

1 **Modelling historical landscape changes**

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15

16 17 **Abstract**

18 **Context**

19 Historical maps of land use/land cover (LULC) enable detection of landscape changes, and
20 help to assess drivers and potential future trajectories. However, historical maps are often
21 limited in their spatial and temporal coverage. There is a need to develop and test methods to
22 improve re-construction of historical landscape change.

23 **Objectives**

24 To implement a modelling method to accurately identify key land use changes over a rural
25 landscape at multiple time points.

26 **Methods**

27 We used existing LULC maps at two time points for 1930 and 2015, along with a habitat
28 time-series dataset, to construct two new, modelled LULC maps for Dorset in 1950 and 1980
29 to produce a four-step time-series. We used the Integrated Valuation of Ecosystem Services
30 and Tradeoffs (InVEST) Scenario Generator tool to model new LULC maps.

31 **Results**

32 The modelled 1950 and 1980 LULC maps were cross-validated against habitat survey data
33 and demonstrated a high level of accuracy (87% and 84%, respectively) and low levels of
34 model uncertainty. The LULC time-series revealed the timing of LULC changes in detail,
35 with the greatest losses in neutral and calcareous grassland having occurred by 1950, the
36 period when arable land expanded the most, whilst the expansion in agriculturally-improved
37 grassland was greatest over the period 1950-1980.

38 **Conclusions**

39 We show that the modelling approach is a viable methodology for re-constructing historical
40 landscapes. The time-series output can be useful for assessing patterns and changes in the
41 landscape, such as fragmentation and ecosystem service delivery, which is important for
42 informing future land management and conservation strategies.
43

44 **Keywords**

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46 Agriculture; intensification; InVEST; LULC; mapping; time-series

47

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1. Introduction

Land use/land cover (LULC) change is one of the main drivers of terrestrial biodiversity loss and altered ecosystem functions and services across the globe (Bateman et al., 2013; Tittensor et al., 2014). Anthropogenic LULC change is continuing to increase in extent and intensity (Marques et al., 2019) and is forecast to remain a major driver influencing terrestrial ecosystems in the future (Sala et al., 2000). Major changes in LULC include agricultural expansion and intensification, urbanisation, industrialisation, deforestation of natural forest and forest planting for timber, undertaken to meet the demands of an increasing population worldwide (Newbold et al., 2015; Song et al., 2018). While most studies focus on recent changes in land use, it is important to set current changes in a historical context (Cousins et al., 2015; Fescenko and Wohlgemuth, 2017). Some studies have examined such changes across networks of sample sites with known history (e.g. Redhead et al., 2014). However because this is restricted to specific locations, broader and complex patterns occurring across landscapes cannot be assessed. Re-constructing historical landscape maps allows LULC change to be examined across large areas, which is important for assessing the degree and type of changes and their spatial distribution. Such analyses can help inform land management decisions and support the implementation of future conservation measures, for example by identifying which areas are at greatest risk of future change.

LULC maps can be produced using a variety of sources, including field survey data, aerial photography and satellite imagery. Satellite images have become increasingly important for obtaining land cover data and are often used to monitor LULC change. Such data can also be used to support the development of LULC models, which aim to detect drivers of historical change and/or predict future changes (Veldkamp and Lambin, 2001). There are a wide variety of approaches used to model LULC change (Lu et al., 2004; Noszczyk, 2019). LULC models require the identification of the most important changes, such as urban expansion, agricultural intensification, or protection of natural areas, along with geographical predictors for where specific changes are most likely to occur. This may include soil type, topography, the previous LULC and other landscape features such as watercourses or infrastructure. As the importance of and demand for understanding LULC change has increased, a number of modelling software programmes have been developed (Fuchs et al., 2013; Sharp et al., 2016). These tools all employ a similar principle, whereby statistical analysis is used to identify patterns between the current distribution of LULC and environmental covariates.

Owing to data availability and time constraints, many LULC change studies are only able to re-construct one historical landscape. Comparisons in LULC are therefore often performed between two snapshots in time (Cousins et al., 2015; Hooftman and Bullock, 2012; Reis, 2008), which provides little information on the dynamics of change during the intervening period. More detailed information on trajectories of LULC change can help land managers and conservationists address more specific problems, which would otherwise be difficult to solve with only two time points. For example, determining where certain habitats occurred in the past and at what time period they were lost can be useful for locating areas where ecological restoration could take place or where habitats could be reconnected (Willems,

2001). Similarly, variation in biodiversity among apparently similar habitats can be explained by their different land use histories, which can inform conservation management choices (Fescenko and Wohlgemuth, 2017).

Our study area is the county of Dorset, a predominantly rural landscape in southern England, which has undergone dramatic land use change, mostly through agricultural intensification, over the twentieth century (Hooftman and Bullock, 2012), in common with many regions across Europe. Dorset is an ideal area to examine LULC change, as there is a wealth of environmental datasets for this county, including an extensive botanical survey conducted by Good (1937). Good's dataset has provided valuable insights into patterns of change in heathland, calcareous grassland and woodland (Diaz et al., 2013; Keith et al., 2009; Newton et al., 2012) and more recently it has enabled the generation of a habitat time-series dataset across Dorset (Ridding et al., 2020). Ridding et al. (2020) determined the habitat type of over 3700 locations that were derived from the original Good survey sites, using contemporary field survey data and spatial datasets, for the years 1930, 1950, 1980, 1990 and 2015. Hooftman and Bullock (2012) created a land use map for Dorset in the 1930s and compared this with the UK Land Cover Map of 2000. They found that 97% of semi-natural grasslands were converted into agriculturally-improved grassland or arable land, as well as a large areas of heathlands and rough grassland. Although the study quantified broad LULC change over time, it was not possible to assess more accurately when these key LULC changes occurred. We aimed to improve on this by producing a time-series of maps spanning the past ca. 80 years in Dorset.

We used a modelling tool and detailed habitat data from Ridding et al. (2020) to inform the model, to generate LULC maps for Dorset in 1950 and 1980. These could then be used to analyse LULC change alongside the existing 1930s land cover map generated by Hooftman and Bullock (2012) and the CEH Land Cover Map 2015 (Rowland et al., 2017a). The aim of our study was to:

- (i) Assess the accuracy of the modelling method;
- (ii) Identify the timing of key LULC changes between 1930 and 2015;
- (iii) Determine the uncertainty associated with the methodology.

2. Method

2.1. Study Area

Dorset, southern England, is currently ca. 2653 km² in area, including the urban areas of Bournemouth, Poole and Christchurch that were added in 1974. Prior to that Dorset was ca. 2500km² in area (Hooftman and Bullock, 2012). The population more than doubled between 1930 and 2017, from ca. 198,000 to ca. 424, 670 excluding the urban centres of Bournemouth and Poole (Office for National Statistics, 2017). Like many regions in Western Europe, Dorset underwent considerable land use change during the 20th and early 21st centuries, through agricultural intensification, afforestation and urbanisation, which led to significant

175 losses of semi-natural habitats and fragmentation of remaining areas (Hooftman and Bullock,
176 2012; Webb, 1990).

177

178 *2.2. InVEST Scenario Generator*

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180 To create LULC maps of Dorset in 1950 and 1980, we used the Integrated Valuation of
181 Ecosystem Services and Tradeoffs (InVEST) Rule Based Scenario Generator tool (Sharp et
182 al., 2016) (subsequently “InVEST”). The years 1950 and 1980 were selected based on the
183 availability of detailed habitat data from Ridding et al. (2020), which was required to inform
184 the model. InVEST uses a range of inputs as predictor variables to model land cover change
185 using multi-criteria evaluation methods and overlay analysis (Sharp et al., 2016). Although
186 the model is relatively simple compared to other approaches (Liping et al., 2018; Verburg et
187 al., 2002), it is ideal for modelling LULC change over large areas because it is
188 computationally efficient. The simplicity of the model also makes it easy for the user to
189 incorporate known drivers and constraints, compared to methods such as cellular automata
190 and neural networks (Sharp et al., 2016).

191

192 InVEST determines the suitability of individual grid cells for LULC change based on the
193 following inputs; a baseline raster LULC map, a transition matrix table and other optional
194 data including land suitability factors, constraints and override layers (Fig. 1). The transition
195 matrix table provides the quantity of change per LULC, and the likelihood of a particular
196 LULC converting to another LULC. Within this table, LULC types are prioritised using a
197 value between 1 and 9; thus when multiple objectives compete for a single cell, the one with
198 the highest priority wins. A proximity value within the same table controls the assumption
199 that pixels close to a LULC type are more likely to be converted to that cover type if they are
200 suitable. The land suitability factors are physical and environmental variables that are likely
201 to affect the suitability of land for a given LULC type and thus where in the landscape
202 changes are likely to occur. The factors are given a factor weight between the value of 0 and
203 1, which determines the weight given to the factors vs. the transition matrix (Fig. 1). For
204 example, a weight of 0.3 means that 30% of the final suitability is contributed by the factors,
205 whilst the remaining 70% is attributed to the transition matrix (Sharp et al., 2016). The
206 constraint input within InVEST prevents particular areas of the baseline landscape from
207 changing where there are known factors that limit the likelihood of change. The override
208 function, changes the LULC type of individual grid cells based on the users input, which
209 occurs after the model has run. The following sections describe the data utilised for each
210 model input.

211

212 *2.3. Baseline LULC maps*

213

214 The 1930 adapted Dudley Stamp Map produced by Hooftman and Bullock (2012) was used
215 as the baseline LULC map for the creation of the 1950 Dorset map. The Dudley Stamp Map
216 was created from the 1930s Land Utilisation Survey of Britain, where volunteers mapped
217 LULC on six-inch to the mile Ordnance Survey (OS) maps (Stamp, 1931). This baseline map
218 is based on the historic county boundary which we used for the entire map time-series to

219 ensure consistency. The 1930 map did not clearly distinguish broadleaved from coniferous
220 woodland. To address this issue we used Good’s survey of 7575 vegetation stands (Good,
221 1937) to identify areas of coniferous woodland, which is likely to have been planted in this
222 part of the country. The Good stands did not give complete coverage over Dorset, so all
223 remaining patches of woodland which were not surveyed by Good were assumed to be
224 broadleaved. This is likely to be an underestimate of coniferous woodland in Dorset; however
225 records suggest that the coverage of coniferous woodland in southern England during this
226 time was limited (Best and Coppock, 1962).

227

228 For the creation of the 1980 Dorset map, we used the CEH Land Cover Map 2015
229 (LCM2015) (Rowland et al., 2017a) as the baseline. The LCM2015 is a parcel-based land
230 cover map for the UK created by classifying satellite data into 21 land classes that are based
231 on the broad habitats defined by Jackson (2000). This method was preferred over using the
232 generated 1950 map, since the LCM2015 is already a validated product, and this avoided
233 using two sequential interpolations to create the 1980 map and the likely propagation of
234 errors. We trialled the alternative approach in preliminary analyses but this gave less accurate
235 results (see Online Resource 1). No acid grassland was identified in the LCM2015 in Dorset,
236 even though this habitat was known to be present at this time (Ridding et al., 2020). This is
237 because small areas of semi-natural habitat are often not detected in the LCM2015, which has
238 a minimum mappable unit of 0.5 ha and is poor at detecting linear features, such as remnant
239 strips of semi-natural grassland (Ridding et al., 2015). To address this and improve the
240 accuracy of the baseline map, we replaced areas that were misclassified in the LCM2015 with
241 acid grassland from Natural England’s Priority Habitats’ Inventory (Natural England, 2015)
242 using ESRI ArcGIS v10.4 (© ESRI, Redlands, CA).

243

244 The baseline maps and consequently the generated LULC time-series contained 12
245 aggregated land classes: “broadleaved woodland”, “coniferous woodland”, “arable”,
246 “calcareous grassland”, “acid grassland”, “neutral grassland”, “improved grassland”, “fen,
247 marsh, swamp”, “heathland”, “coastal”, “water”, “urban” and “other”. The other category
248 includes inland rock, which was only mapped for 1980, since this LULC type only occurred
249 in the LCM2015 and not in the adapted Dudley Stamp map for 1930 (Hooftman and Bullock,
250 2012). The baseline maps were converted to 100 m resolution rasters, using a maximum area
251 cell assignment in ArcGIS, and thus this resolution was also used to create the 1950 and 1980
252 map. The selected resolution, which has been used in other LULC studies (Moulds et al.,
253 2018), was a compromise between capturing detailed LULC change, whilst maintaining a
254 scale at which influential factors, such as soil and slope are likely to impact the InVEST
255 predictions. At finer scales complex factors such as land ownership would likely become
256 important and could not be captured by modelled factors in InVEST. Redhead et al. (2018)
257 found that running the InVEST nutrient model at resolutions finer than 100 m showed only
258 small gains in accuracy compared with the extra running time and large file sizes.

259

260 *2.4.Transition matrix*

261

262 To determine the amount of LULC change between 1930 and 1950, and between 2015 and
263 1980, and the likely transitions between different land covers, we utilised data from a survey
264 time-series dataset where habitat type has been assessed at over 3700 sites across Dorset in
265 1930, 1950, 1980 and 2015 (see Ridding et al., 2020). Subsequently, we refer to this database
266 as the “habitat time-series”. The quantity of LULC change between both 1930 to 1950, and
267 2015 to 1980 was determined by calculating the percentage change in each LULC type, using
268 the habitat time-series. A transition matrix of LULC change based on counts of changes
269 across the habitat time-series sites was also generated for both time periods, which was
270 subsequently adjusted on a scale of 0-10 to meet the input requirements for InVEST (see
271 Online Resource 2 & 3). Where a particular LULC was not present in the original baseline
272 data, for example improved grassland in 1930, an area change rather than a percentage
273 change was required by InVEST. To calculate this we used the number of improved
274 grassland sites in 1950 from the habitat time-series dataset, as a percentage of the total sites
275 multiplied by the area of Dorset.

276

277 Priority values were required for LULCs which increased between 1930 and 1950; arable,
278 coniferous woodland and urban. Priority values rank the LULC type, thus when multiple
279 objectives compete for a single cell, the LULC with the highest priority wins. The literature
280 reveals that there were considerable increases in arable and improved grassland during this
281 period in Britain, and specifically in Dorset (Fuller, 1987; Hooftman and Bullock, 2012),
282 suggesting that the transitions to these LULCs should be high priority in InVEST, thus we
283 assigned scores of 8 and 7, respectively. During this time the planting of coniferous
284 woodlands also increased rapidly (Best and Coppock, 1962), however farming was a higher
285 priority in the British lowlands after the Second World War compared with conifer planting;
286 thus we assigned a priority score of 5 to this LULC type.

287

288 For the 1980 map, the priority values were based on change in the opposite direction (2015 to
289 1980), thus the number of semi-natural habitats (neutral grassland, calcareous grassland,
290 heathland, fen, marsh, swamp habitats) increased, as well as arable and coastal LULCs. The
291 amount of arable land decreases between 1980 and 2015 (Ridding et al., 2020) due to
292 technological advances improving productivity of existing arable land, hence from 2015 to
293 1980 arable land actually increases. Using the habitat time-series dataset from Ridding et al.
294 (2020), we determined that increasing the number of semi-natural habitats was a greater
295 priority than arable and coastal which only increased by a small percentage during the same
296 period Ridding et al. (2020). Values of 9 and 7, were therefore assigned to semi-natural
297 habitats and arable/coastal respectively. We used 1000 m as the proximity value (where cells
298 close to a LULC type within this distance are more likely to be converted to that cover type if
299 suitable) for the increasing habitats for both the 1950 and 1980 map, as any finer scales are
300 likely to be influenced by more complex factors such as accessibility and land ownership as
301 suggested by Redhead et al. (2020).

302

303 *2.5. Modelled factors*

304

305 We examined a range of physical and environmental suitability factors for the generation of
306 both the 1950 and 1980 maps which is a requirement for InVEST, including slope, elevation,
307 rainfall, temperature, soil and Agricultural Land Classification (AGL) (see Table 1). These
308 factors were selected based on similar studies in the literature (Fuchs et al., 2013; Verburg
309 and Overmars, 2009) and the availability of data for the whole of Dorset across multiple time
310 periods where applicable (e.g. rainfall, temperature).

311

312 To determine which factors influenced the suitability of the increasing LULC types, we
313 performed logistic regression using sites from the habitat time-series dataset (Ridding et al.,
314 2020) that had remained versus sites which had undergone change for the 1950 and 1980
315 map. The sample size for habitat time-series sites converting to “urban” between 1930 and
316 1950 was too small to assess (n=20) (noting the historical Dorset boundary excludes the large
317 urban areas), and the same was true for coastal sites (n=17) between 2015 and 1980.
318 Elevation was strongly correlated with average temperature and rainfall (Pearson’s $r > 0.6$ or
319 < -0.6), so this was excluded from all models. Logistic regression analyses were performed in
320 R v.3.4.2 (R Core Team, 2019).

321

322 To determine the most suitable factor weight (factors vs transition matrix, see Fig. 1) we
323 examined three different weights; 0.3, 0.5, 0.7 and evaluated these using the habitat time-
324 series (see section on validation). A weight of 0.5 was selected to understand how equal
325 weighting would perform, whilst 0.3 and 0.7 were arbitrarily selected using the example in
326 Sharp et al. (2016), to represent and test the differences between a high or low weighting for
327 factors versus transition matrix.

328

329 *2.6. Constraints and override*

330

331 In England the basic type of statutory protection is the designation as a Site of Special
332 Scientific Interest (SSSI), which are areas of land selected for ‘special interest by reason of
333 any of its flora, fauna, or geological or physiographical features’ (JNCC, 2015). Although the
334 first SSSIs were not designated until the 1950s (DEFRA, 2009), Ridding et al. (2020) found
335 sites which were classified as protected in the habitat time-series were more likely to remain
336 as their original habitat. For this reason we used the extent of SSSI as a constraints layer. To
337 improve the predicted output further, we also evaluated which 100 m cells had remained
338 consistent between 1930 and 1990 for the 1950 map and 2015 and 1950 for the 1980 map.
339 The partial Land Cover Map 1990 covered 83% of Dorset and was created using the same
340 methodology used to make the LCM2015 (Rowland et al., 2017b). We assumed that where
341 the LULC within the 100 m cell matched, in 1930 and 1990 for example, the LULC would
342 have stayed the same in 1950, thus these matching cells were also used as a constraint layer,
343 to prevent LULC change occurring in those locations.

344

345 For the generation of the 1980 map we also used the override layer in InVEST (Fig. 1). For
346 this we examined which 100 m cells were consistent in both the generated 1950 map and the
347 revised LCM1990 map (Rowland et al., 2017b), and presumed that this remained the same in

348 1980. This data was used as an override rather than a constraint, since the LULC type within
349 particular cells may have differed between 1990 and 2015.

350

351 *2.7.Accuracy*

352

353 To assess the accuracy of the 1950 and 1980 Dorset maps produced using InVEST, we
354 created ten cross-validation datasets from the habitat time-series dataset. In each of the 10
355 datasets, 75% of the habitat time-series sites were randomly selected for the training dataset,
356 whilst the remaining 25% were used as a test dataset. Since some of the habitat time-series
357 data did not completely match the baseline 1930 and 2015 map (see Ridding et al., 2020), we
358 ensured that the test dataset only contained habitat time-series sites where the LULC in the
359 habitat sites matched the corresponding baseline map, to ensure a fair comparison in the
360 following interpolated map. Each of the ten training datasets were used to determine the
361 percentage change for each LULC type and the significant factors which influenced change,
362 as described above. For each of the ten cross-validation datasets for 1950 and 1980, InVEST
363 was run in Python 2.7.0 one hundred times to account for the random selection of cells for
364 change when all suitability factors and transition likelihoods were equal. A final output for
365 each of the ten cross-validation datasets, was created using the modal LULC type for each
366 cell. Where cells had equal counts of two LULC types no modal LULC was identified, thus
367 these cells remain as “No data”. This occurrence was infrequent, occurring in a mean of just
368 0.5% of cells per model run (see Table 2). During the process of combining the one hundred
369 rasters using the modal LULC for each cell, if a LULC type did not demonstrate change due
370 to the large number of possible cells where the conversion could occur, meaning none of the
371 changes were evident in the final modal map, we used the cross-validation dataset with the
372 greatest accuracy and the most accurate run within this set to determine where the LULC
373 change should take place.

374

375 To validate the output for each of the ten datasets, we compared the LULC from the 1950 and
376 1980 map outputs with the LULC assigned in the corresponding year in the habitat time-
377 series (Ridding et al., 2020) using the test datasets (i.e. the remaining 25%). Accuracy was
378 calculated as the percentage of habitat time-series sites which were consistent between the
379 LULC type in Ridding et al. (2020) and the 1950/1980 LULC output from InVEST. In order
380 to determine the Cohen’s Kappa Index, which measures the inter-rate agreement between two
381 datasets (McHugh, 2012), a single LULC type per site is required, so for sites containing
382 multiple LULC types we assigned the LULC from the 1950/1980 InVEST output which had
383 the largest coverage in area within the habitat site.

384

385 To produce the final 1950 and 1980 map output, we determined the modal LULC across the
386 ten map outputs produced from the cross-validation datasets. For individual cells with no
387 modal LULC type, we assigned the LULC to the cross-validation dataset output which
388 performed the best, determined using the highest percentage agreement and Kappa Index
389 values. The final 1950 and 1980 map output was validated and averaged across the ten test
390 datasets.

391

2.8. Uncertainty

To map uncertainty associated with the model runs in InVEST, we calculated how many of the one hundred output rasters matched the final modal LULC for each cell, for each of the ten cross-validation datasets, following Redhead et al. (2020). An average certainty value for the whole study area was generated, excluding cells which were included as a constraint or override layer. This is because these cells were not allowed to change in InVEST, thus the one hundred output rasters would always match the final modal output, therefore biasing the overall certainty score. To map and determine uncertainty for the final 1950 and 1980 map output, we averaged across the ten datasets.

3. Results

3.1. Accuracy

The created 1950 and 1980 LULC maps (Fig. 2) showed a strong correspondence with the LULC from the habitat time-series dataset across all of the ten cross-validation model runs and also the final map output for each time point, as indicated by the accuracy values in Table 2. There were also high levels of agreement between the map output and validation dataset, evidenced by the Kappa Index (Table 2), where values between 0.80 and 0.9 indicate a strong level of agreement (McHugh, 2012). The lowest Kappa Index recorded overall (0.77), still suggests a good level of agreement between the two datasets. The accuracy and agreement was slightly higher for the final 1950 output compared with that for 1980.

Error matrices were also generated for each time point; 1950 and 1980 (Table 3). Many LULC types showed good agreement between the generated map output and the habitat time-series in 1950, including “coastal”, “fen, marsh and swamp” and “broadleaved woodland”. However there was some confusion between semi-natural grasslands and arable/improved grassland. There was also confusion between improved grassland and arable, where more improved grassland sites were classified as arable in the generated 1950 LULC map. Similar patterns were shown in the error matrices for 1980, with LULC types such as “coastal”, “heathland”, “fen, marsh and swamp” and “broadleaved woodland”, being fairly consistent between the two datasets. The classification of calcareous grassland was better for 1980, however there was still confusion between neutral grassland, arable and improved grassland.

3.2. Timing of LULC change between 1930 and 2015

The landscape underwent significant changes between 1930 and 2015 (Fig. 2). In 1930 the landscape was dominated by semi-natural grasslands (ca. 155, 008 ha) compared with 2015 when Dorset was dominated by improved grassland and arable land (ca. 200, 547 ha) (Table 4). Arable land expanded the greatest by 1950 in a region running south-west to north-east in Dorset (Fig. 2). This area and time period also coincided with the greatest loss of calcareous grassland (-25,096 ha). The loss of neutral grassland which occupied much of the north and western area was also higher by 1950 (-57,413 ha). The largest increase in improved

436 grassland however, occurred between 1950 and 1980. Acid grassland and heathland are
437 located in the south-east of the region, but reduced dramatically in area by 2015, with the
438 greatest change occurring by 1980. This was largely due to expansion of coniferous
439 woodland and urbanisation, as well as improved grassland.

440

441 *3.3. Modelled Factors*

442

443 A range of physical and environmental variables were found to have a significant influence
444 on the suitability for LULC change between 1930 and 1950, and 2015 and 1980 (Table 5).
445 Many of the variables, including slope, soil texture and soil fertility were consistently
446 significant across all of the ten cross validation datasets, suggesting they were good
447 predictors of where particular LULC should occur (Table 5). Some variables, including soil
448 texture and fertility, showed no variation for certain LULC types, meaning certain values
449 were strongly associated with particular LULC types. For instance, heathland was
450 consistently found on acidic sandy soils. Consequently models could not converge, which
451 provided a strong justification to include these variables as modelled factors in InVEST.

452

453 To determine the best factor weight for the modelled factors against the transition matrix for
454 InVEST (Fig. 1), we ran InVEST one hundred times for the first cross-validation dataset
455 using three different weightings (0.3, 0.5 and 0.7) and compared the output LULC map with
456 LULC from the habitat time-series. We determined that a factor weight of 0.5 produced the
457 most accurate results and the highest Kappa Index score (Accuracy: 88%, Kappa Index:
458 0.84), compared with 0.3 (87%, 0.82) and 0.7 (79%, 0.71), thus this factor weight was used
459 for remaining cross-validation datasets for the 1950 and 1980 output. A factor weight of 0.5
460 ensures an equal contribution from influential factors and the transition matrix.

461

462 *3.4. Uncertainty*

463

464 There was greater certainty across the 1980 cross-validation datasets and the final map output
465 compared with 1950 (Table 2). However, datasets from both time periods demonstrated high
466 levels of certainty associated with the InVEST model. In each of the certainty maps (Fig. 2),
467 there were particular regions of uncertainty across Dorset, which overlapped to some degree
468 in both time periods. Much of the uncertainty in the 1950 output was concentrated around the
469 south and east of Dorset. There was some overlap in the southern region in the 1980 output,
470 but this appeared to extend further north. Very few cells across all of the cross-validation
471 datasets for 1950 and 1980 contained “No data” suggesting there were only a small number
472 of cells where no modal LULC was identified (Table 2).

473

474 **4. Discussion**

475

476 *4.1. Accuracy*

477

478 The modelling method employed in this study demonstrated high levels of accuracy, with
479 both the 1950 and 1980 LULC maps showing a strong correspondence with the habitat time-

480 series dataset. Although this may be expected given that the rule transitions are based on that
481 dataset, a number of other parameters were determined for InVEST, which were clearly
482 effective in this study. This shows that with just a limited sample of habitat sites, this
483 modelling method can predict and determine historical changes across a landscape.
484

485 A significant proportion of the mismatch between the map outputs and the habitat time-series
486 occurred between arable and improved grassland. However, some confusion between these
487 intensive agricultural LULC types might be expected, particularly when modelling from
488 2015 to 1980, since agricultural systems in the UK often have grass and clover leys
489 incorporated into arable rotations to manage weed problems or to increase soil fertility
490 (AHDB, 2018) so the two classes are not necessarily mutually exclusive. This confusion
491 could also be due to a number of social, economic and political issues that we could not
492 model, including changes in pricing and profitability of crops vs. livestock (Zayed, 2016).
493 There was also some confusion between some of the semi-natural grasslands and arable,
494 particularly for the 1950 map output (Table 2), which is consistent with other historical land
495 cover modelling (e.g. Fuchs et al., 2013). This highlights the difficulty in predicting such
496 change and is likely to arise because other small scale factors which cannot be captured by
497 InVEST, will also be influencing change, such as land ownership.
498

499 Despite the strong correspondence between map outputs and the habitat time-series, some
500 LULC types which are known to have undergone considerable change between 1930 and
501 1950, changed by very little or not at all e.g. acid grassland (Table 4). Little heathland was
502 converted in the 1950 map output, but it is known that this habitat experienced dramatic
503 declines across Dorset over that time period (Moore, 1962; Webb and Haskins, 1980). This is
504 likely to be due to the fact that large areas of heathland were lost to coniferous woodland
505 during this period, which InVEST struggled to predict. This is because the area of coniferous
506 woodland in 1930 was very small to begin with and the modelled factors only assisted in
507 narrowing down the location of change to sandy acidic soils, which corresponded in general
508 to the occurrence of heathland in Dorset, rather than narrowing down to specific 100m cells
509 within heathland areas. Fen, marsh and swamp and acid grassland were other LULC types
510 which reduced by very little, if at all. This may be because these LULC types were competing
511 with change from other LULC types such as calcareous and neutral grassland, which
512 underwent significant conversion to improved grassland and arable and were a higher priority
513 for change (Online Resource 4). This reflects one of the weaknesses of the InVEST tool,
514 which currently models LULC change based on the percentage change of increasing LULC
515 types only and not those which have shrunk.
516

517 Other issues arose due to differences with the baseline maps that were used to model the 1950
518 and 1980 outputs. For instance, the LULC type, “other”, in this study referred to inland rock,
519 which was classified in the 2015 map (Rowland et al., 2017a) and hence the generated 1980
520 output, but was absent from the 1930 and 1950 maps. There were also differences in how
521 water was mapped, with rivers included in the 1930 baseline map, but not in 2015. The same
522 was true for woodlands, with different classes for the baseline maps, which may explain why
523 broadleaved woodland did not follow the trends identified in other studies (Hooftman and

524 Bullock, 2012; Ridding et al., 2020). Furthermore, the definitions of LULC types varied
525 slightly between the start and end maps for fen, marsh and swamp and coastal. For example,
526 coastal in the 1930s map referred to sand dunes/littoral sediment, whilst in the 2015 map this
527 included categories such as littoral rock, littoral sediment, supra-littoral rock and supra-
528 littoral sediment.

529

530 *4.2. Timing of LULC changes between 1930 and 2015*

531

532 The modelling method employed in this study has enabled us to identify the timing and
533 spatial patterns of key LULC changes over ca. 85 year period. Overall, we found that 87% of
534 semi-natural habitat was lost in Dorset, with the greatest losses occurring in neutral (99%)
535 and calcareous (97%) grasslands. These results are consistent with other studies in Dorset
536 (Hooftman and Bullock, 2012) and across England and Wales (Fuller, 1987; Ridding et al.,
537 2015). By creating the time-series of LULC maps, we were able to determine that the greatest
538 loss of calcareous and neutral grassland occurred in the period 1930-1950. This corresponds
539 to the time where arable land increased most across Dorset, which is consistent with the
540 period of agriculture intensification across Europe (Best and Coppock, 1962; Stoate et al.,
541 2001). The time-series also enhanced findings from Ridding et al. (2020) by revealing where
542 the changes occurred spatially; largely to the west of the county and along the fertile band of
543 chalk soil running south-west to north-east. The largest increase in improved grassland
544 occurred between 1950 and 1980. Arable land, however decreased after the 1950s. This most
545 likely reflects the shift in farming, whereby fewer fields were required for conversion after
546 advances in mechanisation and chemical applications led to great increases in yield (Stoate et
547 al., 2001). There were also a number of economic and political factors, including falls in
548 prices for agricultural products. Since a number of land covers, for example heathland, did
549 not change by much between 1930 and 1950 using our modelling methodology, it was
550 difficult to identify a more exact time period of loss, however the generation of the 1980
551 LULC map revealed that by this point there had already been a considerable loss of
552 heathland.

553

554 *4.3. Uncertainty*

555

556 This study found low levels of uncertainty associated with the methodology, with an average
557 of over 90% of the hundred runs matching with the final 1950 and 1980 map outputs. This
558 means we have confidence in the modelled placement of the majority of LULC types,
559 suggesting the modelled factors and transition tables were useful in narrowing down
560 appropriate locations for certain LULC types to occur. This highlights the importance of
561 having comprehensive data which can be used to inform InVEST, as the habitat time-series
562 dataset (Ridding et al., 2020) did in our study. There was slightly greater certainty for the
563 1980 map compared with the 1950 map, which may reflect that more significant modelled
564 factors were identified for changes from 2015 to 1980 compared with 1930 to 1950, giving
565 InVEST more information and thus confidence in the placement of increasing LULC types.

566

567 There were particular areas in Dorset that demonstrated higher levels of uncertainty, which
568 were generally found around the southern and eastern areas of the region. There were areas of
569 overlap along the southern coast towards the east on both the 1950 and 1980 maps. For 1950
570 this resulted in large amounts of arable land being predicted in these areas. It is likely that
571 these areas were suitable for arable, including being flatter, having high soil fertility and a
572 lower average temperature (significant modelled factors) and InVEST struggled to decide the
573 exact 100 m x 100 m cells in which to position arable, so when the final modal map was
574 created numerous arable cells were generated.

575

576 **5. Conclusion**

577

578 This study has shown that it is possible to generate a time-series of historical landscapes
579 using a modelling method which involved the use of InVEST and detailed habitat time-series
580 data to inform the model. To our knowledge this is the first time InVEST has been used
581 reconstruct historical landscapes, rather than predict future scenarios (Gibson and Quinn,
582 2017; Sharma et al., 2018). We have shown that the method produced accurate outputs, but
583 highlight the importance of obtaining appropriate data to inform the model. The creation of
584 this LULC time-series allowed spatial and temporal changes in LULC to be identified over
585 multiple time periods. This builds on Hooftman and Bullock (2012) by revealing more
586 accurately the timing of change for certain LULC types, for instance the greatest losses in
587 neutral and calcareous grassland occurred in 1950, the period when arable land expanded the
588 most. We also determined a high level of certainty in using the modelling method employed
589 in this study. This is important to assess, but is often overlooked in other LULC prediction
590 studies (Sharma et al., 2018). Although the generated maps are not suitable for performing
591 fine-scale analysis, particularly where high levels of uncertainty were detected, they are
592 however useful for looking at more general patterns at the landscape scale, including habitat
593 fragmentation and changes in ecosystem service delivery. This can be useful for
594 environmental managers and landscape planners for informing future land management
595 plans, as well as conservation strategies such as restoration. The modelling methodology can
596 be used to create historical landscapes in any situation, providing there is sufficient data to
597 inform the InVEST model.

598

599 This study however, has also highlighted some of limitations of reconstructing historical
600 LULC maps, even when a region has abundant data, as in this study. This is particularly
601 relevant for LULC types which cover a small area or those which have little information on
602 environmental or physical factors which inform where a LULC type should occur. Increasing
603 the availability of relevant data would improve such mapping approaches. This has also been
604 identified in other studies (Liping et al., 2018; Sharma et al., 2018). For instance, increasing
605 the availability of temporal datasets would be very beneficial for historical mapping, since
606 most data are often static in time, such as accessibility and distance to roads. Furthermore, the
607 indirect factors which are often very influential on LULC change, including political or
608 economic drivers, such as the market for agricultural goods or the introduction of a new
609 policies, are currently not incorporated due to model limitations. The incorporation of such

610 factors into modelling programs such as InVEST and the associated effect on accuracy is
611 required.

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Table 1 A summary of variables used to model LULC change in Dorset between 1930 and 1950, and 2015 and 1980, with their source, scale/resolution and description

Variable	Source	Scale	Description
Elevation	Digital Elevation Model (Intermap Technologies, 2007)	5m	Average elevation per 100 m grid square
Slope	Digital Elevation Model (Intermap Technologies, 2007)	5m	Average slope per 100 m grid square
Average temperature	CEH-CHESS (Robinson et al., 2017)	1km	Average temperature between 1930 and 1950 (and 1980 and 2015)
Temperature change	CEH-CHESS (Robinson et al., 2017)	1km	Slope of temperature change between 1930 and 1950 (and 1980 and 2015)
Average rainfall	CEH-GEAR (Tanguy et al., 2016)	1km	Average rainfall between 1930 and 1950 (and 1980 and 2015)
Rainfall change	CEH-GEAR (Tanguy et al., 2016)	1km	Slope of rainfall change between 1930 and 1950 (and 1980 and 2015)
Soil Texture	National Soilscape Map (Cranfield University, 2004)	1:250,000	Five classes of soil texture; clayey, loamy, sandy, peaty, 0
Soil Fertility	National Soilscape Map (Cranfield University, 2004)	1:250,000	Seven classes of soil fertility, ranging from very low to high.
Soil Drainage	National Soilscape Map (Cranfield University, 2004)	1:250,000	Six classes of drainage, ranging from freely draining to impeded draining
Agricultural Land Classification (AGL)	(Natural England, 2012)	1:250,000	Five classes which represent the quality of farmland, ranging from excellent to very poor

Table 2 Accuracy, Kappa Index and certainty scores for each of the ten cross-validation datasets for the creation of the 1950 and 1980 LULC map for Dorset

Year	Cross-validation dataset	Accuracy (%)	Kappa Index	Average certainty	% of No Data
1950	1	88	0.84	89.83	0.19
	2	86	0.81	91.19	0.75
	3	88	0.83	90.41	1
	4	86	0.81	90.38	0.57
	5	88	0.83	89.83	2.03
	6	84	0.79	90.59	0.77
	7	88	0.84	90.73	0.93
	8	86	0.81	90.68	0.61
	9	89	0.85	90.31	0.77
	10	89	0.85	90.37	1.53
	Final	87	0.82	90.30	0
1980	1	83	0.77	94.33	0.17
	2	86	0.82	95.32	0.17
	3	83	0.78	96.42	0.17
	4	85	0.80	94.39	0.17
	5	87	0.82	94.34	0.17
	6	86	0.81	94.40	0.17
	7	82	0.77	95.69	0.17
	8	82	0.77	97.23	0.17
	9	86	0.81	95.00	0.17
	10	84	0.79	95.30	0.17
	Final	84	0.78	95.24	0

Table 3 Error matrices for (a) the final 1950 LULC map compared with the corresponding LULC from the habitat time-series (Ridding et al., 2020) and (b) the final 1980 LULC map compared with the corresponding LULC from the habitat time-series.

(a)

		Generated 1950 LULC map											
		Coastal	Arable	Fen, marsh, swamp	Acid grassland	Calcareous grassland	Improved grassland	Neutral grassland	Heathland	Urban	Water	Broadleaved woodland	Coniferous woodland
1950 LULC from habitat time-series	Coastal	16	0	0	0	0	0	0	0	0	0	0	0
	Arable	0	139	0	1	10	4	6	4	0	0	2	0
	Fen, marsh, swamp	0	0	20	0	0	1	0	0	0	0	0	0
	Acid grassland	0	0	0	6	0	0	0	0	0	0	0	0
	Calcareous grassland	0	40	0	0	355	1	0	0	0	0	0	0
	Improved grassland	0	53	0	5	13	22	28	11	1	0	4	0
	Neutral grassland	0	41	0	0	0	2	146	0	0	0	0	0
	Heathland	0	0	0	0	0	0	0	170	0	0	3	0
	Urban	0	0	0	0	2	0	1	0	2	0	3	0
	Water	0	0	0	0	0	0	0	0	0	19	0	0
	Broadleaved woodland	0	5	0	0	4	0	2	0	0	0	1022	3
	Coniferous woodland	0	1	0	0	2	0	0	30	0	0	3	6

The diagonal elements (bold) represent number of correctly classified sites

(b)

		Generated 1980 LULC map												
		Coastal	Arable	Fen, marsh, swamp	Acid grassland	Calcareous grassland	Improved grassland	Neutral grassland	Heathland	Other	Urban	Water	Broadleaved woodland	Coniferous woodland
1980 LULC from habitat time-series	Coastal	38	2	1	0	1	1	0	0	0	0	0	0	0
	Arable	0	361	0	0	1	79	0	0	0	0	0	4	1
	Fen, marsh, swamp	1	3	21	1	0	38	0	4	1	2	0	24	6
	Acid grassland	0	1	0	2	0	4	0	1	0	0	0	0	0
	Calcareous grassland	1	8	0	0	80	39	0	0	0	2	0	3	1
	Improved grassland	0	53	0	1	4	522	1	1	0	0	0	3	0
	Neutral grassland	2	8	0	0	0	42	5	1	0	0	0	4	0
	Heathland	0	2	0	1	0	4	0	118	0	3	0	1	5
	Other	0	0	0	0	0	0	0	0	0	0	0	0	0
	Urban	0	0	0	0	0	1	0	0	0	10	0	0	0
	Water	0	0	0	0	0	2	0	0	0	0	6	0	1
	Broadleaved woodland	0	16	1	0	2	24	0	0	0	0	0	892	0
	Coniferous woodland	0	0	0	0	1	3	0	0	0	0	0	1	76

The diagonal elements (bold) represent number of correctly classified sites
Table 4 Area (ha) of each LULC type in Dorset between 1930 and 2015.

LULC	1930	1950	1980	2015
Water	1720	1762	651	665
Arable	44807	112443	86305	80426
Neutral grassland	101994	44202	946	672
Calcareous grassland	49022	23225	4331	1522
Acid grassland	4458	4458	412	422
Fen, marsh, swamp	478	476	489	605
Improved grassland	0	16104	111435	120121
Heathland	13912	13908	6091	5737
Coastal	460	460	1329	1222
Urban	14147	14288	14264	14396
Broadleaved woodland	20229	19132	16414	15822
Coniferous woodland	45	855	7477	8420
Other	0	0	703	814

Table 5 Factors, their direction of change indicated by arrows (↑ = increase, ↓ = decrease) and significance (*p < 0.05, **p < 0.01, ***p < 0.001), included in each of the ten-cross validation sites for (a) increasing the area of coniferous woodland, improved grassland and arable in 1950 compared to 1930, and (b) increasing the area of arable, neutral grassland, calcareous grassland, heathland, coastal and FMS (fen, marsh, swamp) habitats for 1980 compared to 2015. # indicates model could not converge with these variables present, due to a large number of sites being allocated within the same category (these variables were thus included for use in InVEST).

(a) 1950 from 1930

Habitat	Factors	1	2	3	4	5	6	7	8	9	10
Coniferous	Rainfall change	↓**	↓**	↓**	↓***	↓***	↓**	↓***	↓**	↓**	↓***
Coniferous	Temperature change	↑**	↑**	↑**			↑**	↑**	↑**		
Coniferous	Soil fertility	#	***	#	***		#	#	#		
Coniferous	Soil texture	#	***	#			#	#	#		
Coniferous	Soil drainage	#	***	#			#	#	#		
Improved	Temperature change							↑*			
Improved	Slope	↓**	↓***	↓***	↓**	↓***	↓**	↓**	↓**	↓**	↓**
Arable	Slope	↓***	↓***	↓***	↓***	↓***	↓***	↓***	↓***	↓***	↓***
Arable	Soil fertility	**	**	**	**	**	**	**	**	**	**
Arable	Average temperature	↓***	↓*	↓*	↓***	↓**	↓**	↓**	↓***	↓**	↓**

(b) 1980 from 2015

Habitat	Factors	1	2	3	4	5	6	7	8	9	10
Neutral	Soil drainage	#			#						
Neutral	Temperature change	↓*			↓**		↓*			↓*	
Neutral	AGL			#						#	
Neutral	Rainfall change				↑*						
Neutral	Soil fertility								#		
Neutral	Soil texture								#		#
Calcareous	Temp change	↓*		↓*	↓**		↓*	↓*	↓*	↓*	↓**
Calcareous	Slope	↑**	↑*			↑*			↑*		↑**
Calcareous	AGL			#		#	#			#	
Calcareous	Rainfall change				↑*						
Calcareous	Soil fertility										
FMS	Slope	↓*								↓*	↓*
FMS	Soil texture	**	**	**	**	**	**	**	**	**	**

FMS	Soil fertility	**	**	**	***	**	**	**	**	**	**
FMS	Soil drainage	#	#	#		#		#		#	#
FMS	Temperature change	↓***	↓***	↓**	↓*	↓**	↓***	↓***	↓**	↓**	↓***
FMS	Average temperature	↑*	↑***	↑***	↑***	↑*	↑**		↑**	↑*	↑*
FMS	Average rainfall	↑**	↑**	↑**	↑***	↑**	↑**	↑**	↑*	↑**	↑**
Arable	Slope	↓***	↓***	↓***	↓***	↓***	↓***	↓***	↓***	↓***	↓***
Arable	Temperature change	↓**	↓*		↓*				↓*	↓*	↓*
Arable	Soil fertility			*		*				*	**
Arable	AGL				*		*				
Arable	Average temperature									↓*	
Heathland	Soil drainage	#	#	#	#	#	#	#	#	#	#
Heathland	Slope	↓*	↓*	↓*		↓*		↓*	↓*	↓*	↓**
Heathland	Soil fertility	#	#	#	#	#	#	#	#	#	#
Heathland	Soil texture	#	#	#	#	#	#	#	#	#	#

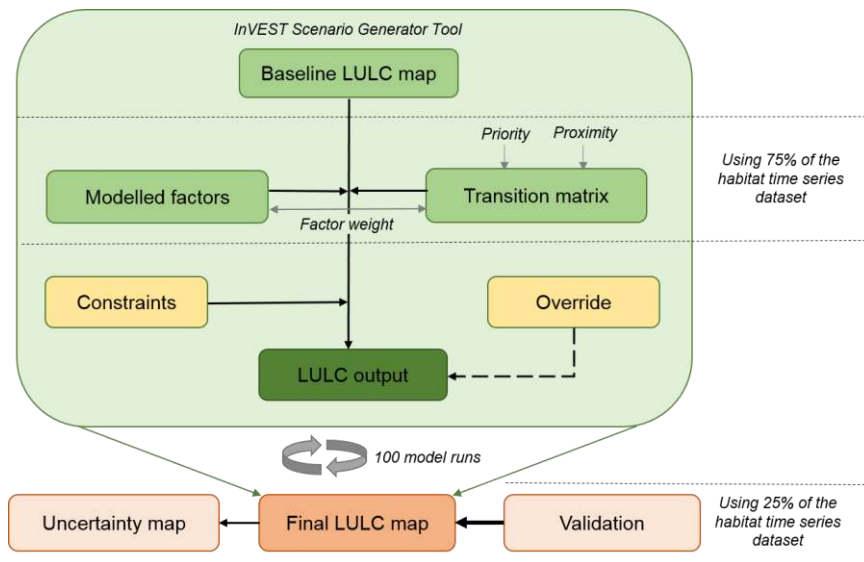


Fig. 1 Schematic showing the methodology used to create the 1950 and 1980 LULC maps of Dorset (adapted from Sharp et al. (2016))

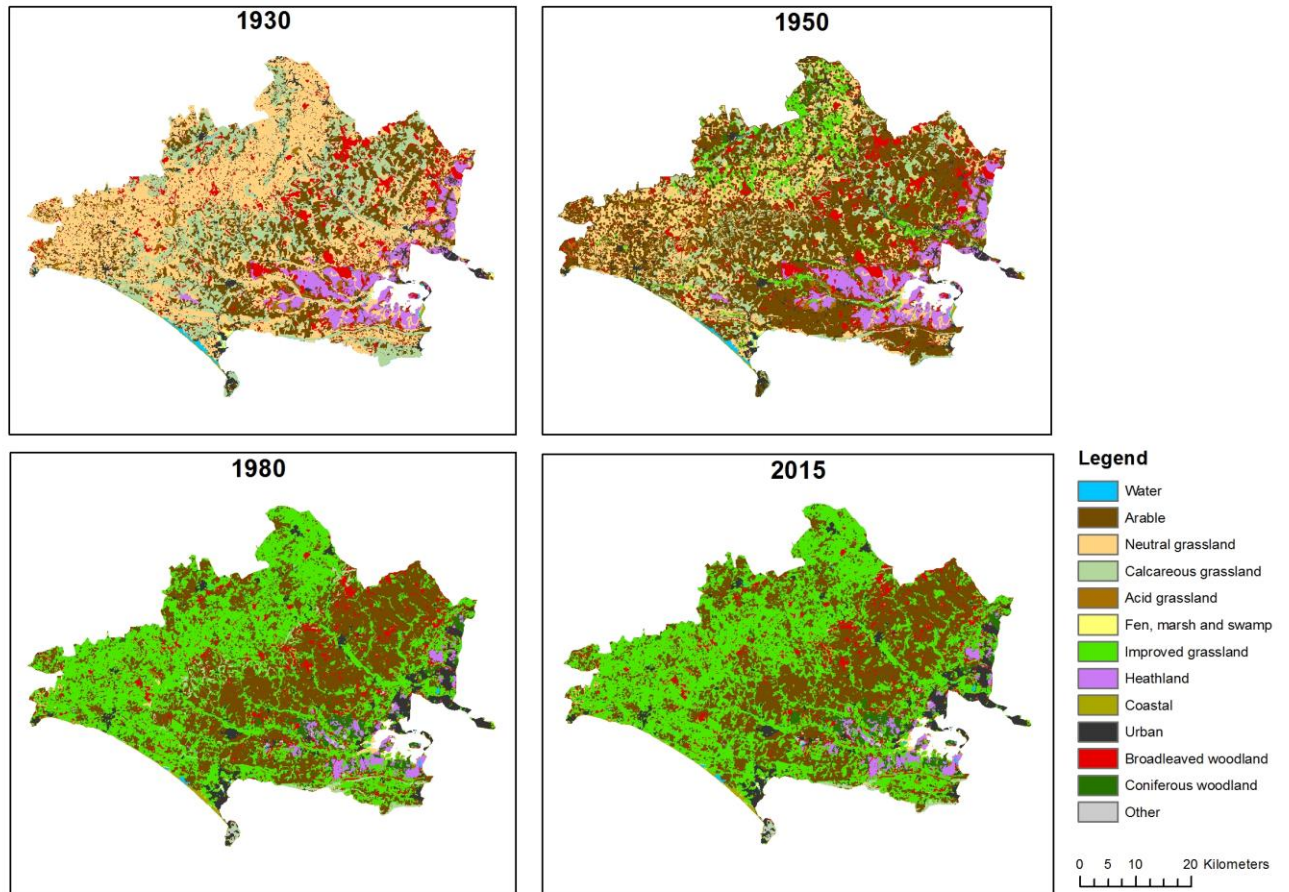


Fig. 2 LULC maps of Dorset indicating the 11 LULC types in 1930 (Hooftman and Bullock, 2012), 1950, 1980 and 2015 (Rowland et al., 2017a)

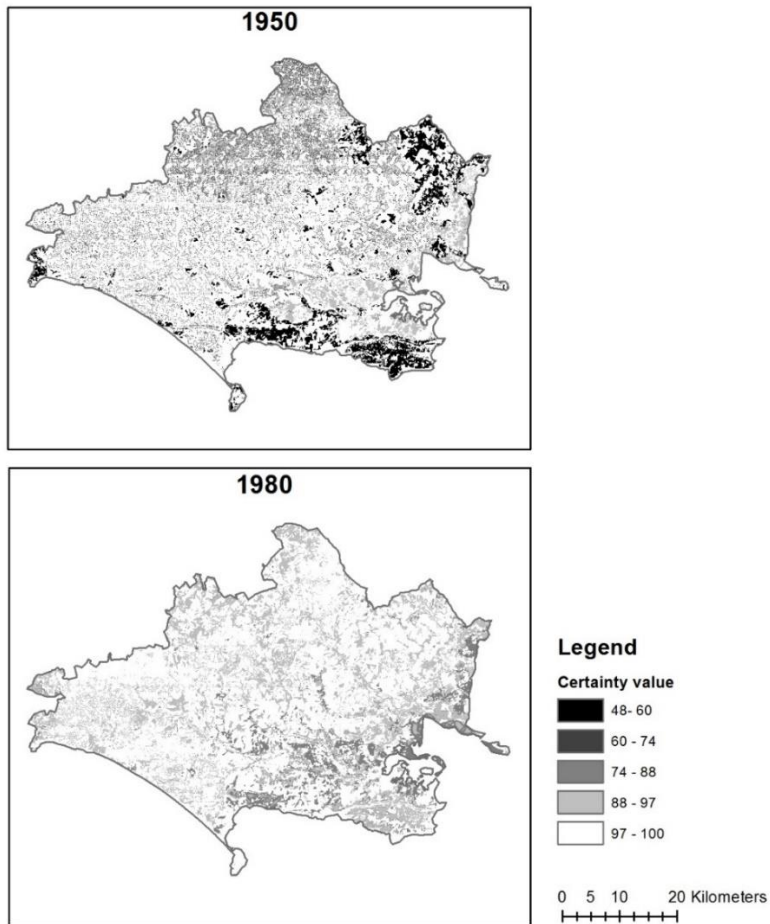


Fig. 3 Certainty maps of Dorset for 1950 and 1980, where light areas show good agreement between the hundred runs and the final modal map, whilst areas in black show greater uncertainty

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Online Resources

Online Resource 1 Justification of methodology for 1980 LULC map

To generate the 1980 LULC map for Dorset, we also modelled landscape change using the generated 1950 map as the baseline, rather than the Land Cover Map 2015 (LCM2015) (Rowland et al., 2017a). The same methodology of using the habitat time-series from Ridding et al. (2020) was employed to quantify the LULC change and generate the transition matrix, except this time we evaluated the change between 1950 and 1980, rather than 2015 to 1980. The LULCs which increased between 1950 and 1980 were consistent with the changes between 1930 and 1950, which included arable, improved grassland, coniferous woodland and urban. The same environmental factors (Table 1) were analysed using a logistic regression for the increasing LULCs, as described in the main text.

The resulting map output can be seen in Fig. S1a, alongside the 1980 map output produced using the LCM2015. The key difference between the 1980 output maps is the large difference in arable land that has been predicted from the two different baseline maps. To determine which map is likely to be the most accurate we used an alternative data source to validate the area of arable across Dorset in the 1980s. For this we used the Agriculture Census data which revealed the area of “total crops” in 1981 in 2km x 2km grid squares (data obtained from <http://edina.ac.uk/agcensus/>, accessed 24/10/18). We calculated the area of arable in both of the 1980 maps using the same 2km x 2km grid squares. To determine which of the 1980 maps matched the Agricultural Census best, we compared histograms and examined the association between each map with the Agricultural Census data using Spearman’s Rank Correlation. The histogram of the area of arable from the 1980 map created from LCM2015 (1980 from 2015) matches more closely with the Agricultural Census data compared with the 1980 map created from the 1950 (1980 from 1950) (Fig. S1b). The 1980 from 1950 histogram shows a more even frequency spread across the different areas, whilst the 1980 from 2015 shows a large proportion of 2km x 2km grid squares have smaller areas of arable, as in the Agriculture Census dataset. This is further confirmed by the stronger association detected between the 1980 from 2015 data and the Agricultural Census data ($R_s = 0.66$), compared with the 1980 from 1950 ($R_s = 0.58$) (Fig. S1c).

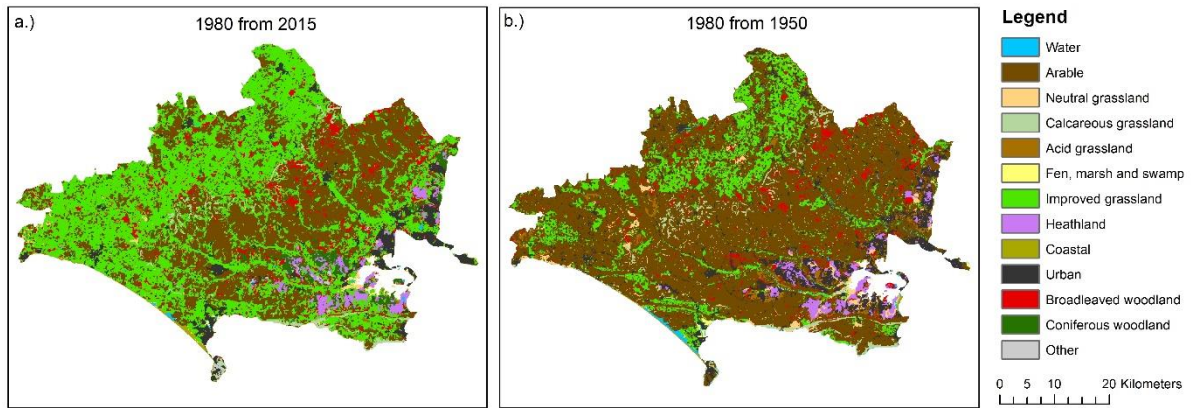


Fig. S1a Dorset LULC maps for 1980 created from a.) the Land Cover Map 2015 (Rowland et al., 2017a) and b.) the modelled 1950 map

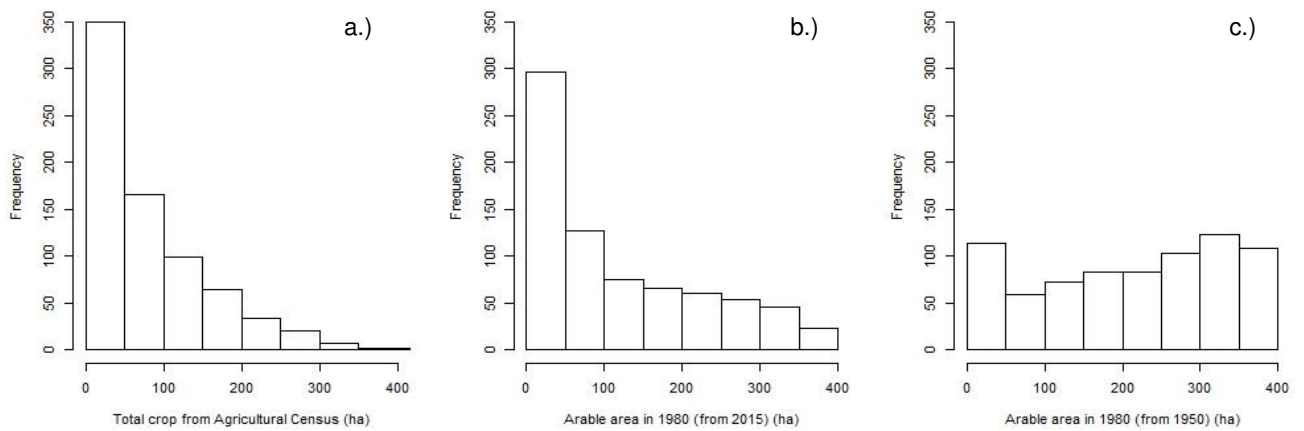


Fig. S1b Histograms showing the area of arable in Dorset in a.) 1981 from the Agricultural Census, b.) 1980 created from the Land Cover Map 2015 (Rowland et al., 2017a) and c.) 1980 created from the modelled 1950 map

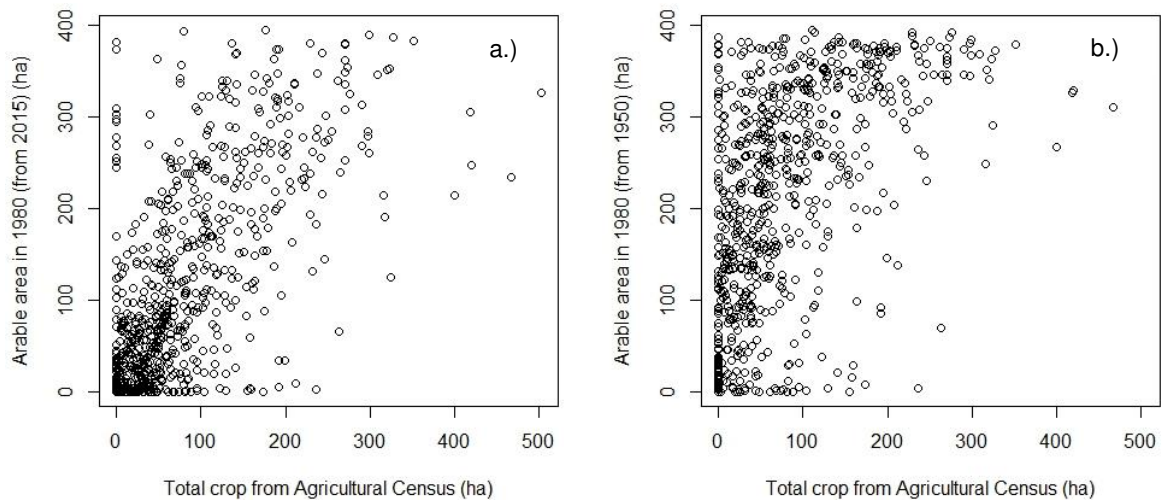


Fig. S1b Scatterplots showing the relationships between total crop in the Agricultural Census and arable in 1980 created from a.) the Land Cover Map 2015 (Rowland et al., 2017a) and b.) the modelled 1950 map

Online Resource 2 Transition matrix required for the InVEST Scenario Generator Tool (Sharp et al., 2016). This example is for the first cross-validation dataset for the creation of the 1950 map.

Id	Name	Water	Arable	Neutral	Calcareous	Acid	Fen, marsh, swamp	Improved	Heathland	Coastal	Urban	Broadleaved	Coniferous	Percent Change	Area Change	Priority	Proximity
1	Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Arable	0	0	0	0	0	0	0	0	0	0	0	0	122	0	8	1000
3	Neutral grassland	0	9	0	0	0	0	9	0	0	4	4	0	0	0	0	0
4	Calcareous grassland	0	9	0	0	0	0	9	0	0	4	4	6	0	0	0	0
5	Acid grassland	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0
6	Fen, marsh, swamp	0	9	0	0	0	0	8	0	0	4	8	4	0	0	0	0
7	Improved grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	15100	7	0
8	Heathland	0	5	0	0	0	0	8	0	0	4	4	8	0	0	0	0
9	Coastal	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0
10	Urban	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
11	Broadleaved woodland	0	6	0	0	0	0	7	0	0	0	0	6	0	0	0	0
12	Coniferous woodland	0	0	0	0	0	0	0	0	0	0	0	0	1275	0	5	1000

Online Resource 3 Transition matrix required for the InVEST Scenario Generator Tool (Sharp et al., 2016). This example is for the first cross-validation dataset for the creation of the 1980 map

Id	Name	Water	Arable	Neutral	Calcareous	Acid	Fen, marsh, swamp	Improved	Heathland	Coastal	Urban	Broadleaved	Coniferous	Other	Percent Change	Area Change	Priority	Proximity
1	Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Arable	0	0	7	8	0	0	7	0	0	0	0	0	0	5	0	7	1000
3	Neutral grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	375	0	9	1000
4	Calcareous grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	9	1000
5	Acid grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Fen, marsh, swamp	0	0	0	0	0	0	0	6	6	0	0	0	0	62	0	9	1000
7	Improved grassland	0	9	8	9	0	8	0	0	5	0	0	0	0	0	0	0	0
8	Heathland	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	9	1000
9	Coastal	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	7	1000
10	Urban	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
11	Broadleaved woodland	0	0	7	7	0	9	0	7	0	0	0	0	0	0	0	0	0
12	Coniferous woodland	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	1000
13	Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

