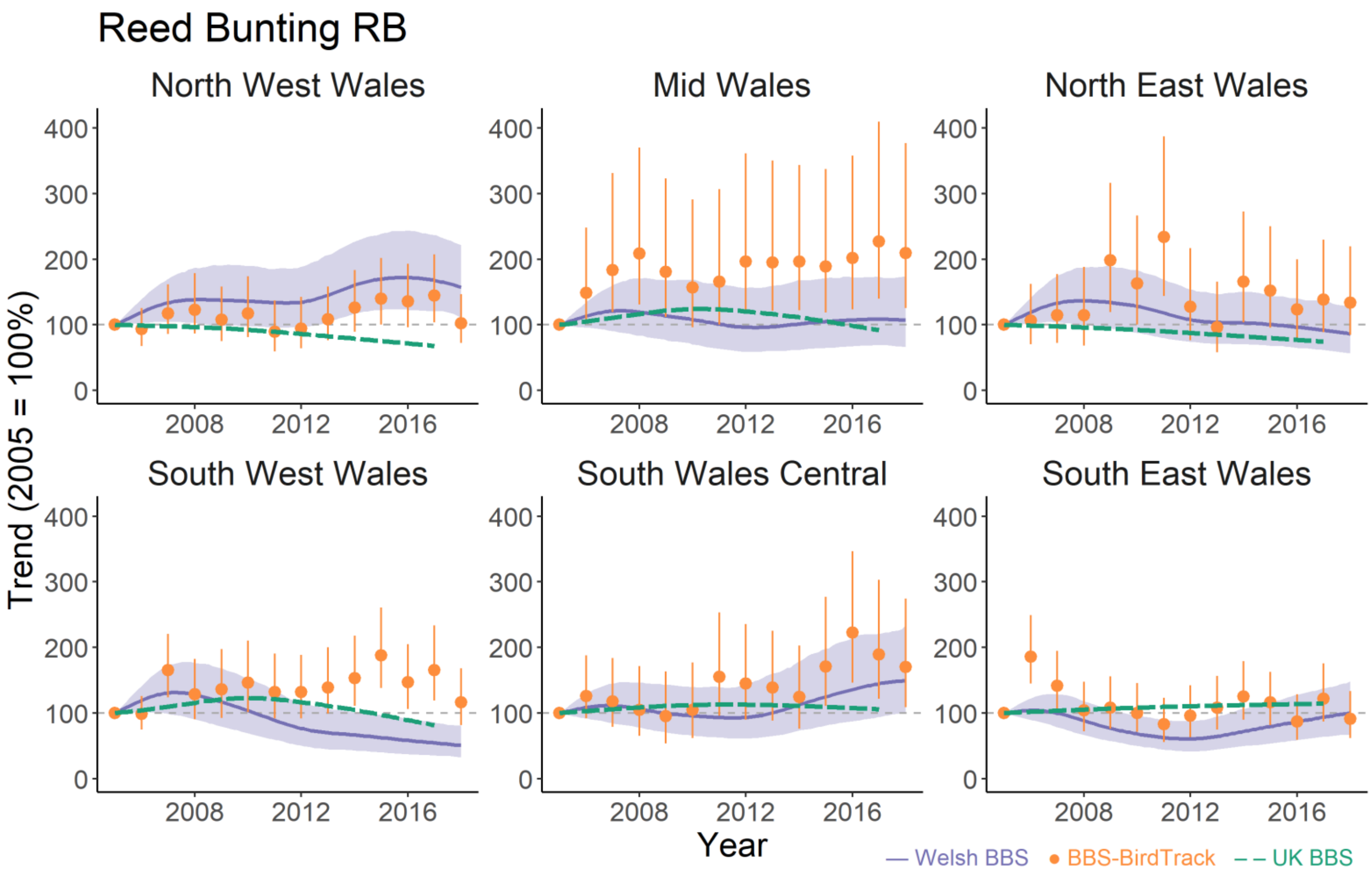

Nuthatch NH
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
50
100
150
200
250
2008
2012
2016
Year
— Welsh BBS
● BBS-BirdTrack
– – UK BBS

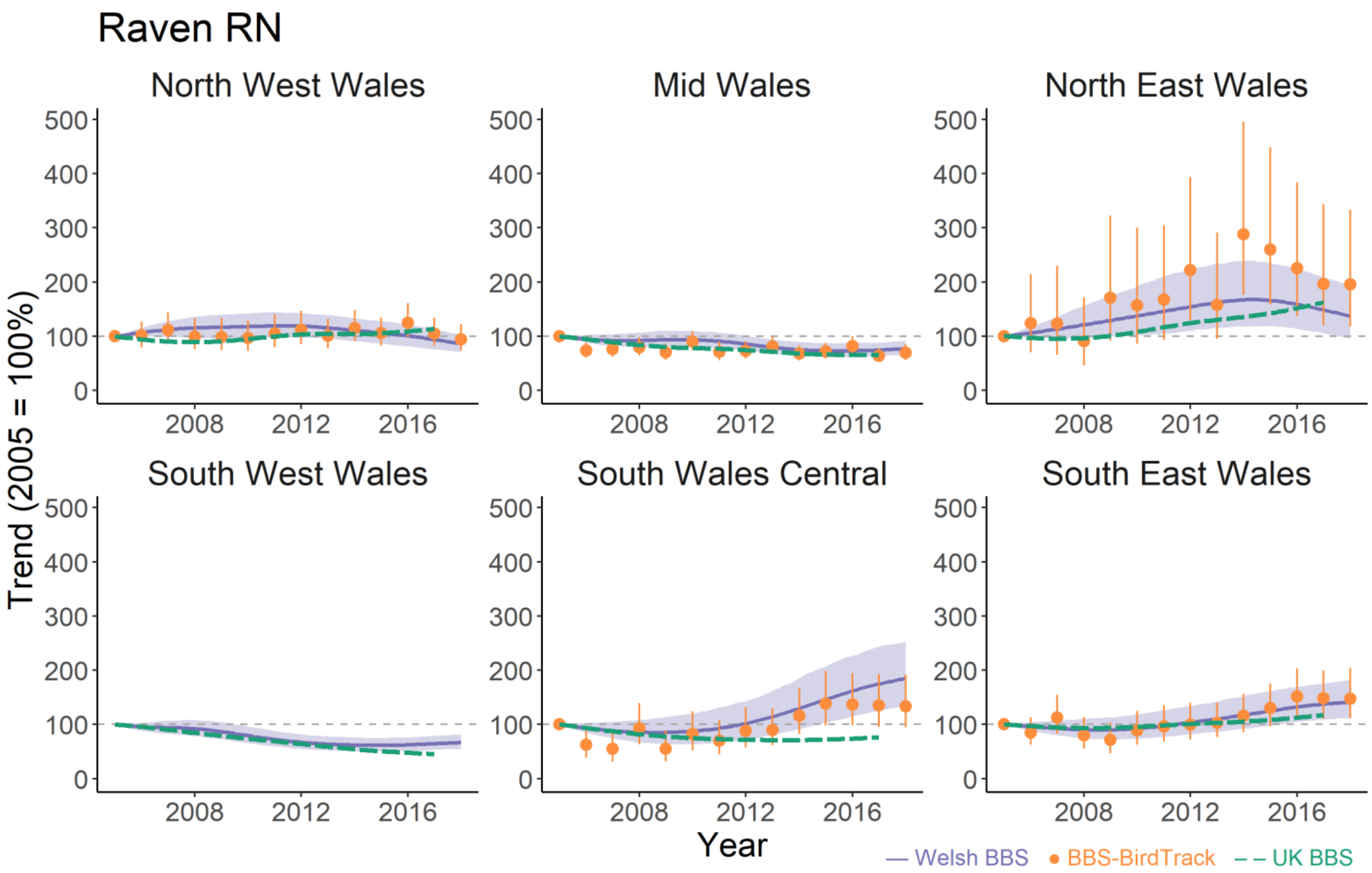

Pied Flycatcher PF
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
800
600
400
200
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

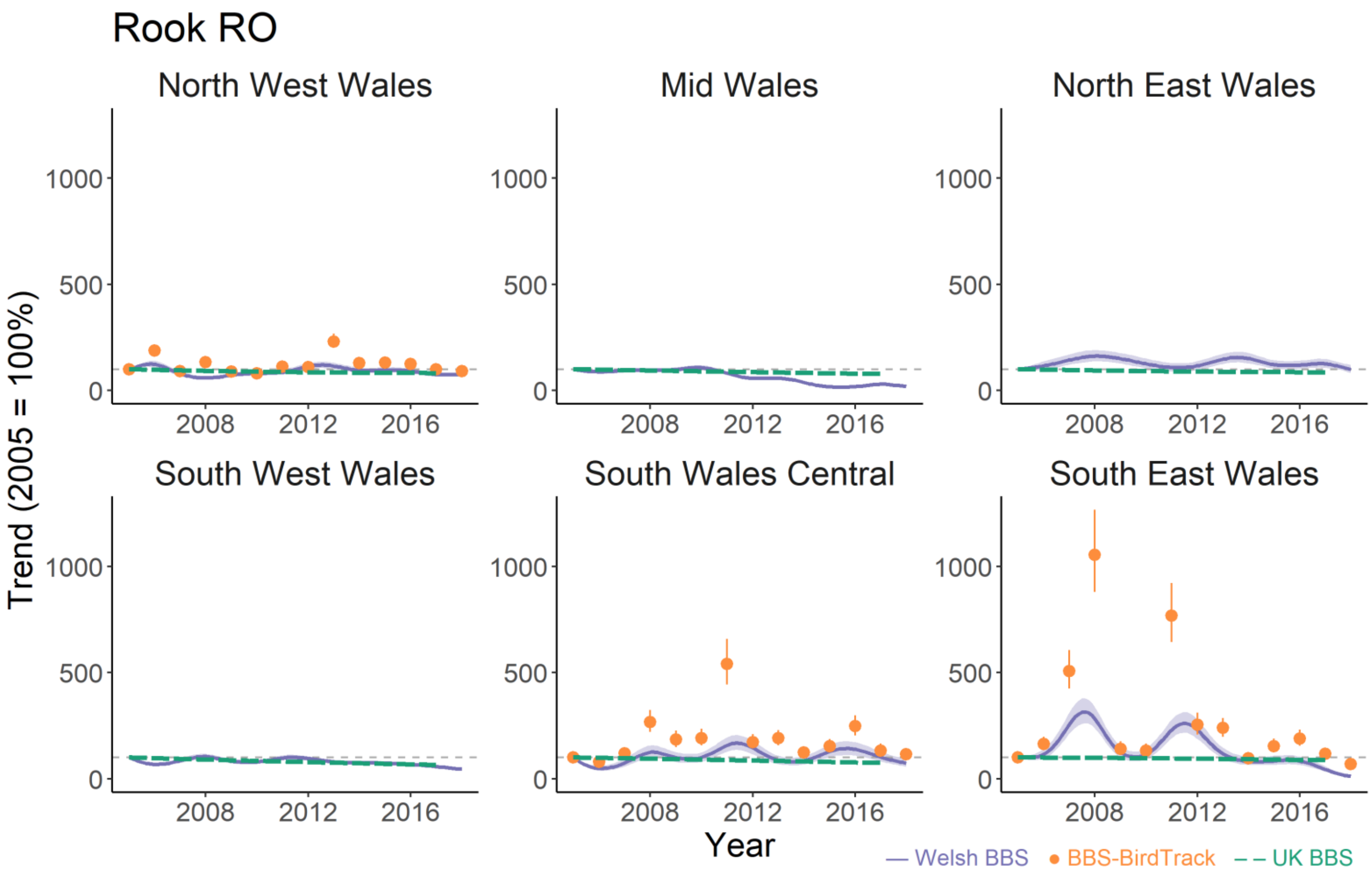

Pheasant PH
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
50
100
150
200
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS


Pied/White Wagtail PW
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

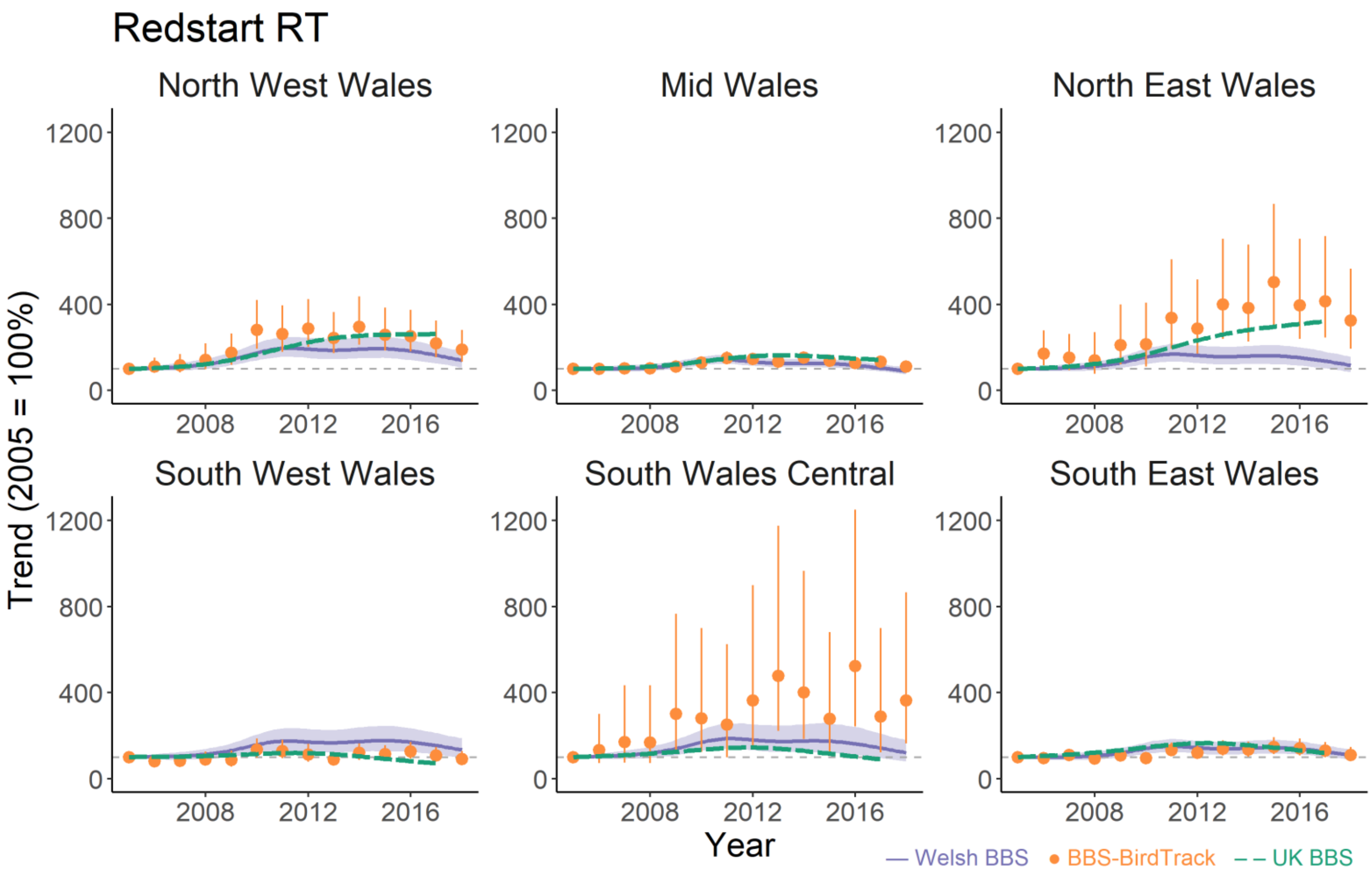

Robin R.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
150
100
50
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

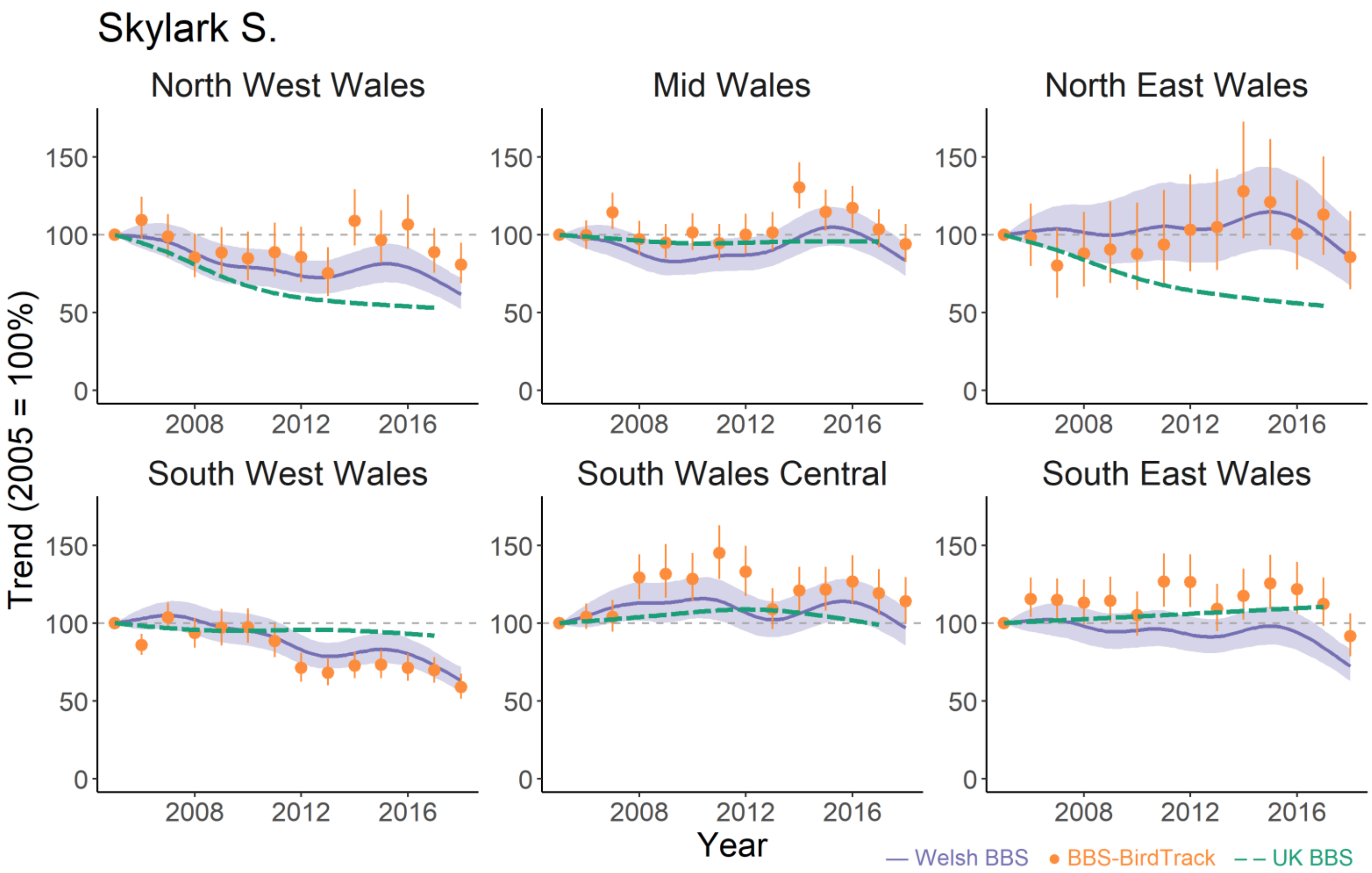

Reed Bunting RB
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
400
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

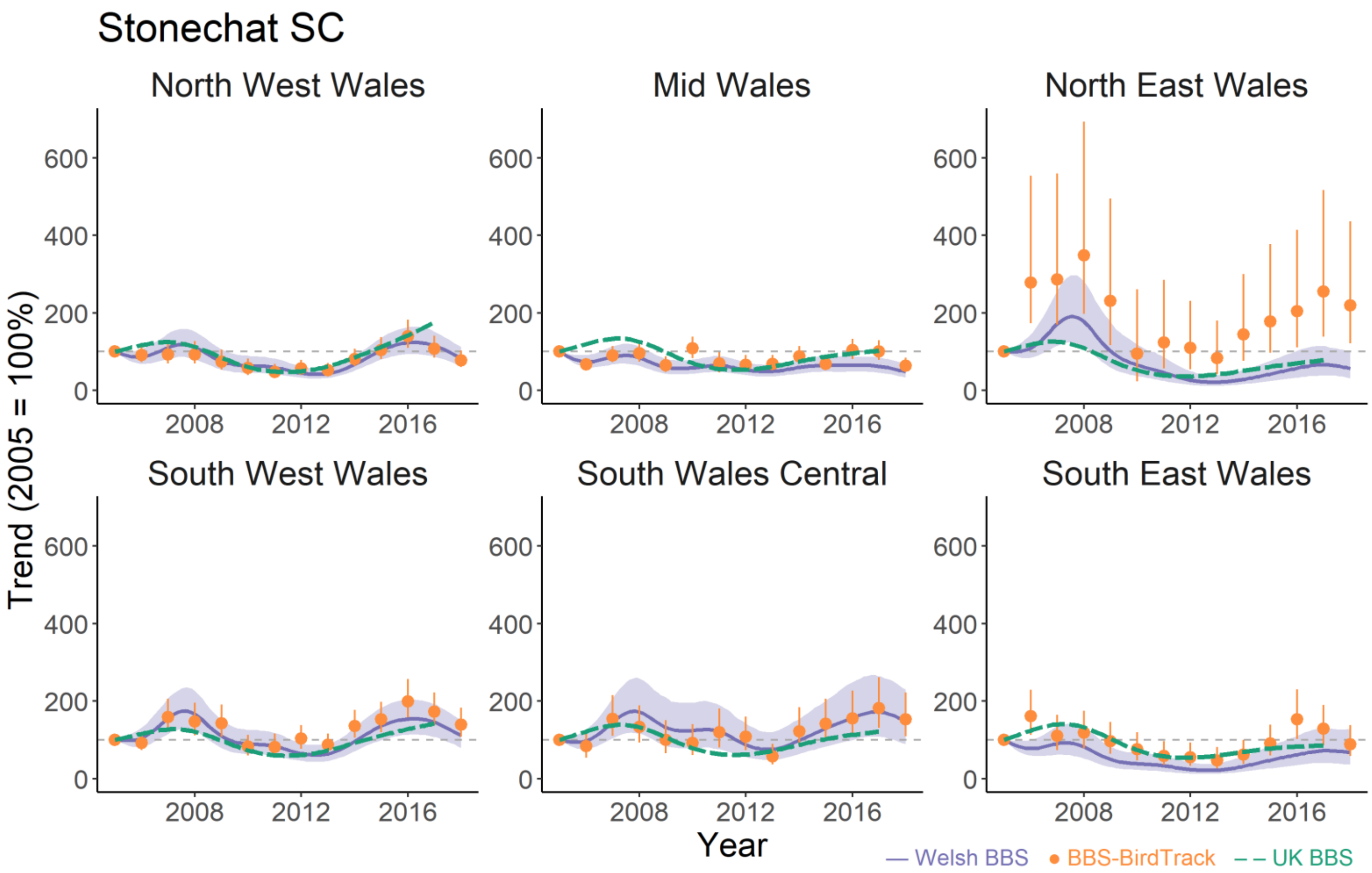

Raven RN
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
400
500
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

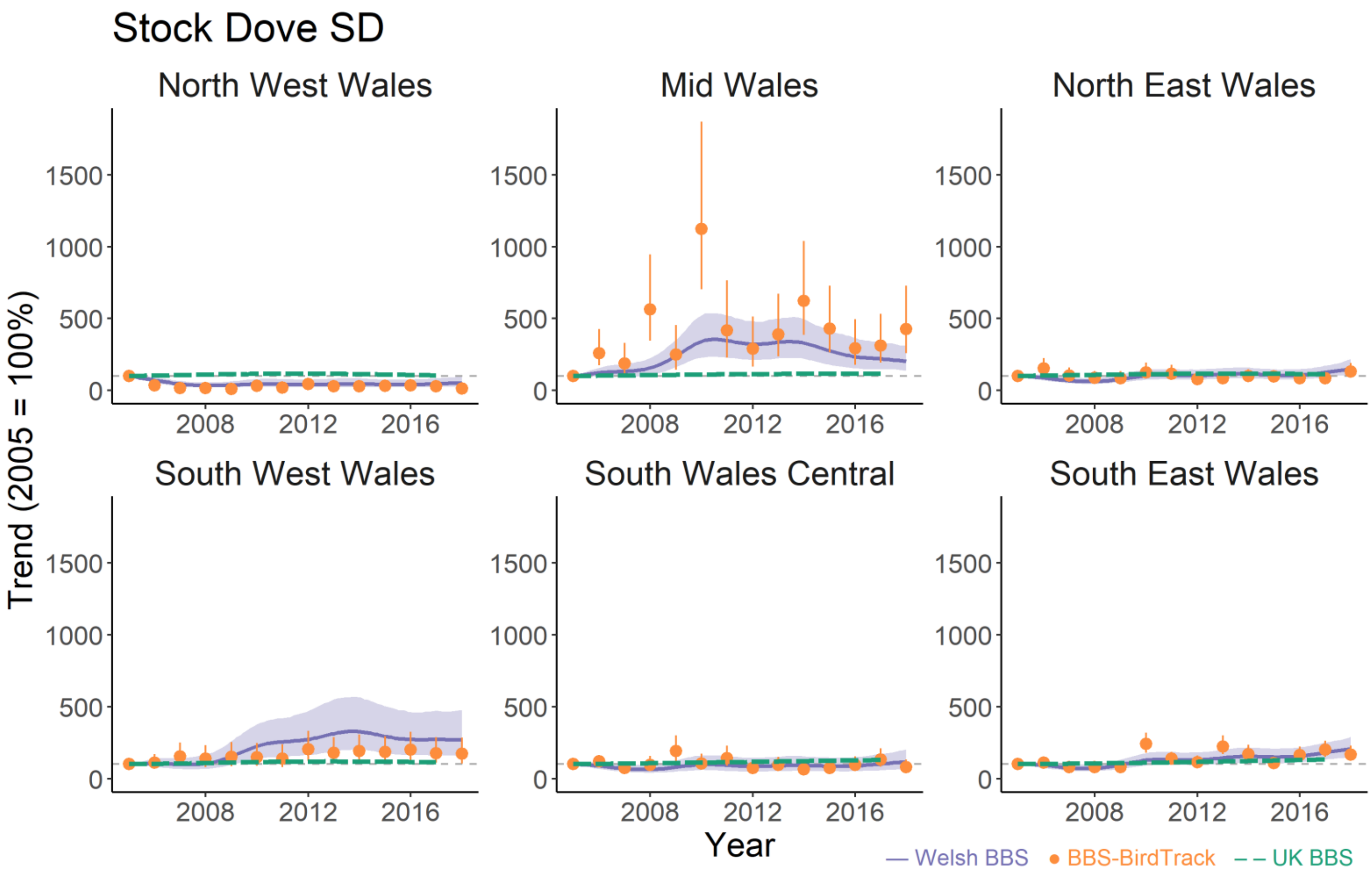


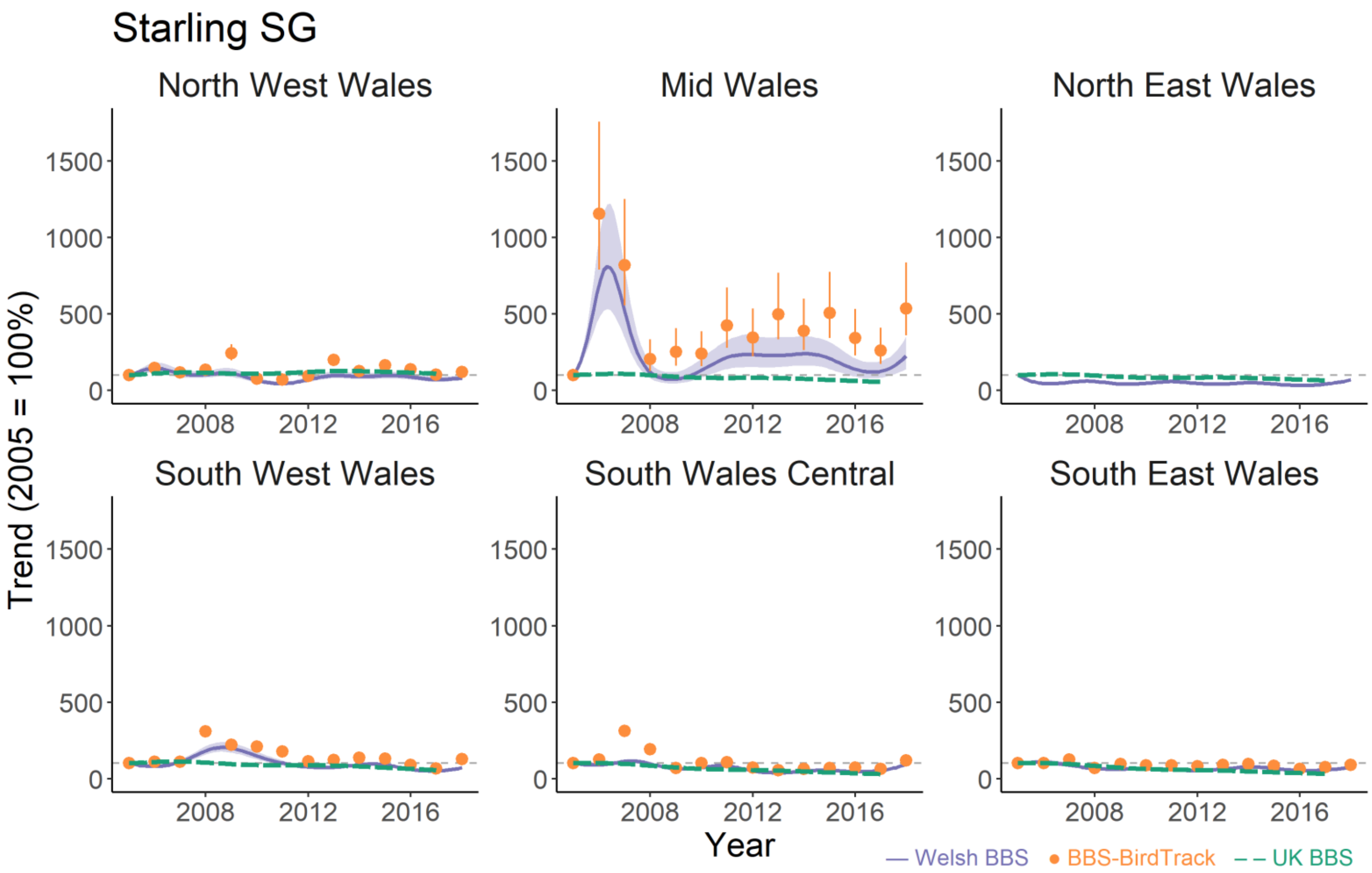
Rook RO
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
1000
500
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

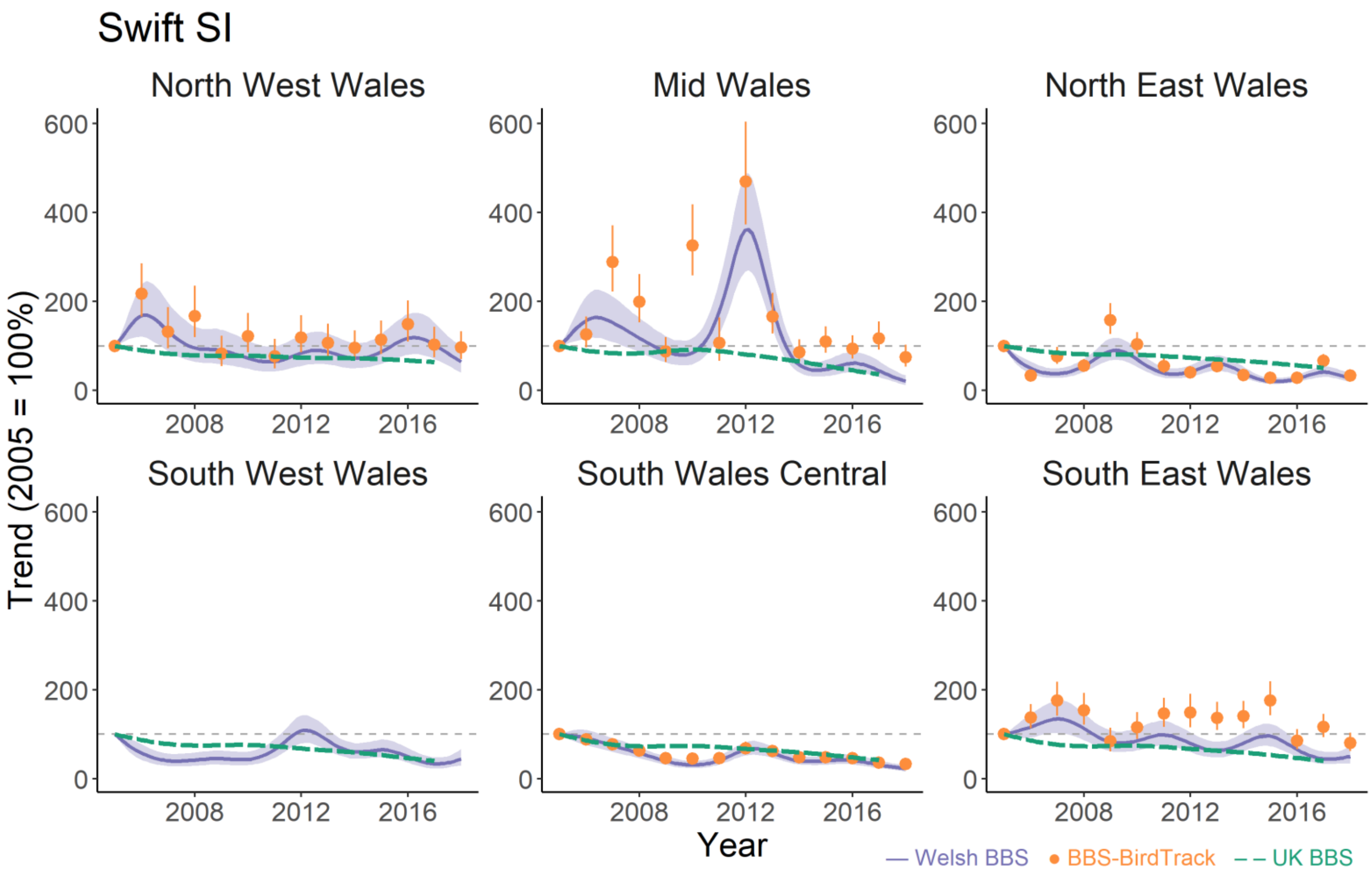

Redstart RT
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
1200
800
400
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

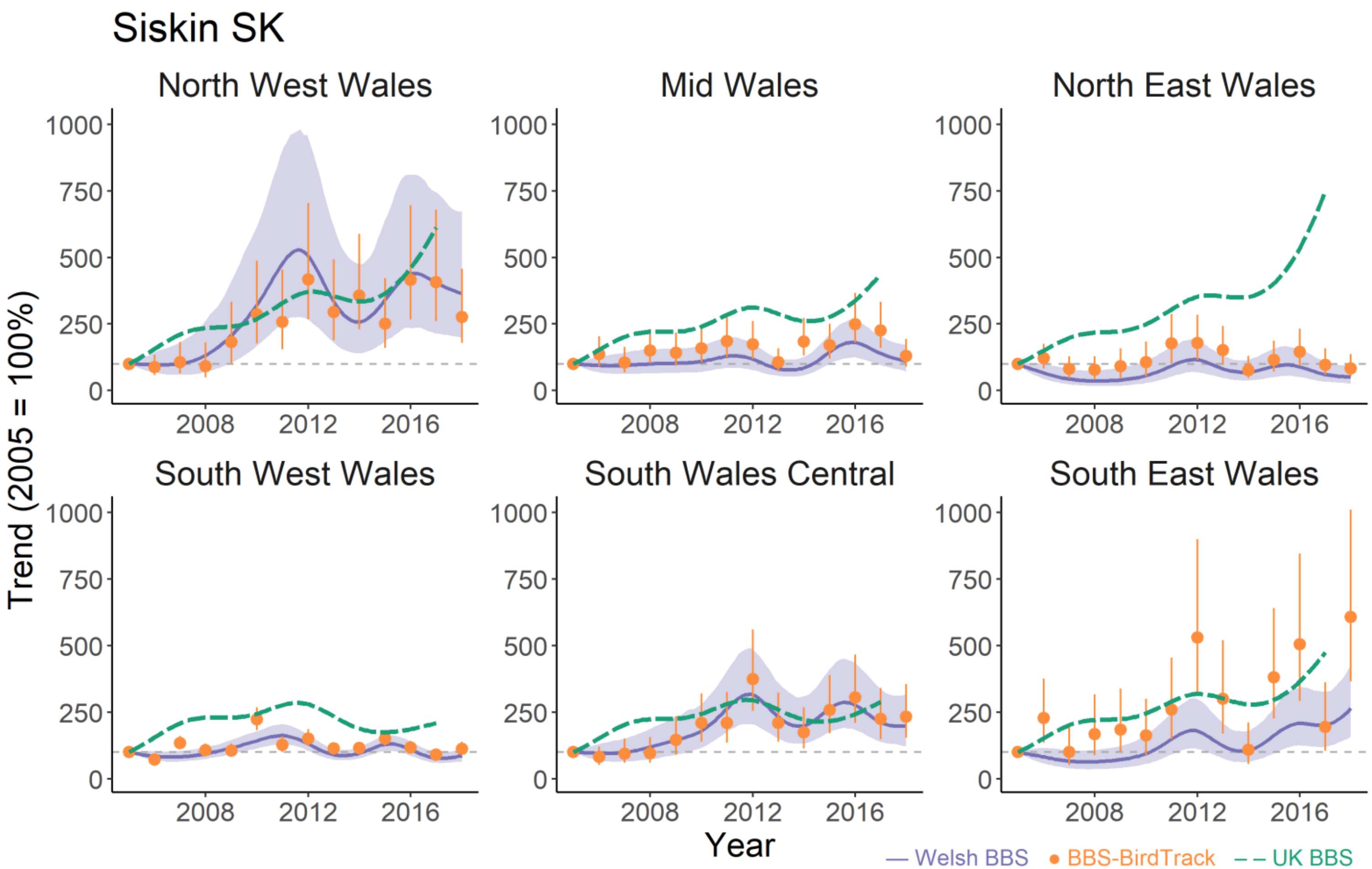

Skylark S.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
150
100
50
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

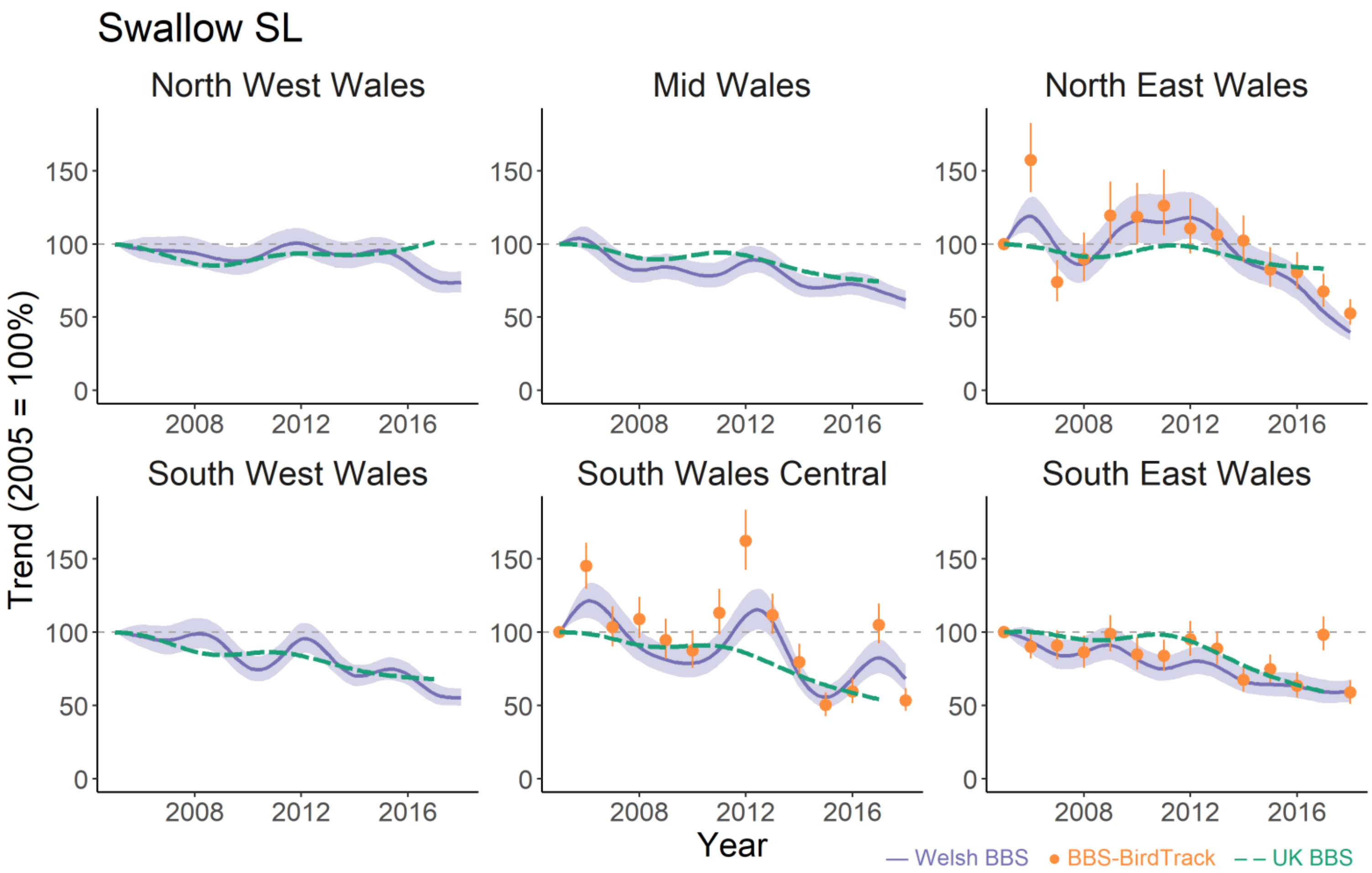

Stonechat SC
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
200
400
600
2008
2012
2016
Year
— Welsh BBS
● BBS-BirdTrack
– – UK BBS

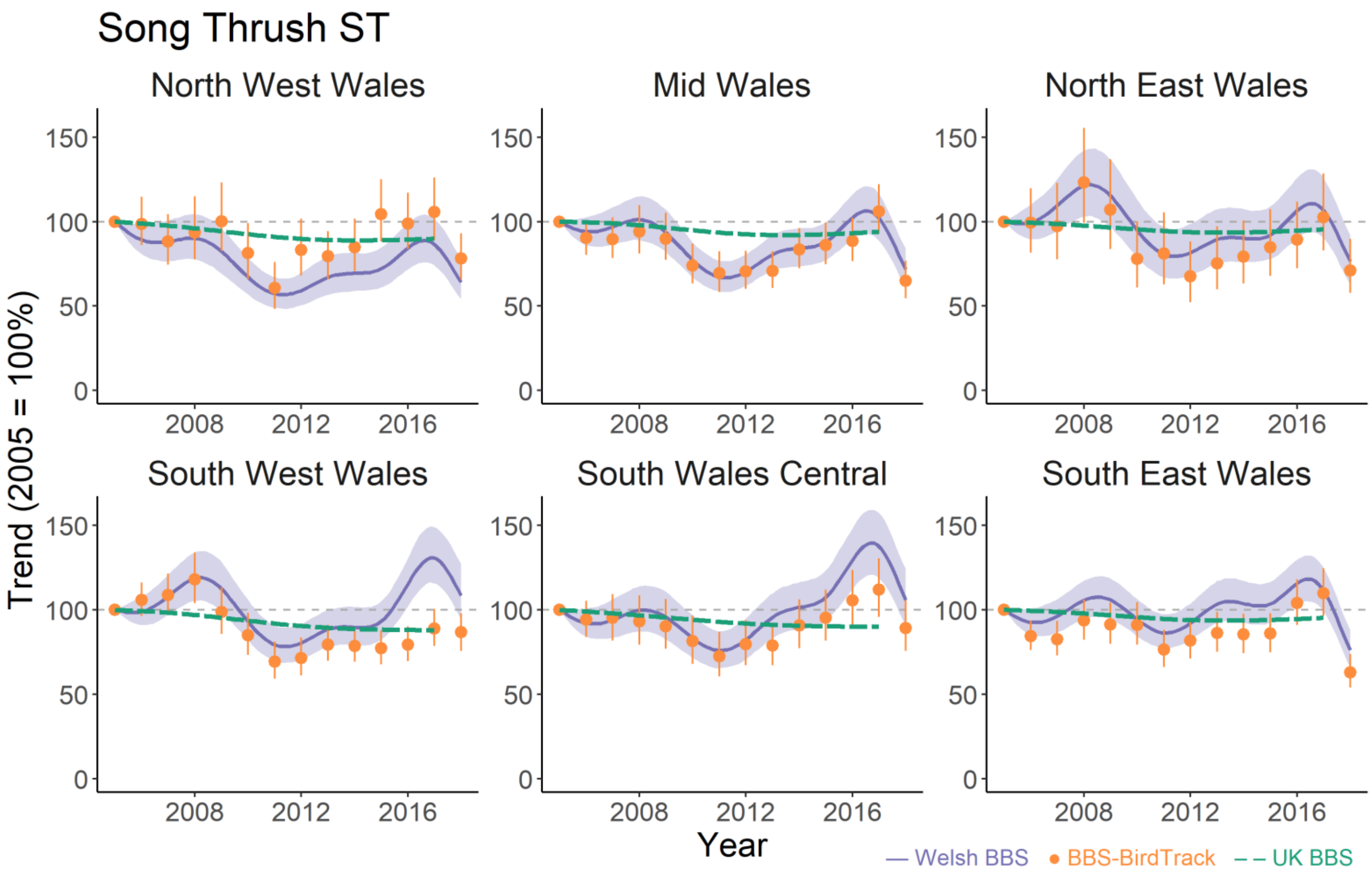

Stock Dove SD
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
500
1000
1500
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

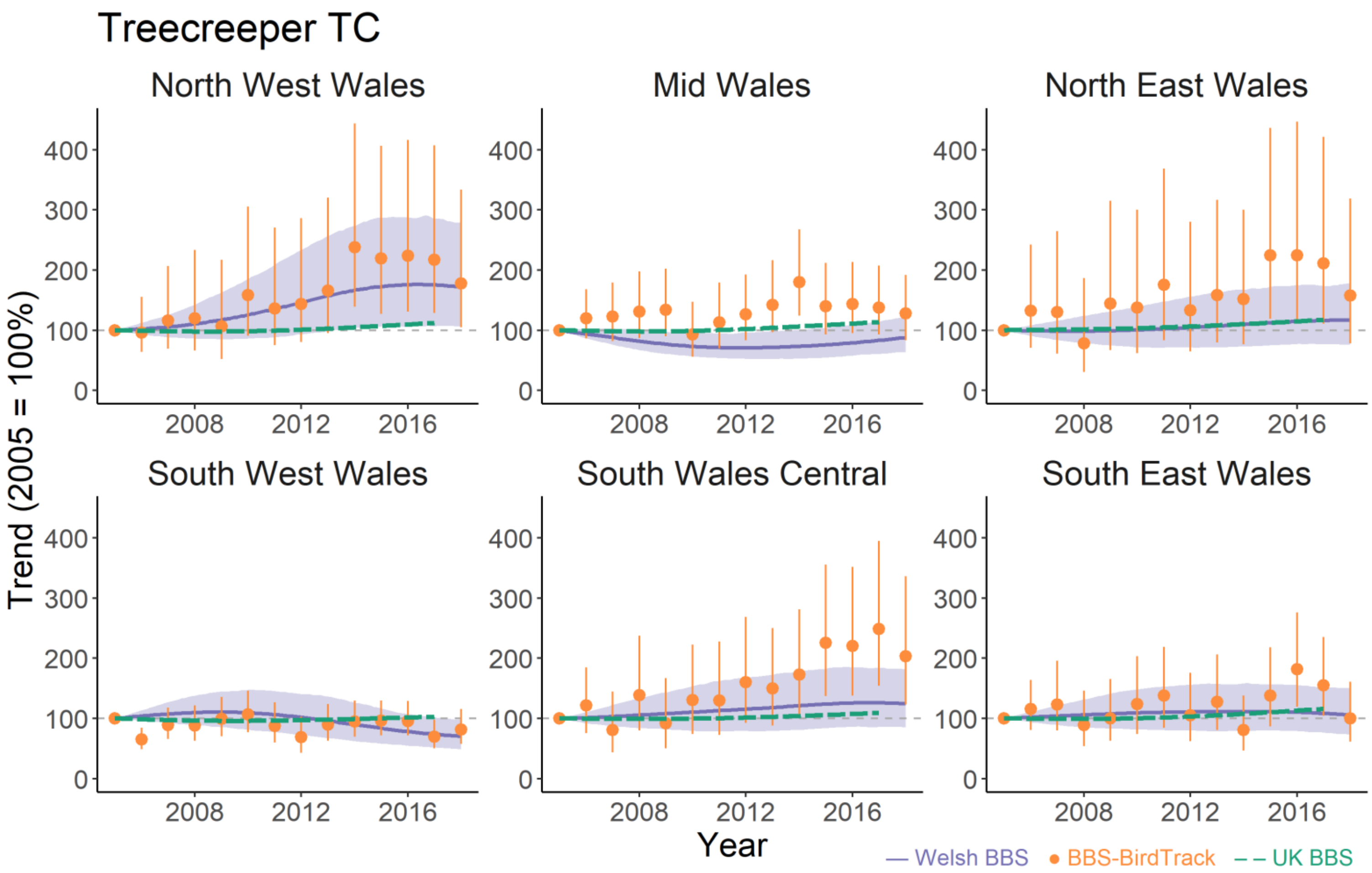

Starling SG
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
1500
1000
500
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

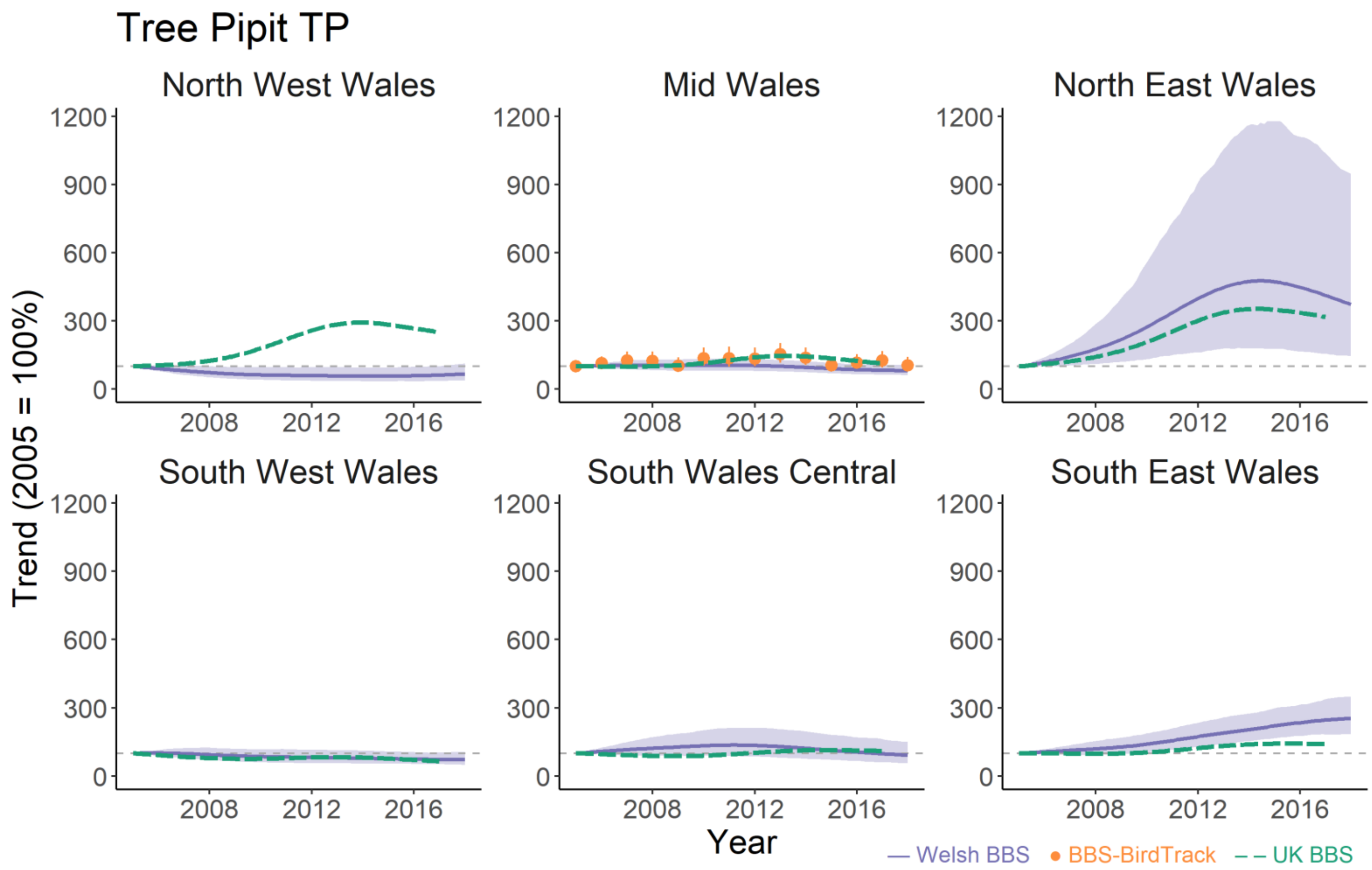

Swift SI
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
600
400
200
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

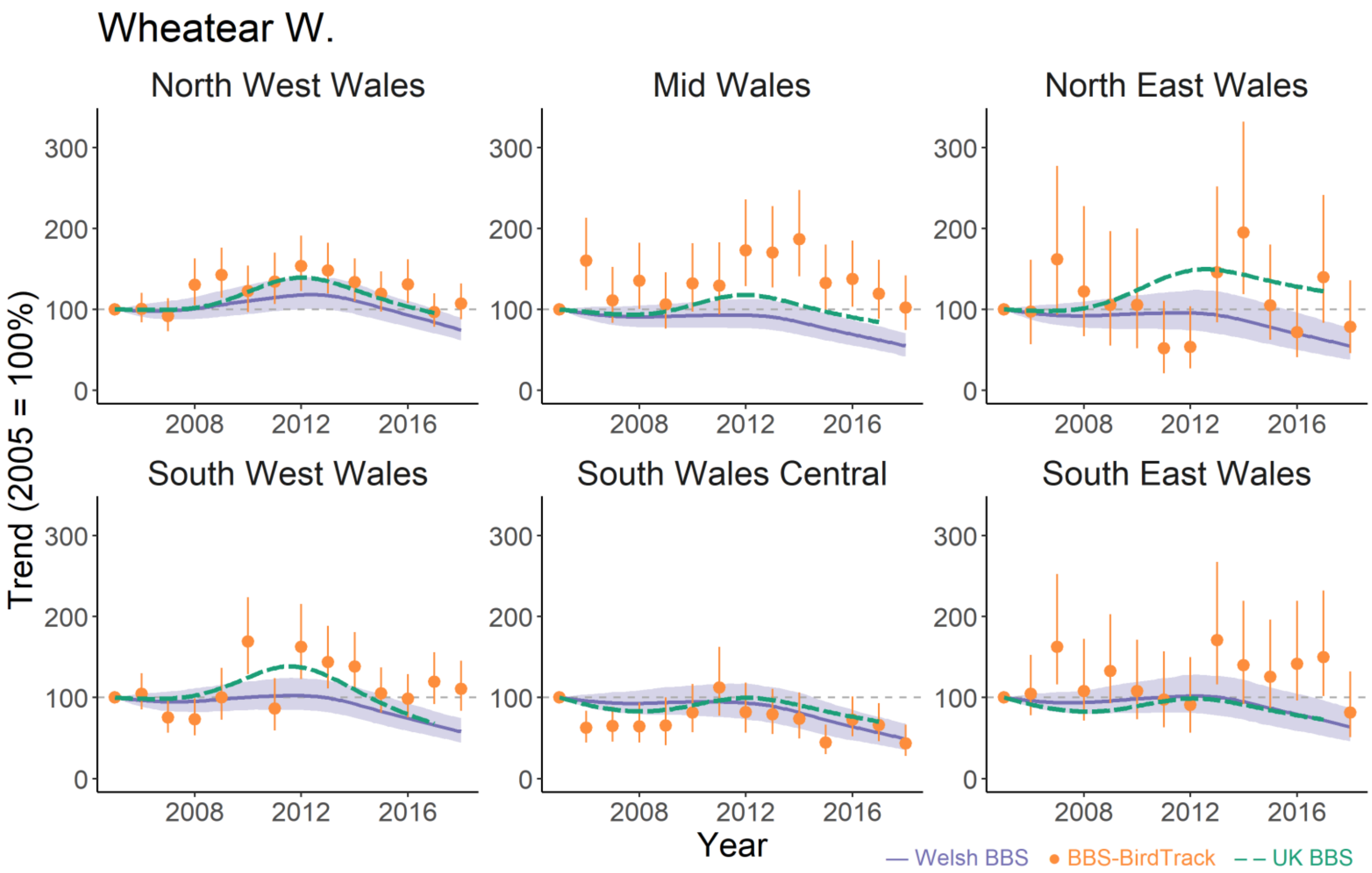

Siskin SK
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
1000
750
500
250
0
2008
2012
2016
Year
— Welsh BBS
● BBS-BirdTrack
– – UK BBS

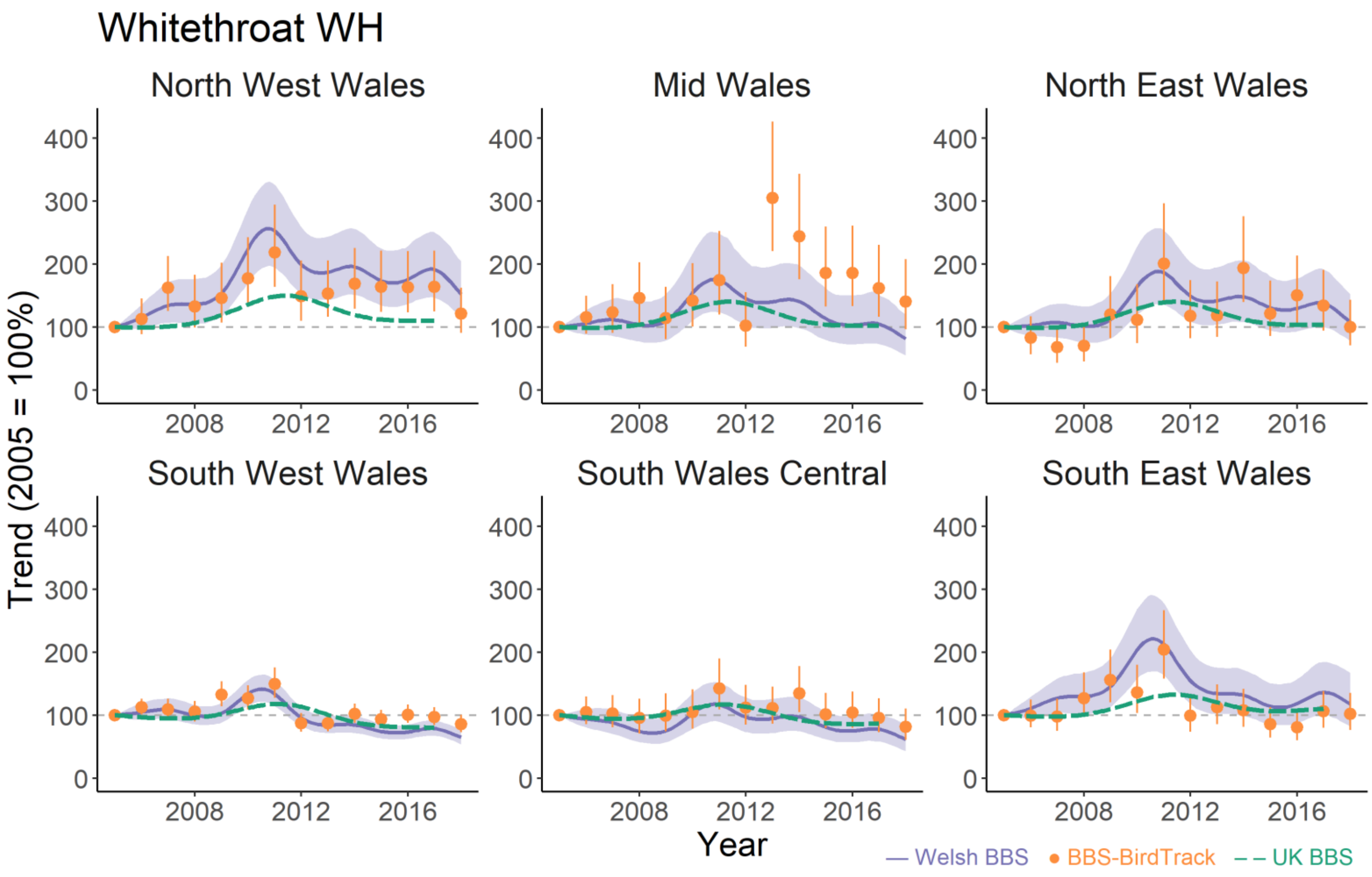

Swallow SL
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
150
100
50
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

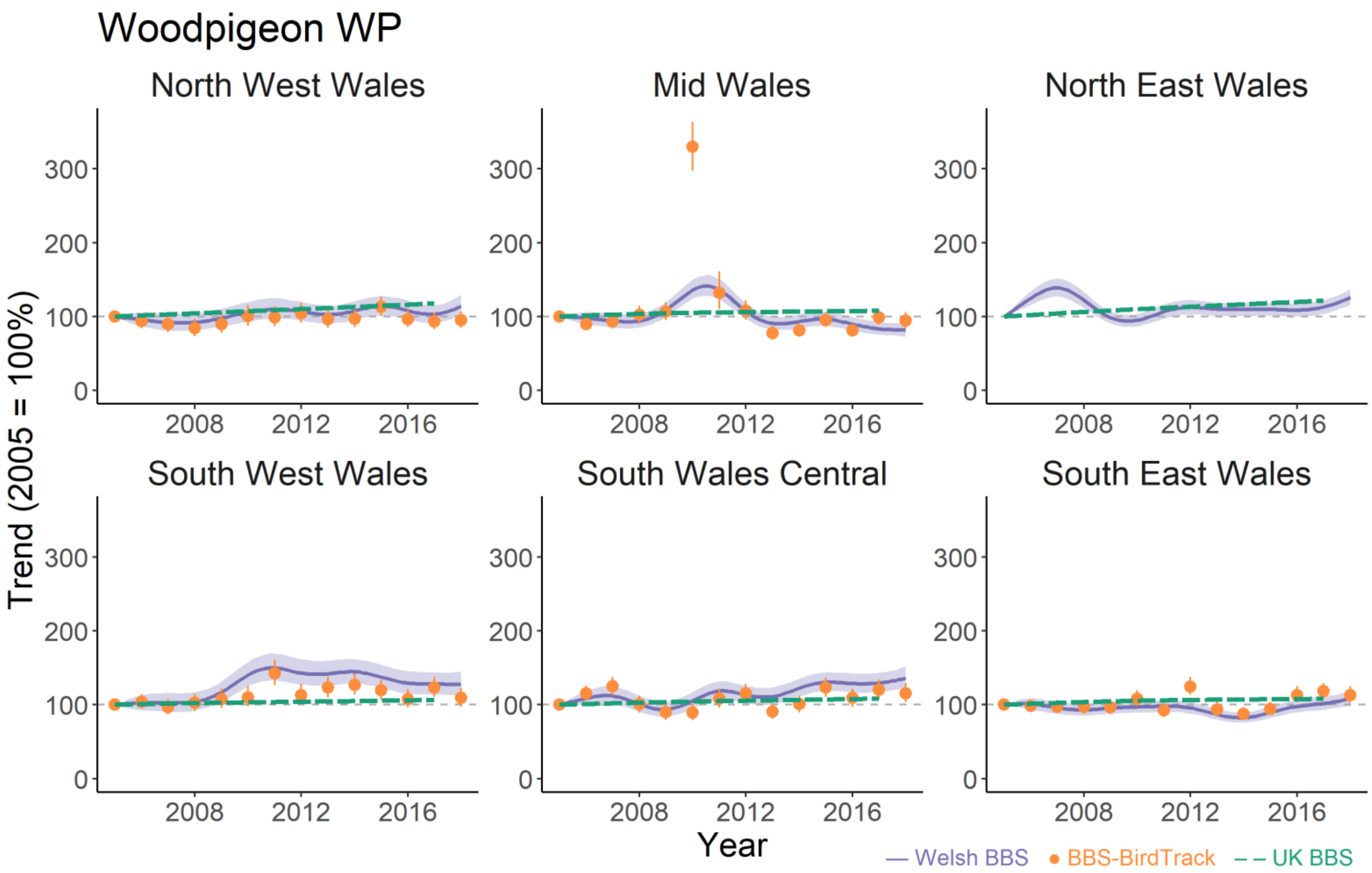

Song Thrush ST
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
150
100
50
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

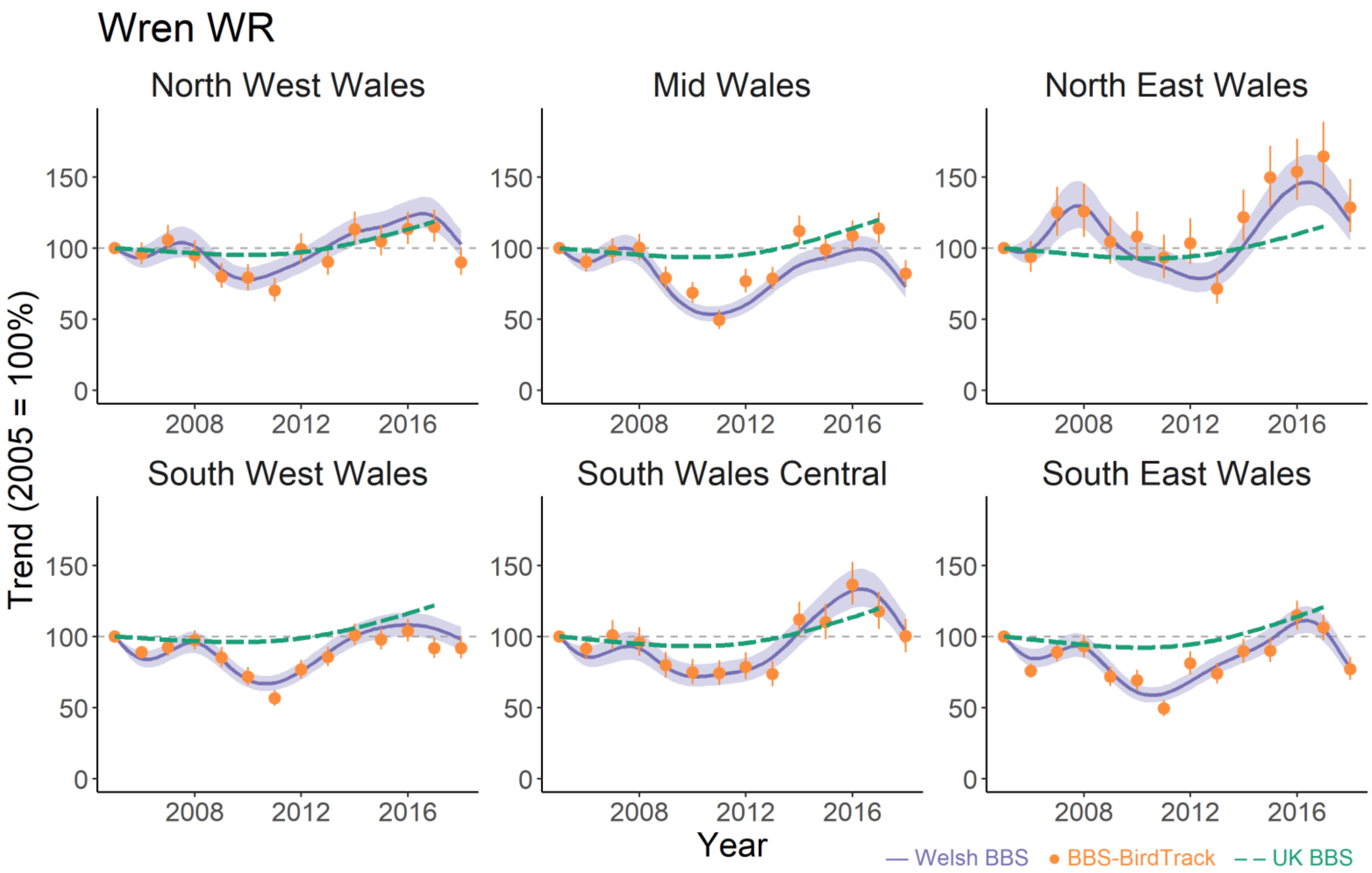

Treecreeper TC
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
400
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS

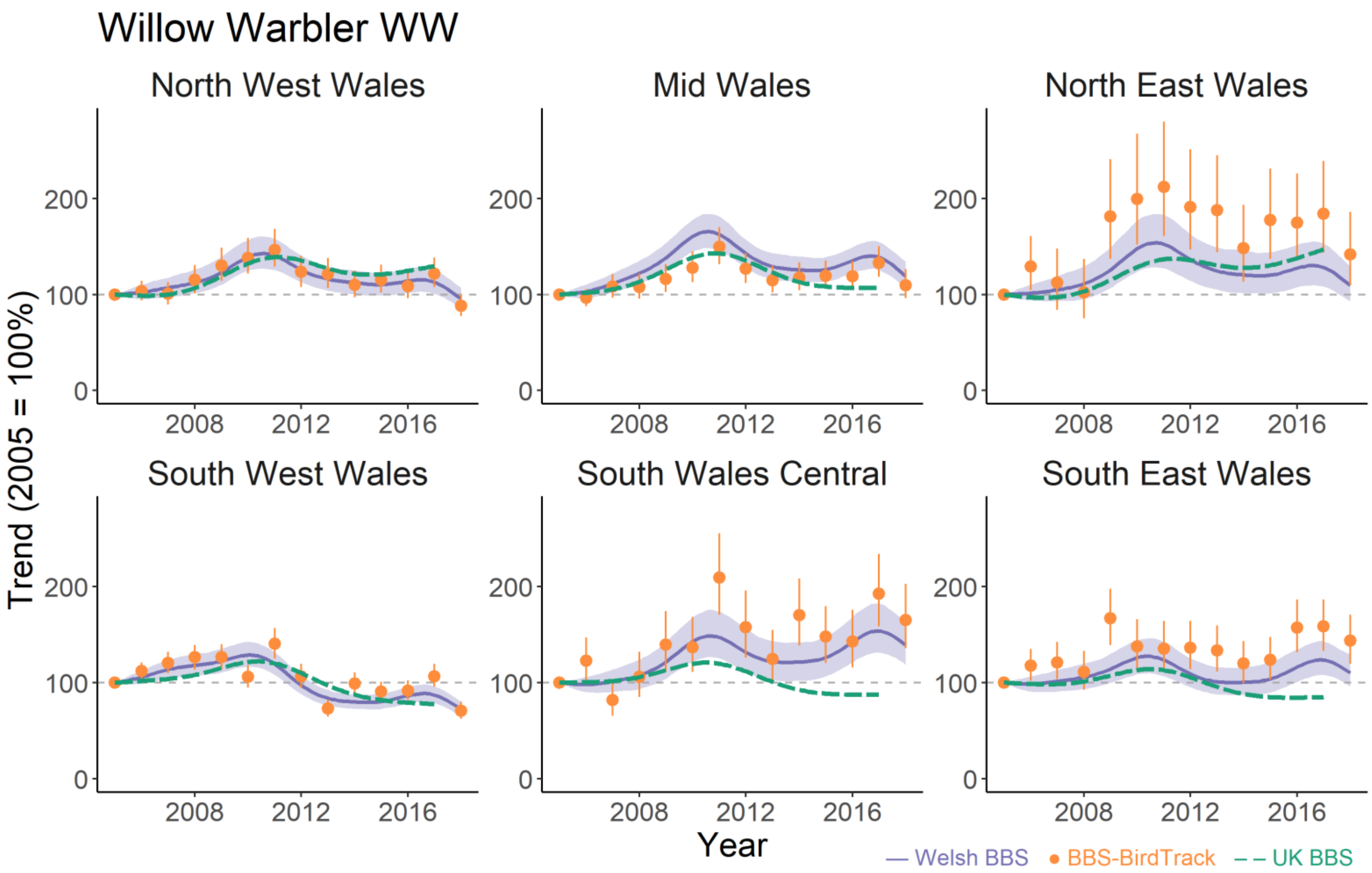

Tree Pipit TP
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
1200
900
600
300
0
2008
2012
2016
Trend (2005 = 100%)
Year
Welsh BBS
BBS-BirdTrack
UK BBS

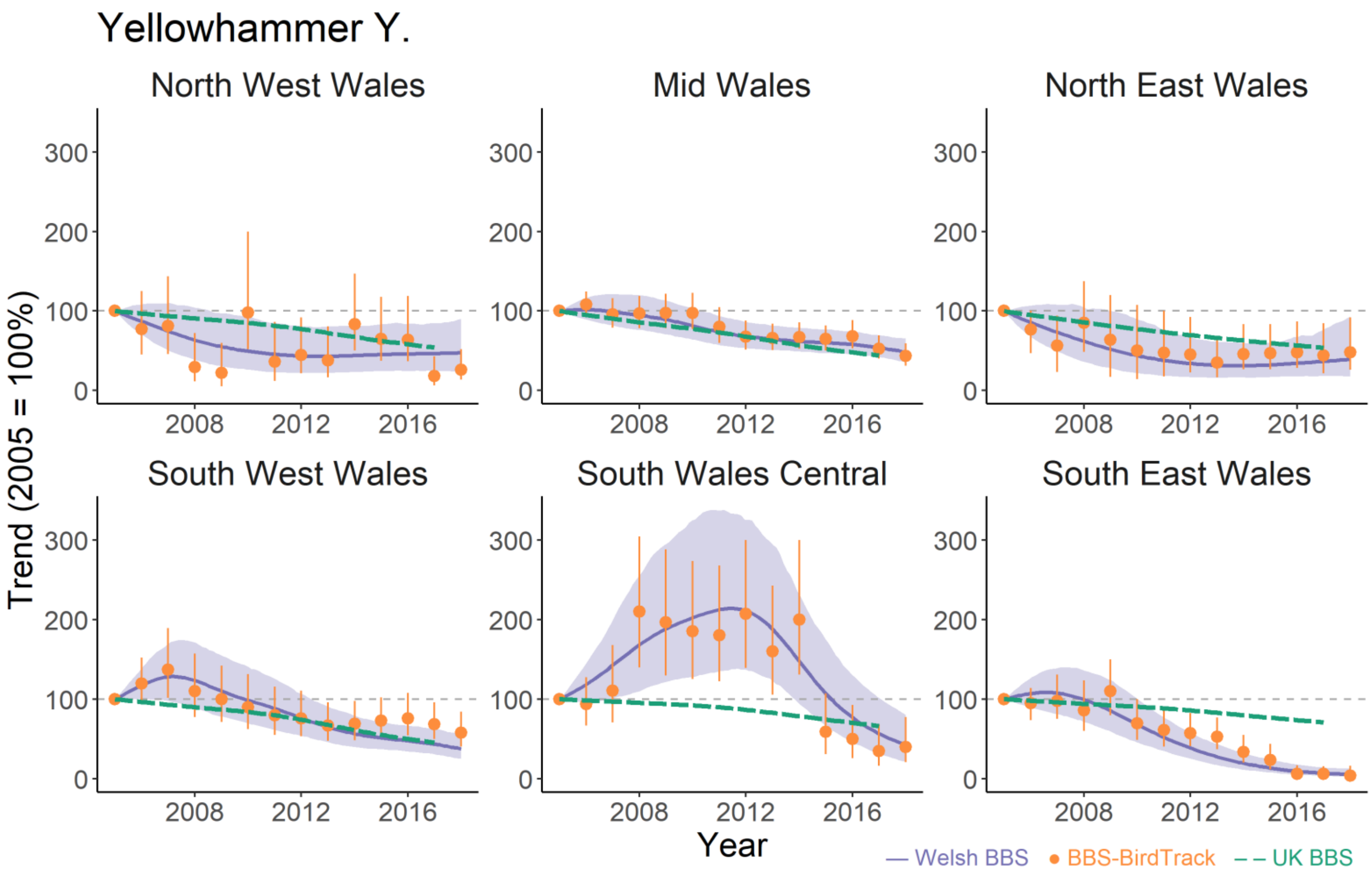

Wheatear W.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS


Whitethroat WH
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
400
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS


Woodpigeon WP
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS


Wren WR
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
150
100
50
0
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS


Willow Warbler WW
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS


Yellowhammer Y.
North West Wales
Mid Wales
North East Wales
South West Wales
South Wales Central
South East Wales
Trend (2005 = 100%)
0
100
200
300
2008
2012
2016
Year
Welsh BBS
BBS-BirdTrack
UK BBS