Supplementary Material to:

To what extent has Sustainable Intensification in England been achieved?

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The final published journal version can be found at:

https://doi.org/10.1016/j.scitotenv.2018.08.207

1. Climate Metrics

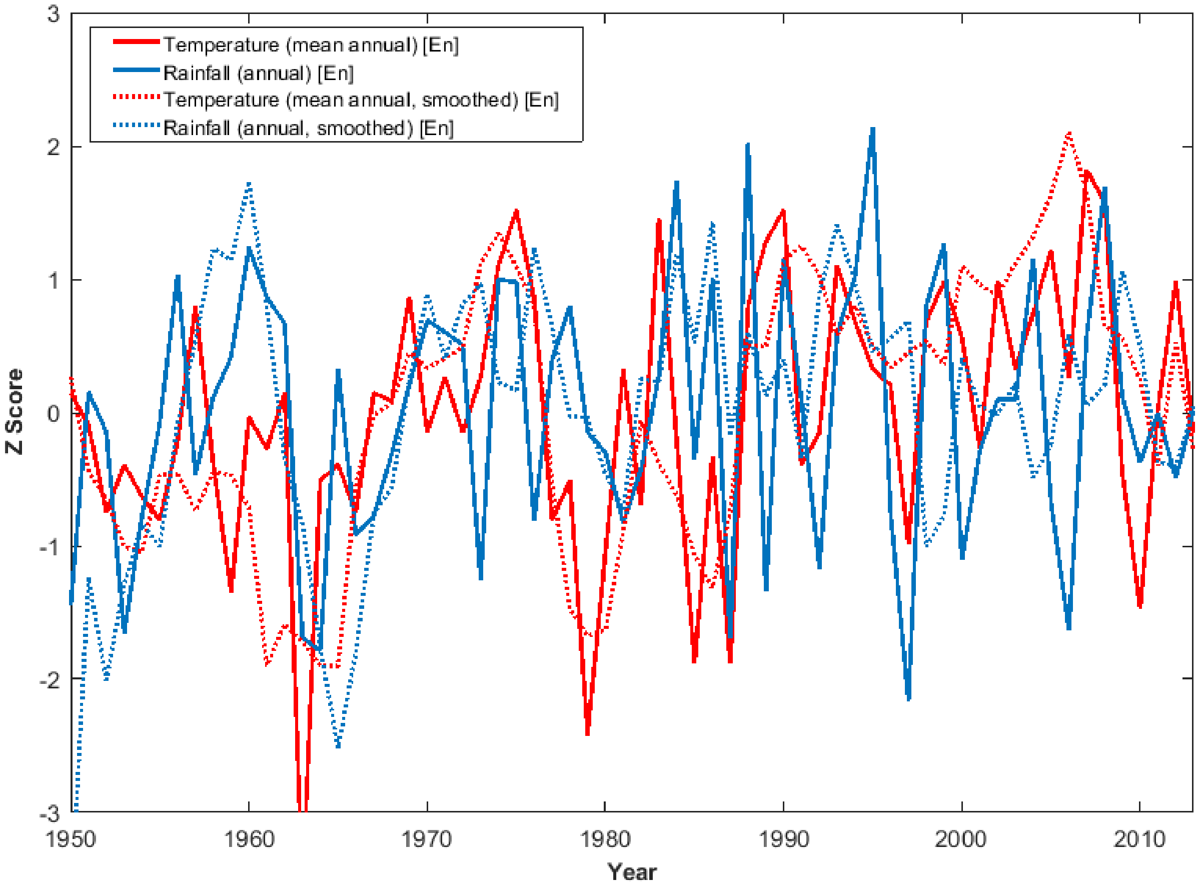

Figure S1: Climate metrics (mean annual temperature and annual rainfall) for England between 1950 and 2013 (Met Office, 2015). Mean Annual Temperature (unsmoothed) and Annual Rainfall (unsmoothed) are used for the England agroecosystem DCA, PCA, and correlation analyses as Climate-Temperature (Ct) and Climate-Rainfall (Cr) respectively.

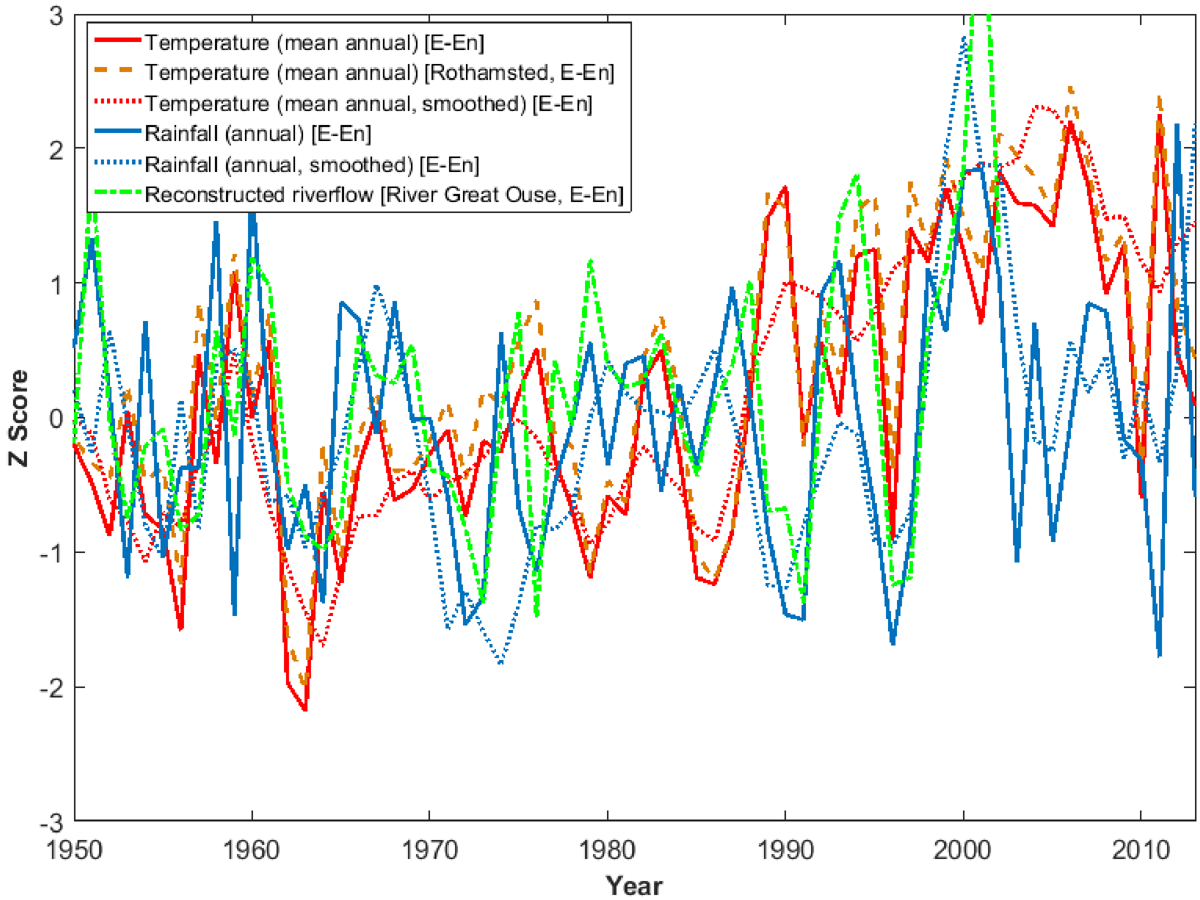

Figure S2: Climate metrics (mean annual temperature over the region and at Rothamsted, annual rainfall, and reconstructed riverflow of the River Great Ouse at Ely) for Eastern England between 1950 and 2013 (Jones et al., 2004; Met Office, 2015; Scott, 2014). Mean Annual Temperature (unsmoothed) and Annual Rainfall (unsmoothed) are used for the Eastern England agroecosystem DCA, PCA, and correlation analyses as Climate-Temperature (Ct) and Climate-Rainfall (Cr) respectively.

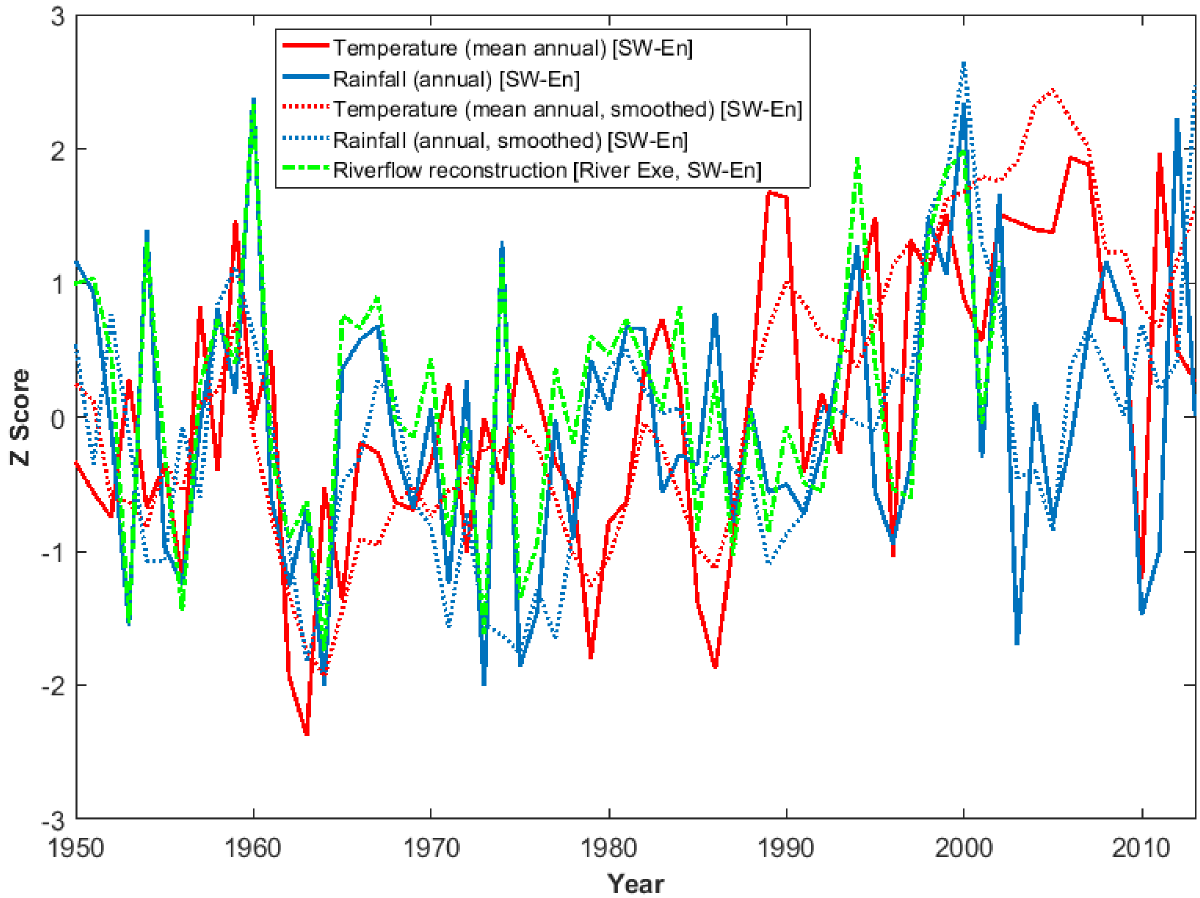

Figure S3: Climate metrics (mean annual temperature over the region, annual rainfall, and reconstructed riverflow of the River Exe) for Eastern England between 1950 and 2013 (Jones et al., 2004; Met Office, 2015). Mean Annual Temperature (unsmoothed) and Annual Rainfall (unsmoothed) are used for the South-Western England DCA, PCA, and correlation analyses as Climate-Temperature (Ct) and Climate-Rainfall (Cr) respectively.

2. Agricultural Area, Yield, and Self-Sufficiency

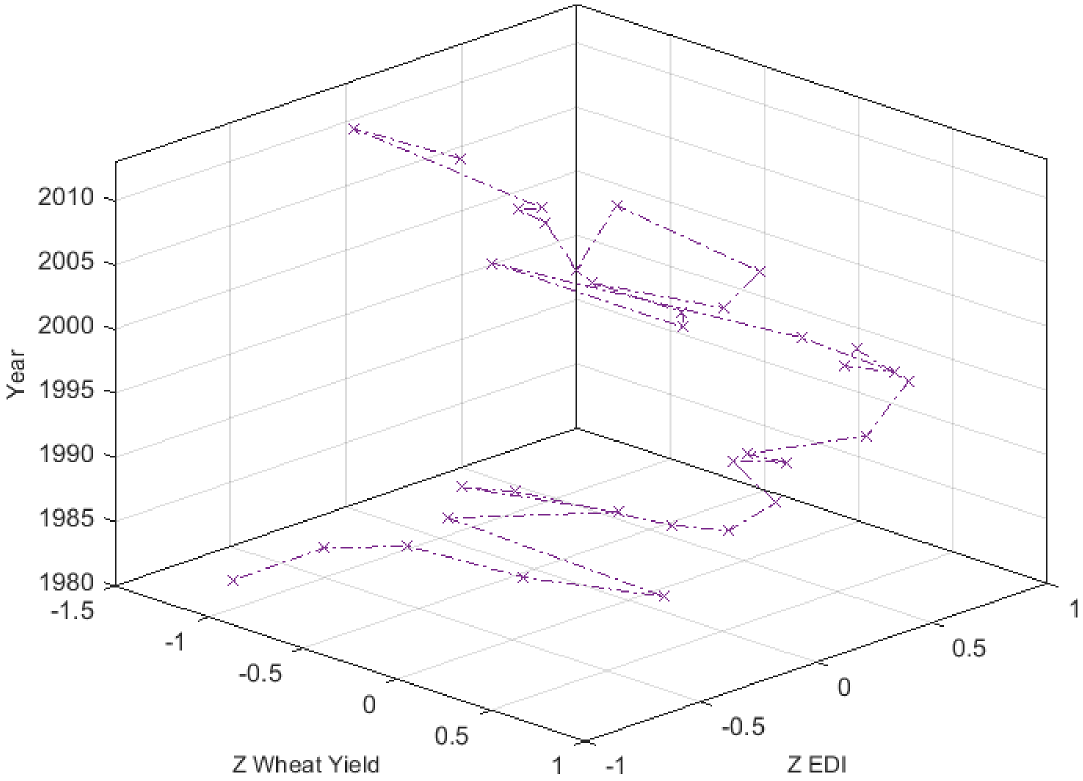

Figure S4: Phase plot showing the relationship between wheat yield (reflecting provisioning ecosystem services) and environmental degradation (reflecting regulating and cultural ecosystem services) through time. Wheat yield increases along with EDI until the mid-90s, after which yield remains high while EDI begins to fall. This illustrates the shift from 'green revolution' intensification to sustainable intensification.

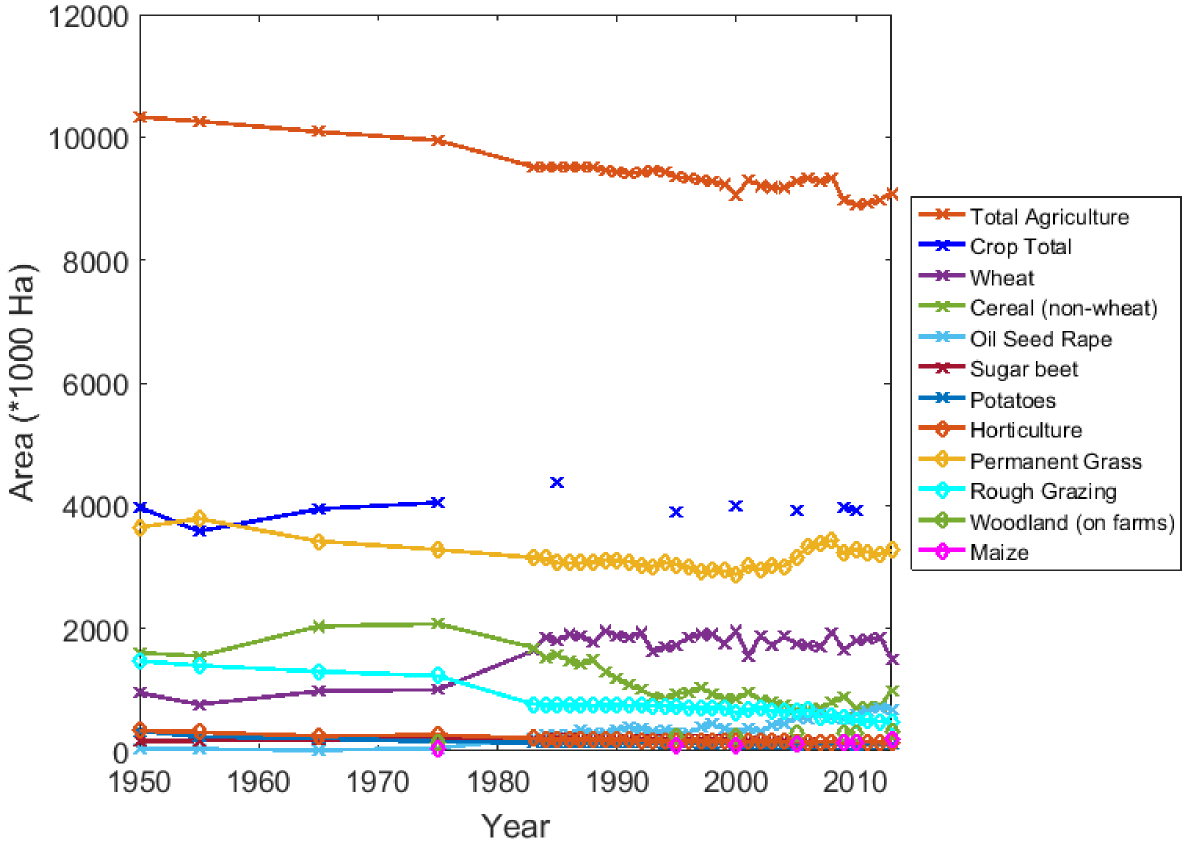

Figure S5: Changes in English agricultural land use between 1950 and 2013 (DEFRA, 2014). Total agricultural area has gradually fallen throughout this time (dominated by reduced rough grazing and mirrored by gradual reforestation (Smith and Gilbert, 2001)), wheat has become the dominant cereal by acreage, oil seed rape and maize have become major crops, and many minor crops (e.g. potatoes, sugar beet, horticultural crops) have declined. This suggests that 'land sparing' has predominantly affected rough grazing, and that arable areas have become more focused on wheat.

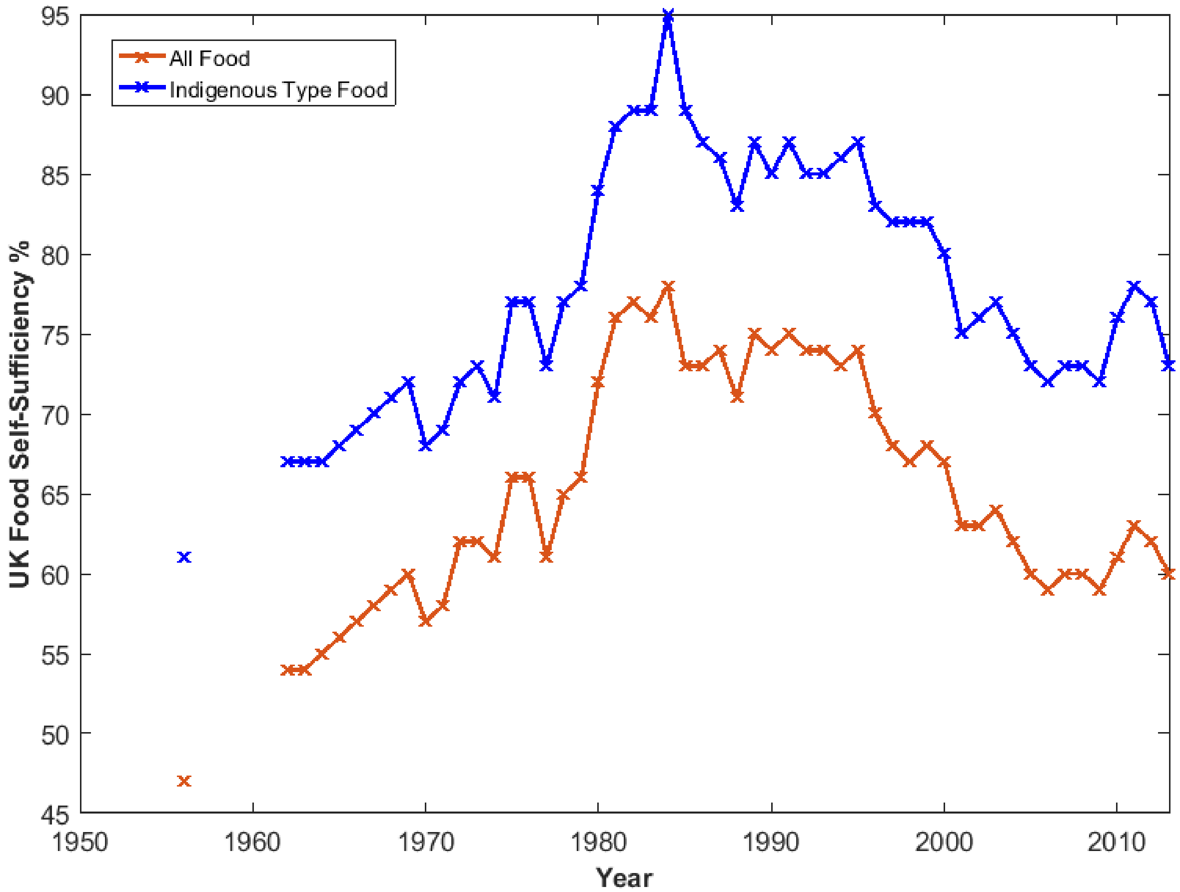

Figure S6: UK food self-sufficiency (i.e. food production to supply ratio, merged series) over time for both all food and indigenous type food (DEFRA, 2016). Self-sufficiency increased by nearly 20% during the agricultural intensification of the late 1970s and early 1980s, but has fallen since the mid-1990s during the time SI began to emerge in the England agroecosystem.

3. All-England Data Analysis

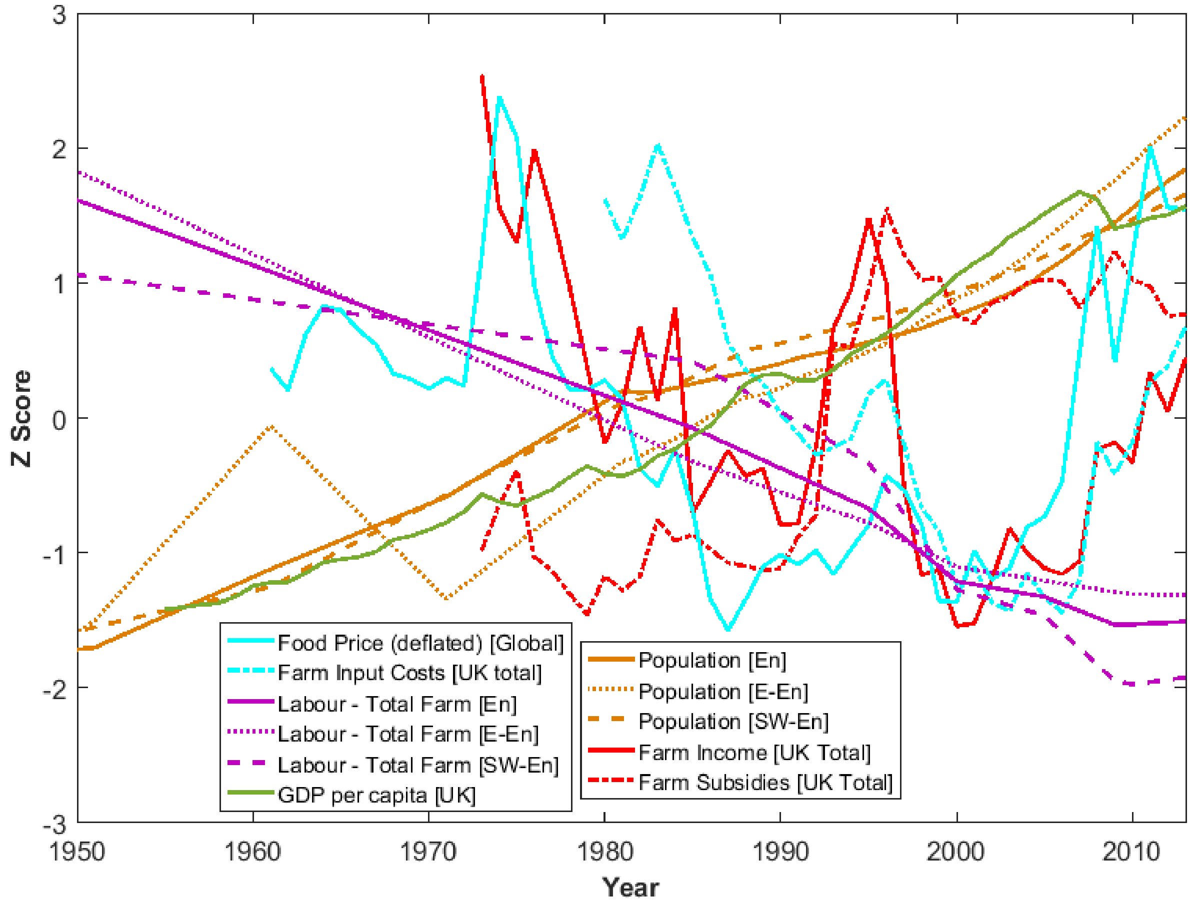

Figure S7: Z-score plot illustrating the socioeconomic parameters of the all-England, Eastern England, and South-Western England agroecosystems, with regional data shown where available. The population and agricultural labour headcount curves illustrates the declining proportion of agricultural employment in England and the regions of Eastern and South-Western England, while the food price indices, farm subsidies, and farm income illustrate the economic changes affecting agriculture across the UK in this time.

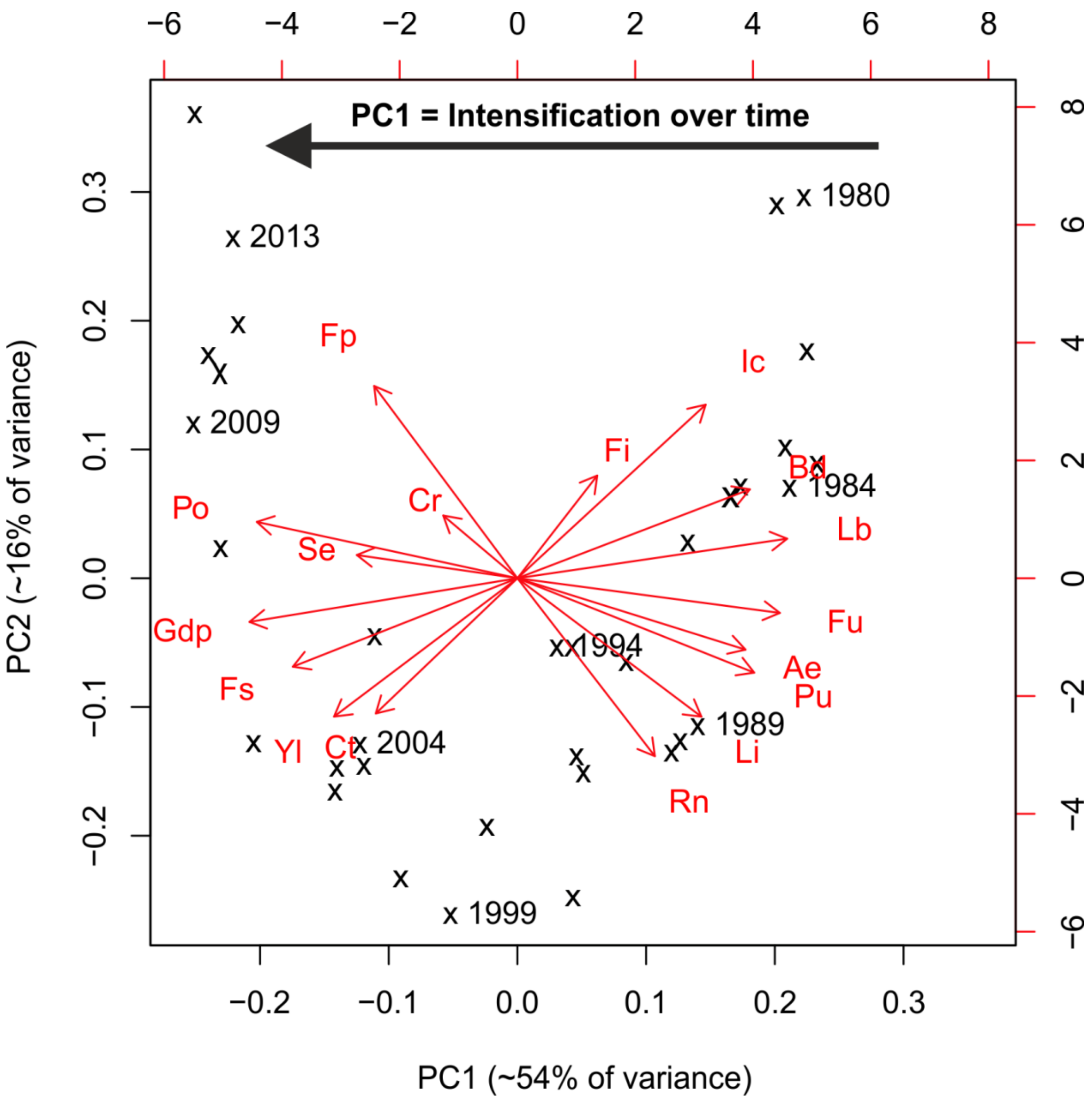

Figure S8: Biplot of the Principal Component Analysis (PCA) of the 17 key biophysical and socioeconomic variables of the England agroecosystem. Principal Component 1 (PC1) explains 54.1% of the data variance, while Principal Component 2 (PC2) explains a further 16.2%. Variables are labelled as in text, and the data-points represent sequential years (from 1980 to 2013, progressing from right to left with key years labelled).

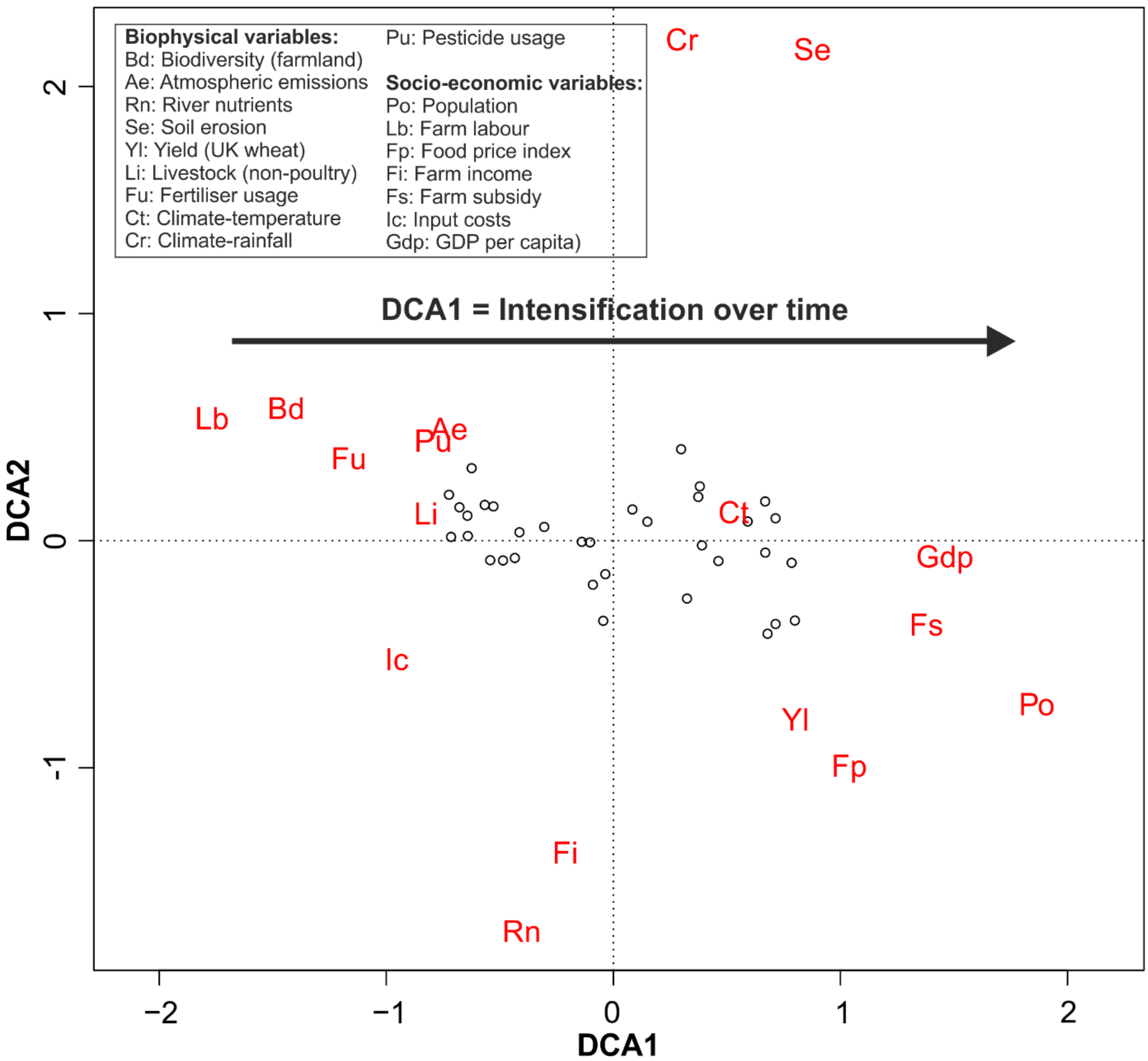

Figure S9: Biplot of the Detrended Correspondence Analysis (DCA) of the 17 key biophysical and socioeconomic variables of the England agroecosystem, using the same variables plotted and labelled in Figure S10. The first axis (DCA1) explains most of the data variance (eigenvalue = 0.2278, axis length = 1.5235) and mostly reflects the increase in intensification over time, while the second axis (DCA2) explains relatively little variance (eigenvalue = 0.03905, axis length = 0.81272). Variables are labelled as in text, and the data-points represent sequential years (from 1980 to 2013, progressing from left to right).

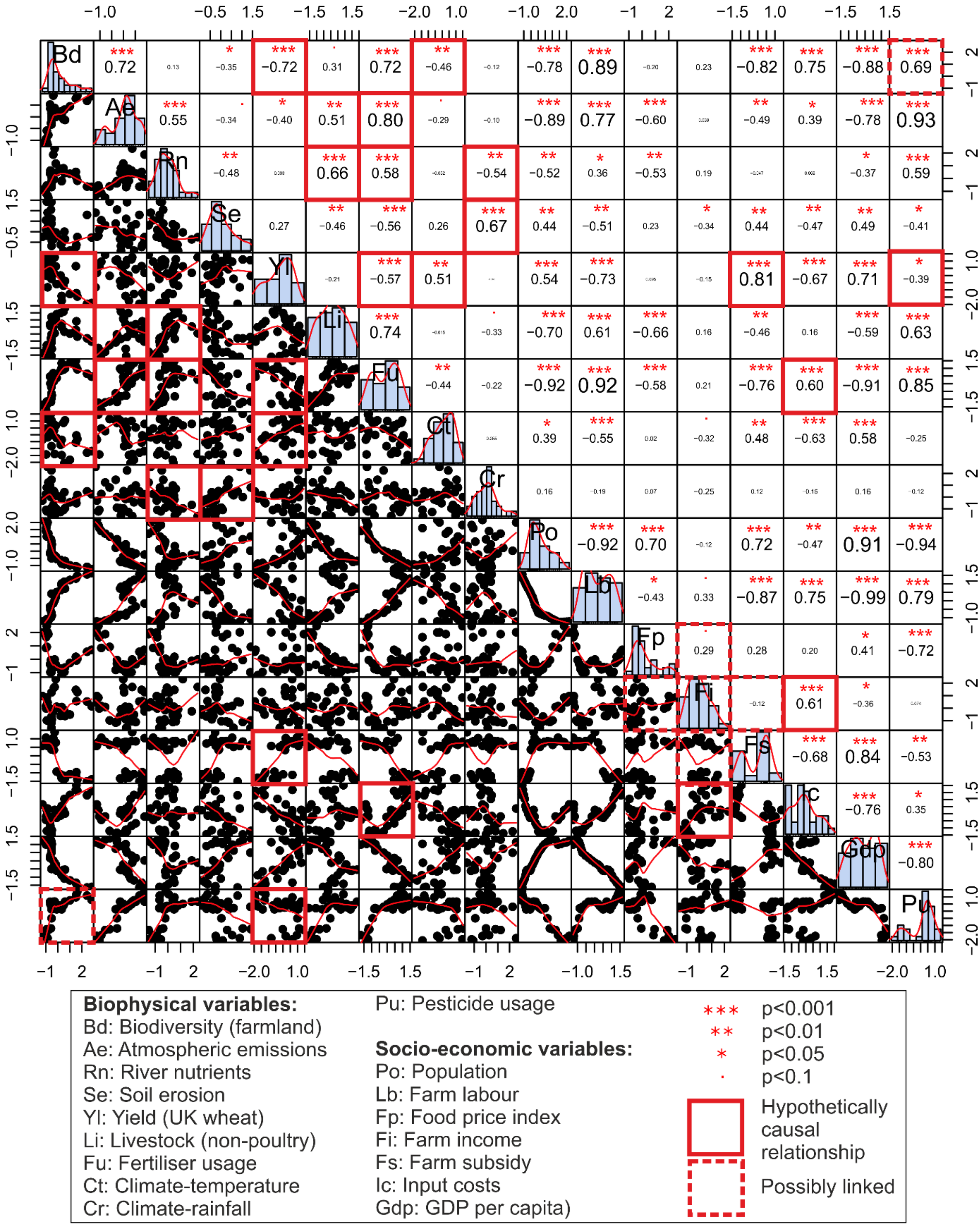

Figure S10: Correlation matrix of biophysical and socioeconomic variables of the England agroecosystem. On the diagonal are univariate plots and kernel density plot (red line) of each variable, to the right of the diagonal are the pairwise pearson correlation coefficients of each variable pairing (number and font size) and the significance of this correlation (red stars), and to the left of the diagonal are the scatterplots and loess smoothing (red lines) for each variable pairing (standardised values, scales on axes). The red boxes indicate significant relationships we hypothesise to be causal rather than sharing a common driver or are coincidentally correlated (with dashed-red boxes indicating possible but uncertain causal relationships), from which we built data-driven models in Section 5.

4. Eastern England Regional Data Analysis

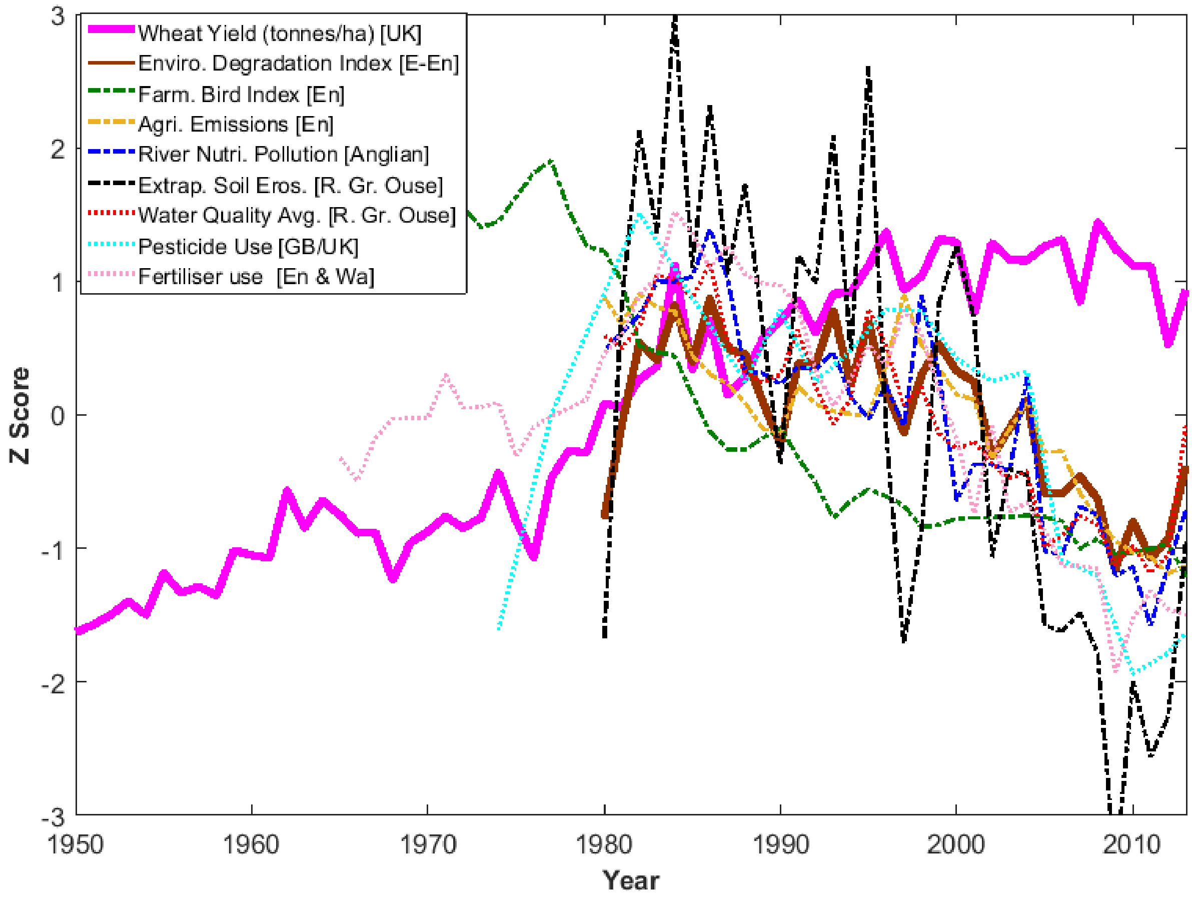

Figure S11: Z-score plot illustrating the impact of agricultural intensification on the biophysical parameters of the Eastern England agroecosystem. UK wheat yield (which is closely matched by Eastern England wheat yield where data is available (DEFRA, 2015, indicator B11)) is used as a proxy for key regional provisioning services, fertiliser and pesticide use is used as a proxy for agricultural inputs, and the Environmental Degradation Index is constructed from the mean of the proxies for regional riverine nutrient contamination (for the Anglian river basin district, includes Eastern England GOR), extrapolated soil erosion (reconstructed from the relative difference between suspended solids and biological oxygen demand in the River Great Ouse at Bedford), all-England farm biodiversity, and all-England atmospheric pollution between 1980 and 2013. An overall Water Quality Index (the average of the Z scores for Nitrate, Orthophosphate, Ammoniacal Nitrogen, Biological Oxygen Demand (BOD), and Suspended Solids) is also plotted for the River Great Ouse at Bedford (Environment Agency, 2014).

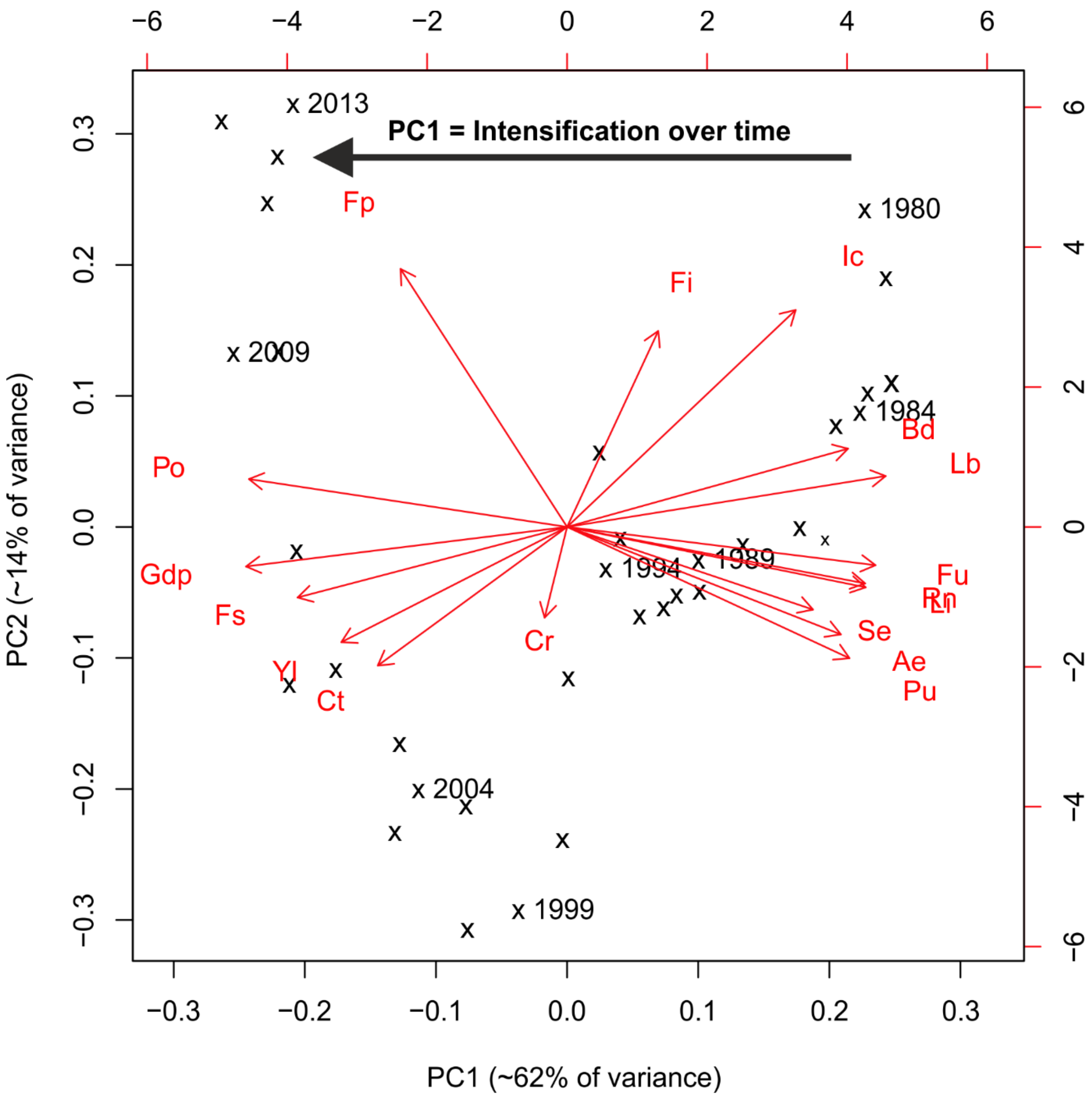

Figure S12: Biplot of the Principal Component Analysis (PCA) of the 17 key biophysical and socioeconomic variables of the Eastern England agroecosystem, using the same variables plotted and labelled in Figure S5. Principal Component 1 (PC1) explains 61.9% of the data variance, while Principal Component 2 (PC2) explains a further 14.1%. Variables are labelled as in text, and the data-points represent sequential years (from 1980 to 2013, progressing from right to left with key years labelled).

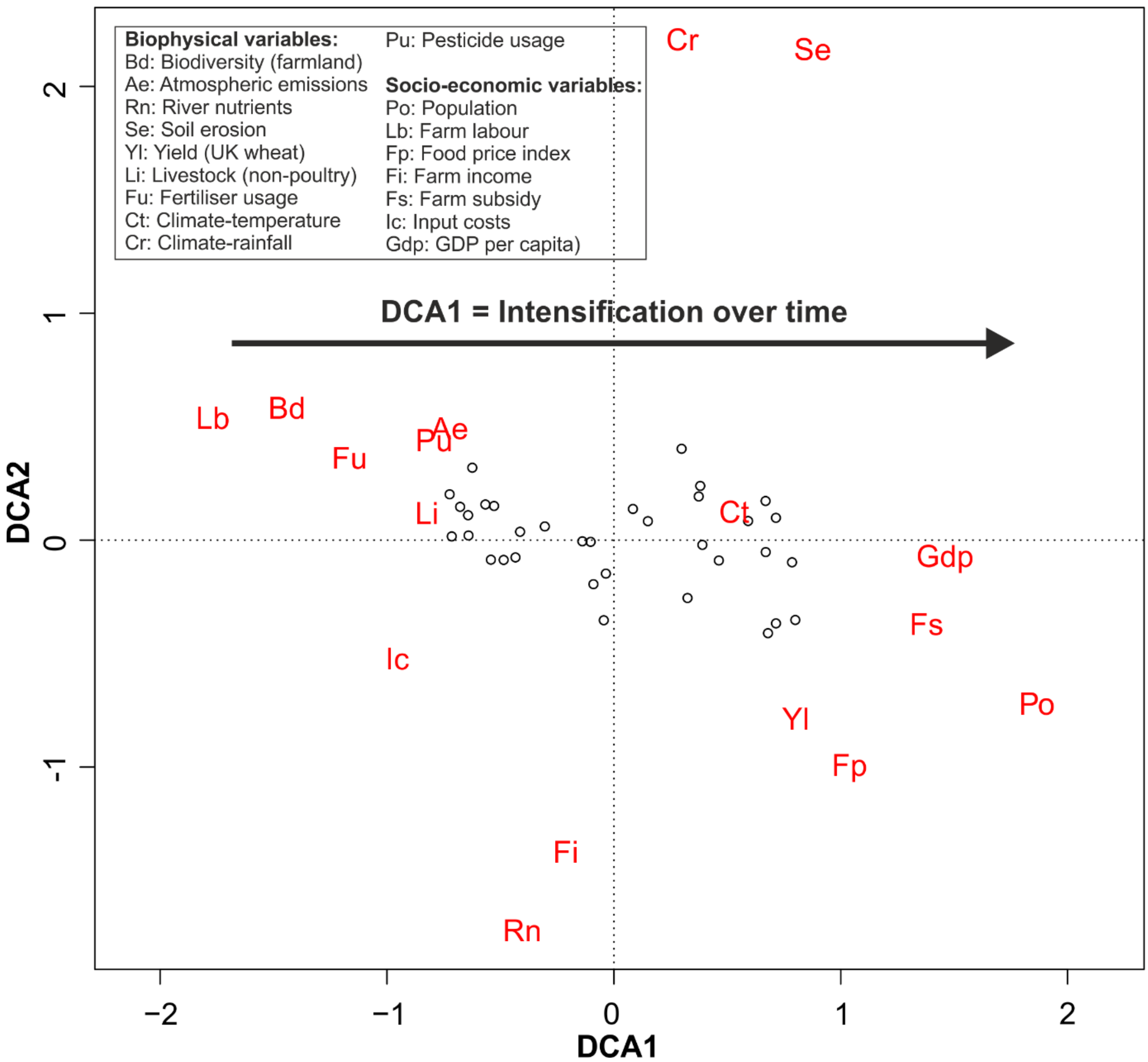

Figure S13: Biplot of the Detrended Correspondence Analysis (DCA) of the 17 key biophysical and socioeconomic variables of the Eastern England agroecosystem, using the same variables plotted and labelled in Figure S5. The first axis (DCA1) explains most of the data variance (eigenvalue = 0.2314, axis length = 1.6309) and mostly reflects the increase in intensification over time, while the second axis (DCA2) explains relatively little variance (eigenvalue = 0.04545, axis length = 0.71522). Variables are labelled as in text, and the data-points represent sequential years (from 1980 to 2013, progressing from left to right).

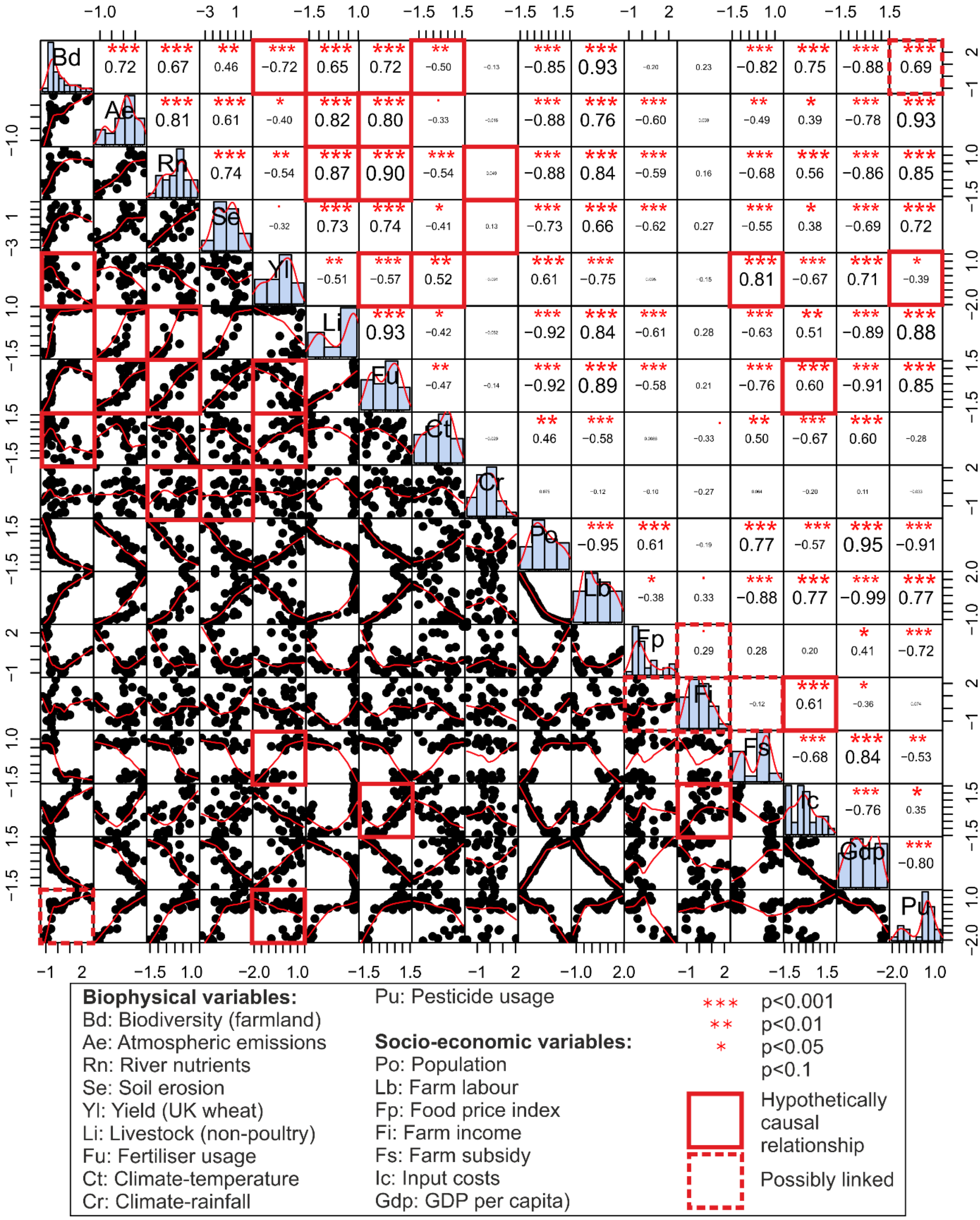

Figure S14: Correlation matrix of biophysical and socioeconomic variables of the Eastern England agroecosystem. On the diagonal are univariate plots and kernel density plot (red line) of each variable, to the right of the diagonal are the pairwise pearson correlation coefficients of each variable pairing (number and font size) and the significance of this correlation (red stars), and to the left of the diagonal are the scatterplots and loess smoothing (red lines) for each variable pairing (standardised values, scales on axes). The red boxes indicate significant relationships we hypothesise to be causal rather than sharing a common driver or are coincidentally correlated (with dashed-red boxes indicating possible but uncertain causal relationships), from which we built data-driven models in Section 5. For Livestock we use population rather than outputs in the regional analyses due to lack of regional livestock output data.

5. South-Western England Regional Data Analysis

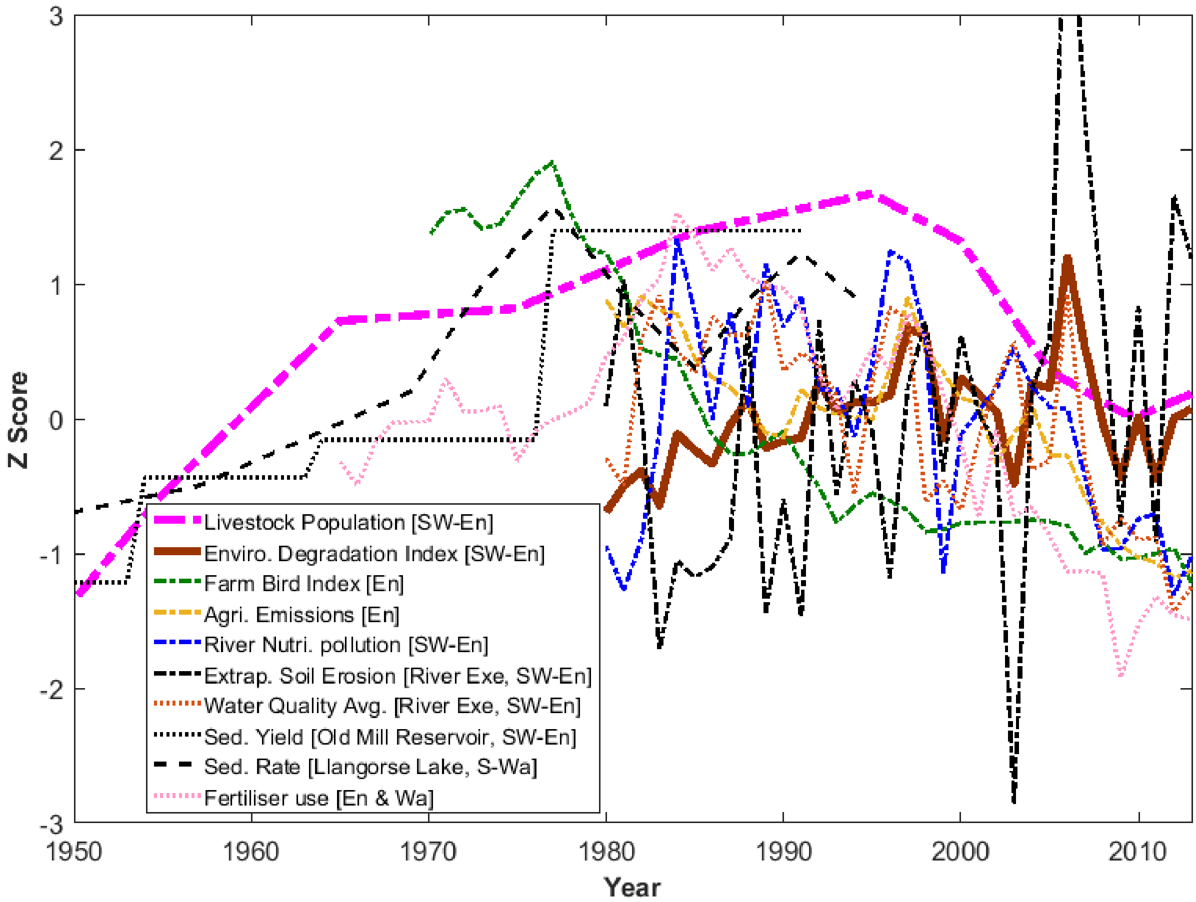

Figure S15: Z score plot illustrating the impact of agricultural intensification on the biophysical parameters of the South-Western England agroecosystem. Livestock population is used as a proxy for key regional provisioning services, fertiliser use is used as a proxy for agricultural inputs, and the Environmental Degradation Index is constructed from the mean of the proxies for regional riverine nutrient contamination (for the SW England river basin district, covers majority of SW England GOR), extrapolated soil erosion (reconstructed from the relative difference between suspended solids and biological oxygen demand in the River Exe), all-England farm biodiversity, and all-England atmospheric emissions between 1980 and 2013. Sedimentation data from Llangorse Lake in nearby South Wales (Bennion and Appleby, 1999) and Old Mill Reservoir in Devon (Foster and Walling, 1994) are also provided as potential proxies of longer term soil erosion trends within a similar meteorological and agroecosystem zone, but these are limited to localised catchments. An overall Water Quality Index (the average of the Z scores for Nitrate, Orthophosphate, Ammoniacal Nitrogen, Biological Oxygen Demand (BOD), and Suspended Solids) is also plotted for the River Exe (Environment Agency, 2014).

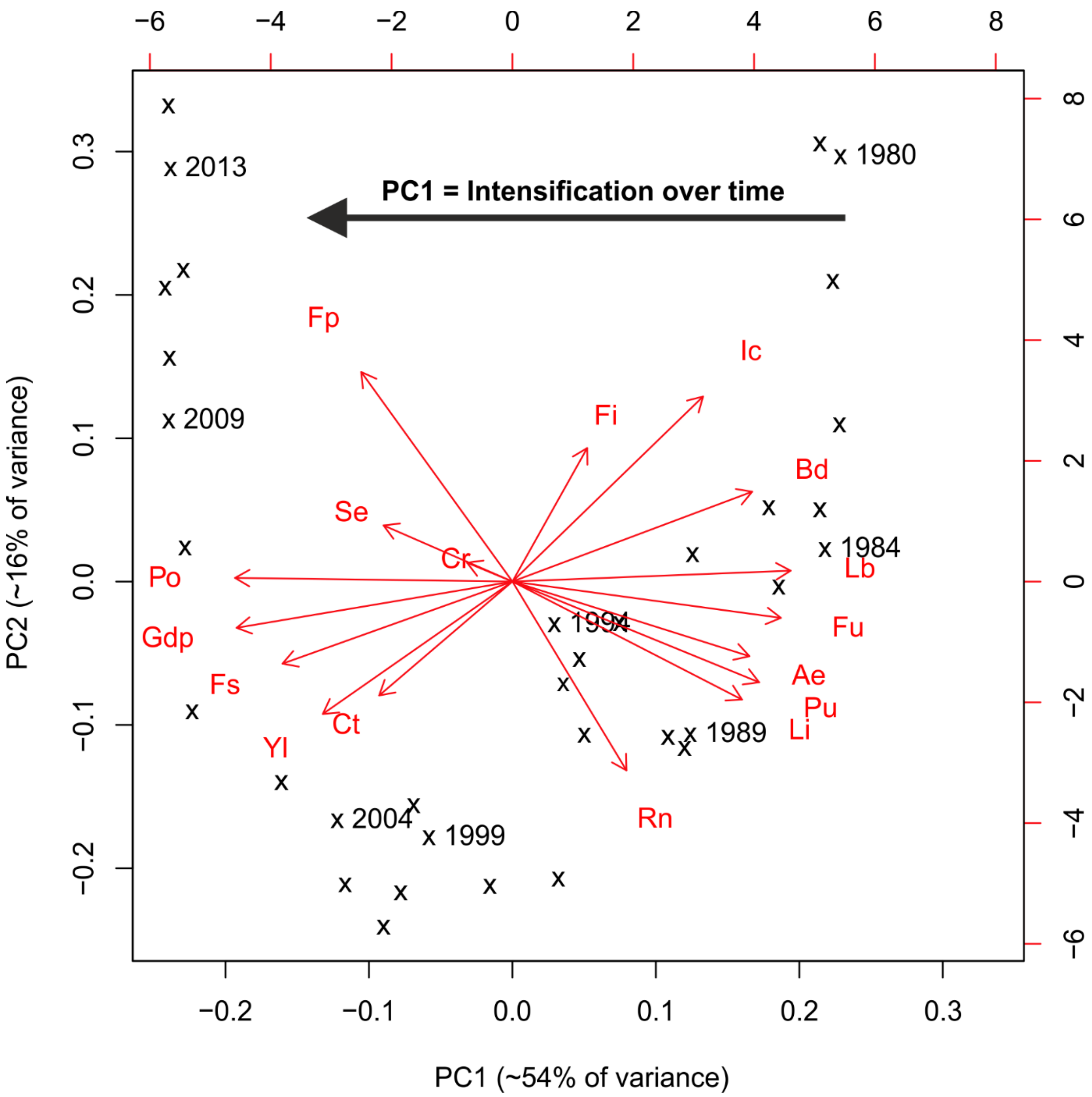

Figure S16: Biplot of the Principal Component Analysis (PCA) of the 17 key biophysical and socioeconomic variables of the South-Western England agroecosystem, using the same variables plotted and labelled in Figure S6. Principal Component 1 (PC1) explains 54.3% of the data variance, while Principal Component 2 (PC2) explains a further 15.9%. Variables are labelled as in text, and the data-points represent sequential years (from 1980 to 2013, progressing from right to left with key years labelled).

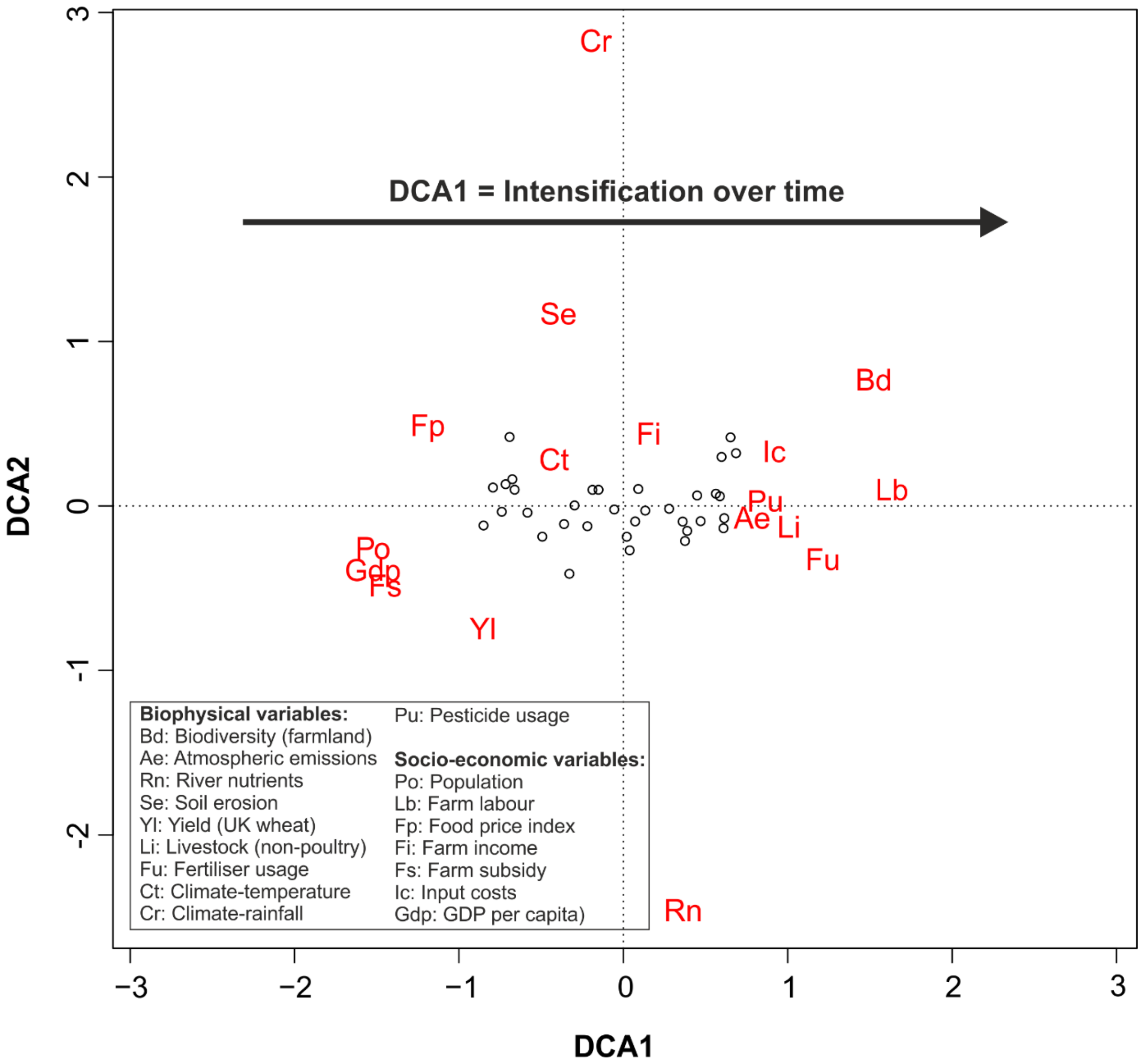

Figure S17: Biplot of the Detrended Correspondence Analysis (DCA) of the 17 key biophysical and socioeconomic variables of the South-Western England agroecosystem, using the same variables plotted and labelled in Figure S6. The first axis (DCA1) explains most of the data variance (eigenvalue = 0.2073, axis length = 1.5358) and mostly reflects the increase in intensification over time, while the second axis (DCA2) explains relatively little variance (eigenvalue = 0.03211, axis length = 0.83177). Variables are labelled as in text, and the data-points represent sequential years (from 1980 to 2013, progressing from left to right).

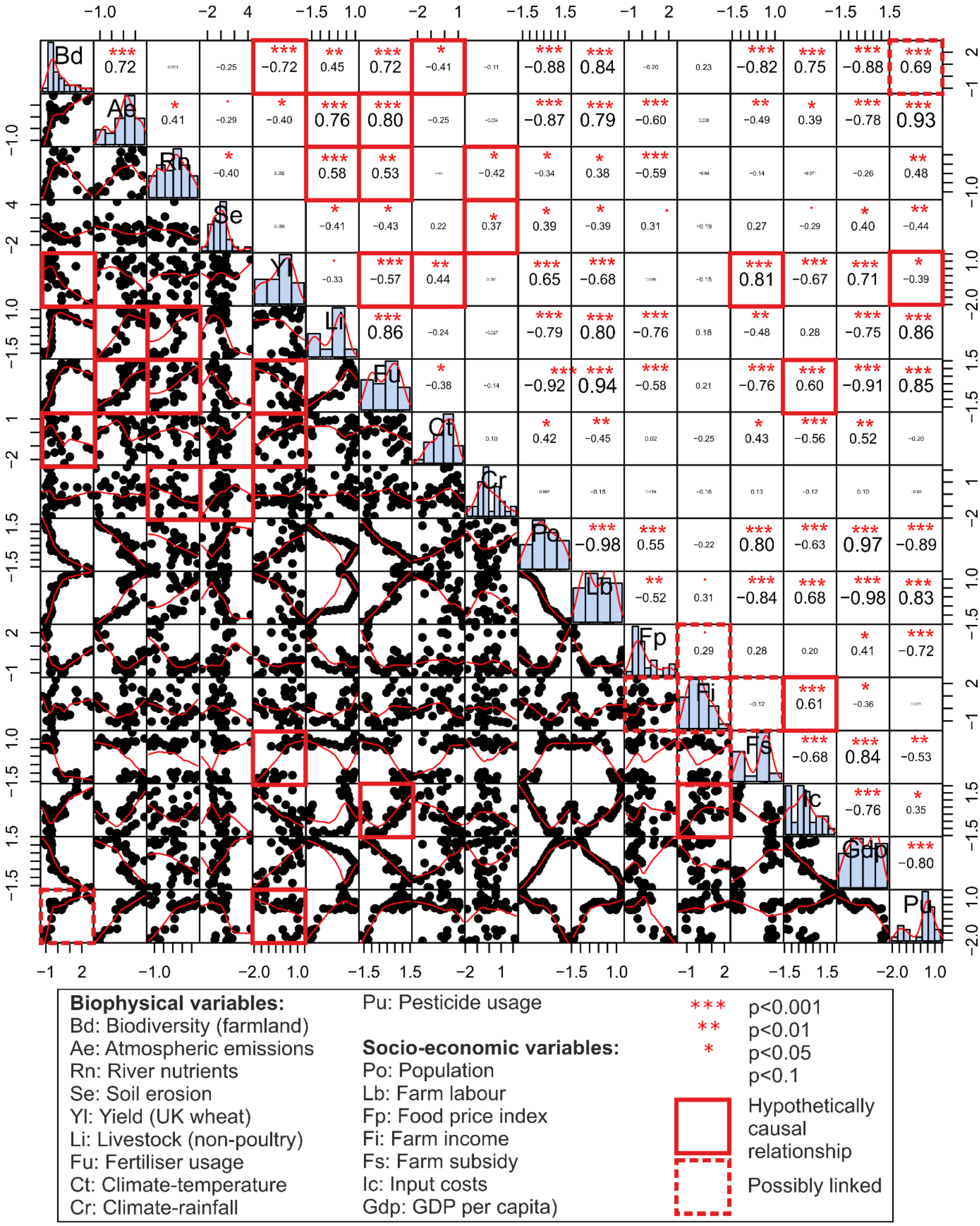

Figure S18: Correlation matrix of biophysical and socioeconomic variables of the South-Western England agroecosystem. On the diagonal are univariate plots and kernel density plot (red line) of each variable, to the right of the diagonal are the pairwise pearson correlation coefficients of each variable pairing (number and font size) and the significance of this correlation (red stars), and to the left of the diagonal are the scatterplots and loess smoothing (red lines) for each variable pairing (standardised values, scales on axes). The red boxes indicate significant relationships we hypothesise to be causal rather than sharing a common driver or are coincidentally correlated (with dashed-red boxes indicating possible but uncertain causal relationships), from which we built data-driven models in Section 5. For Livestock we use population rather than outputs in the regional analyses due to lack of regional livestock output data.

6. Statistical Analysis – General R Commands

Principal Component Analysis

```
> PCA_data <- read.delim("C:/Users/User/…/Inputdata.txt") #import data from .txt file with Z score variables in columns with headers & no time column
> PCA_results <- prcomp(PCA_data, center=TRUE, scale.=TRUE) #perform analysis
> print(PCA_results) #display results
> summary(PCA_results) #display results summary
> biplot(PCA_results) #plot results
```

Detrended Correspondence Analysis

```
> install.packages("vegan") #install required package
> PCA_Normaliseddata <- read.delim("C:/Users/User/…/Inputdata_Normalised.txt") #import data, requires data to be normalised 0 to 1 in each column
> DCA_results <- decorana(PCA_Normaliseddata) #perform analysis
> summary(DCA_results) #display results summary
> plot(DCA_results) #plot results
```

Correlation Analysis

```
> install.packages("PerformanceAnalytics") #install required package
> COR_results <- cor(PCA_data, use="all.obs", method="pearson") #perform analysis
> COR_results #display results
> chart.Correlation(PCA_data, histogram=TRUE, pch=19) #plot correlation matrix
```

Supplementary References

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