Willow Tit declines in Britain – a species distribution modelling approach

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* Word count
* Check refs
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* Logic and consistency
* Submit for originality check
* Add a bit more on value and application of SDM
* Tidy up rapid sdm page
* Review maps ? add one or two more

# 1 Introduction

The Willow Tit (*Poecile montanus*) is one of Britain’s rarest breeding birds.(Lewis et al., 2009) It is thought to be at risk of extinction as a breeding species in this country.(Stanbury et al., 2017) having declined by 94% since 1970 (Figure 1) and suffered a major contraction in range.

The race prevalent in Britain is *kleinschmidti* which seems to behave differently to its European and global counterparts, preferring wet woodland and early-successional woodland and scrub, with alder, birch and willow which are particularly prevalent at post-industrial sites. (Snow and Perrins, 1998) They do not travel long distances, preferring extensive cover, and excavate nests in dead wood and fallen trees. They have a largely invertebrate diet – especially crane flies – which prefer damper habitat.(Willow Tit - Back From The Brink, 2021)

Habitat loss, competition from other tit species and increased predation from Great Spotted Woodpecker and Jay, have been proposed as contributors to the decline. (Siriwardena, 2004) As shown in Figure 1, there have been large increases in Blue Tit, Great Tit and woodpecker populations over the period of Willow Tit declines.

Blue Tits (*Cyanistes caeruleus*) and Great Tits (*Parus major*) have been noted to compete for nesting sites and take over sites excavated by willow tits. For example a survey of the Clyde area of Scotland found that (Andersonian Naturalists of Glasgow. et al., 2002) found Blue Tits ousted Willow Tits from 18 of 30 nest sites. Siriwardena, analysing Common Bird Census (CBC) and Constant Effort Scheme (CES) Willow Tit data between 1985 and 2000 showed Willow Tit declines in arable and woodland, but not in wet woodland, potential predation effects of Great Spotted Woodpecker but no evidence of competition effects from Blue Tits.(Siriwardena, 2004) By contrast Parry and Broughton found strong evidence of Blue Tit competition and Great Spotted Woodpecker predation in an intensive study of Willow Tit habitats in the North West of England.(Parry and Broughton, 2018)

Broughton et al analysed the relationship between land cover patterns and Willow Tit distributions and found that data from the 25m raster Land Cover Maps of Great Britain(Rowland et al., 2020) could be used to describe habitat preferences, but found no significant relationship between land cover change and Willow Tit declines. (Broughton, Hill and Hinsley, 2013)

Climate change has not been extensively studied in relationship to Willow Tit distributions but it is increasingly thought to be contributing to range expansion and contraction of many taxa and it has been noted that ‘northern’ species are losing the southern parts of their range. (Virkkala and Lehikoinen, 2014) Voous noted willow tits breed between the 12℃ and 23℃ July isotherms.(Voous, 1960)

Understanding the reasons for decline remain unclear with discrepancies between secondary data analyses and results of field work. Nevertheless, habitat loss, competition and predation remain extant hypotheses and further exploration of these is essential for willow tit conservation.

## Study objectives

This study aim is twofold:

* to estimate the current willow tit distribution and habitat and change over time
* to estimate factors associated with core habitat.

Chart, histogram

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Figure Relative change in smoothed population index relative to 2018 for true tit species and Great Spotted Woodpecker (Dendrocopos major) since 1970. Data from the Breeding Bird Survey (BBS), Common Bird Census (CBC) and Constant Effort Scheme (CES). Shown with 85% confidence intervals. Adapted from (Woodward et al., 2020)

# Methods

The study population is the whole of Great Britain.

### Data sources and cleaning

Species occurrence data for 1970 – 2019 was obtained for ‘true’ tits (Great Tit, Willow Tit, Blue Tit and Marsh Tit) and Great Spotted Woodpecker via the National Biodiversity Atlas (NBN) plug in for QGIS. (The FSC Plugin for QGIS v3 (2016)) The NBN Atlas is a major source of species observation data for British species and draws on numerous primary sources - for example Willow Tit observations are drawn from more than 60 datasets. CBC data is only available up to 2000 and the latest breeding atlas data for 2008-11 so occurrence data was used throughout this study.

Excluding records with missing dates, geographical information or species information, deduplication and filtering the dataset to include only those observations classified as ‘accepted’ gave a dataset of 2.3 million records.

Climate data were obtained from the Worldclim dataset ((Global climate and weather data — WorldClim 1 documentation, 2021), extracted directly into R using the getData function in the raster R package.(Hijmans et al., 2021) Mean temperature and annual rainfall

## Habitat preference and range

Willow Tit ranges were calculated using core kernel density estimation (KDE) using QGIS.(QGIS Development Team, 2021) To balance counts across time, ranges were calculated for 1970-2000, 2000-2010 and 2010-19. KDE involves creating a spatial point-density heatmap of observations with a parameter (bandwidth) which determines the smoothness of the density distribution. A polygon which represents areas of highest density was extracted as shape files to represent Willow Tit strongholds (core area).

These areas were used to calculate land-cover statistics per core area. Dominant aggregate class land cover raster data at 1km2 resolution for 1990 and 2015 was obtained from the Centre for Hydrology and Ecology (CEH). These data are aggregated from more fine-grained rasters (20m resolution) and assign each 1km2 to the habitat type occupying the greatest proportion of each area across 10 broad habitat categories.(Rowland et al., 2017)

### Species distribution modelling (SDM)

SDM is a tool for estimating habitat preference and has been widely used for threatened species to aid conservation .(Riordan, Montalvo and Beyers, 2018) It calculates the probability of occupancy for a species based on predictor variables though to be relevant. Based on the literature review land cover variables, density estimates for Blue Tit and Great Spotted Woodpecker and climate variables were included in the modelling. Tetrad estimates (observations per km2) were calculated and converted to rasters using the rasterize function in the raster package.(Hijmans et al., 2021)

For the analysis raster files needed to have the same extent, resolution, and Coordinate Reference System (CRS). Raster files were aligned by reprojecting to EPSG:27700 (British Nation Grid), clipping to the extent of Great Britain (shape file obtained from the ONS Open Geography Portal) and scaled to 1km x 1km resolution. The resulting rasters were ‘stacked’ using the stack procedure in the raster package. (Hijmans et al., 2021)

SDM was undertaken using the sdm package in R.(Naimi and Araújo, 2016) This takes species spatial-point data and predictor data as a raster stack or data frame as inputs to a data object, which is then passed to the modelling function. sdm allows multiple runs of range of algorithms through bootstrapping and/or cross-validation. For this study *glmnet, gam, ranger, brt* models were run with 3-fold cross validation using a 70:30 test-train split. Model fit was inspected using Receiver Operating Characteristic (ROC) curves and Area under the curve statistics (AUC). Variable importance was used to assess the contribution of predictors to the distribution and response curves were examined to evaluate how predicted outcomes varied with input variable values.

The sdm output was then passed to the predict function in sdm to estimate the spatial distribution.

All analysis was undertaken using the Quantum Geographical Information System (QGIS)(QGIS Development Team, 2021) and R Software.(R Core Team, 2019)

# Results

### Distribution

The change in Willow Tit distribution is summarised in Figure 2. The range has contracted considerably with losses from the South-East of England, much of the East of England, and contraction of former strongholds in the Midlands and Wales. There is evidence of increased fragmentation. There appear to be pockets in the South West and Scotland, and the stronghold in the North East appears to have expanded.

### Habitat

Changes in Willow Tit habitat preferences are shown in Figure 3 – there has been a loss especially in arable an imorved grassland habitats.

Map

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Figure Change in core density of Willow Tit distribution between 1970-90 (blue) and 2010-19 (red)

Chart, waterfall chart

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Figure Difference in % of land-cover class of Willow Tit core areas between 1970-90 and 2010-19 based on 2015 land cover classes

### Model outcomes

The ROC curves for each algorithm in shown in Graphical user interface, chart, line chart

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Figure ROC curves for each algorithm

Figure 4. The ranger algorithm performed best with an AUC of 0.79, although Figure 4 over-fitting. Boosted regression trees (BRT) and generalized additive models had similar performance with AUCs of 0.74 and 0.75 respectively. glmnet had an AUC of 0.66.

Figure 5 shows the variable importance averaged across all the models. This clearly shows that climate variables are the biggest predictors in the models, followed by land cover in 1990 and Great Spotted Woodpecker density.

Figure ROC curves for algorithms averaged over replications

Chart, box and whisker chart

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Figure Mean variable importance

Chart, histogram

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Figure Response curves for each predictor averaged across models

## Predicted distribution

Map

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Figure Predicted habitat suitability from sdm

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# Discussion

This study has shown contraction of Willow Tit distribution and confirmed the loss of strongholds from the East and South East of England and fragmentation in Wales and the Midlands. Central England the North east now seem to be important locations for the survival of the Willow Tit in England. The study also confirms population disappearance from arable land and grassland,

SDM suggests that climate variables are important distribution predictors and biotic predictors and land cover predictors less so.

Response curves suggest that the probability of willow tit presence increases as blue tit and great spotted woodpecker frequency increase hinting shared habitat rather than competitor or predator effect. Probability of presence is highest within a narrow range of temperatures and increases with rainfall.

This study provides no strong evidence that land cover per se is a strong predictor of Willow Tit populations, but this may due the coarse resolution of the land cover data which would smooth out the more specific habitat requirement of the Willow Tit. Given that finer grained resolution is available for land cover data repeating the exercise might be helpful although it is beyond the scope of this work and would require significant computing resources given the size of the raster files.

The predicted habitat suitability suggest that large parts of former range may still be suitable but less so former populations in the South and East of England

Taken together these data suggest that the Willow Tit may continue to decline, and climate change may impact future habitat suitability.

## Conservation implications

Changes in habitat and climate waring pose ongoing threats to the Willow Tit population and early-successional woodland and scrub seem to be key to conservation – wilded post-industrial site for example at ex mining sites in the North East which are otherwise considered of low conservation value may require conservation and action and protection if the Willow tit is to survive in Britain. (Broughton, Parry and Maziarz, 2020)

Although evidence is mixed, biotic threats from other Tit species or predation by Great Spotted Woodpecker may declines as numbers stabilise or even decrease (Figure 1).

Projects like *Back from the Brink* may provide a model for Willow Tit conservation using a mixture of regular surveys, habitat improvement – coppicing, corridor creation and technology like radio tracking.(Willow Tit - Back From The Brink, 2021)

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