Supplementary information: Functional data analysis to quantify and investigate controls on and changes in baseflow seasonality

Kathryn A Leeming[1], John P Bloomfield[2], Gemma Coxon[3] and Yanchen Zheng[3]

[1] British Geological Survey, Keyworth, NG12 5GG, UK
[2] British Geological Survey, Wallingford, OX10 8BB, UK
[3] School of Geographical Sciences, University of Bristol, Bristol, BS8 1SS, UK

Correspondence to: Kathryn A. Leeming (kle@bgs.ac.uk)

S1 Precipitation, temperature, and effective rainfall results

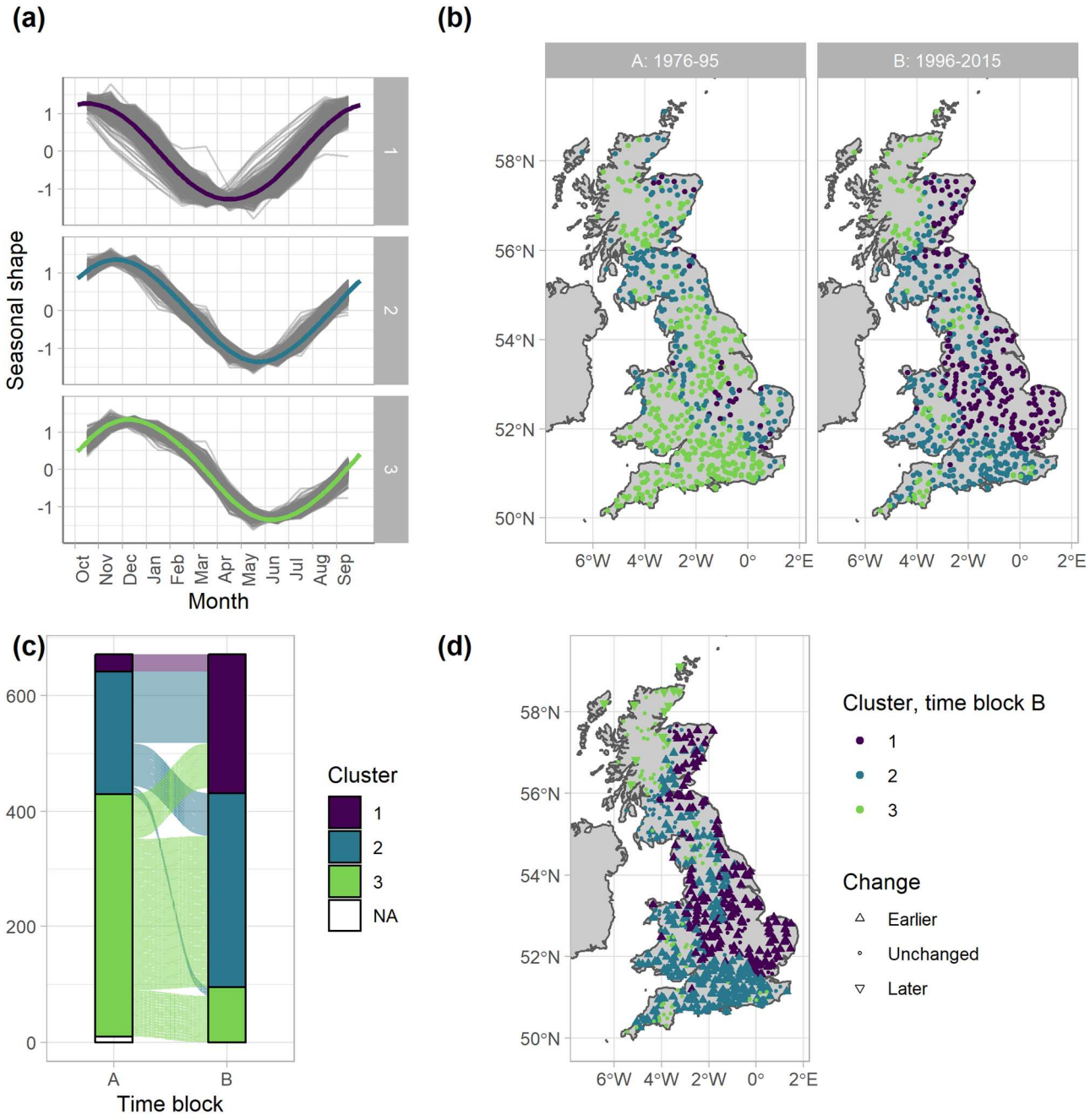

Figure S1: FDA clustering result for 6-month smoothed precipitation (median). (a) Median annual smoothed precipitation for each location and time block plotted by cluster (grey lines), with the cluster means overlaid (in cluster colour and bold). (b) Cluster membership of each location within each time block. (c) Flow diagram of each location showing cluster membership over the time blocks. Each location is a thin line within the plot. (d) Map showing the cluster membership of each location in time block B (shown by colour), with triangular symbols for those locations in an earlier or later cluster compared to time block A.

Cluster	Block A	Block B
1	30	240
2	212	336
3	419	95

Table S1: Number of locations assigned to each precipitation cluster within each time block.

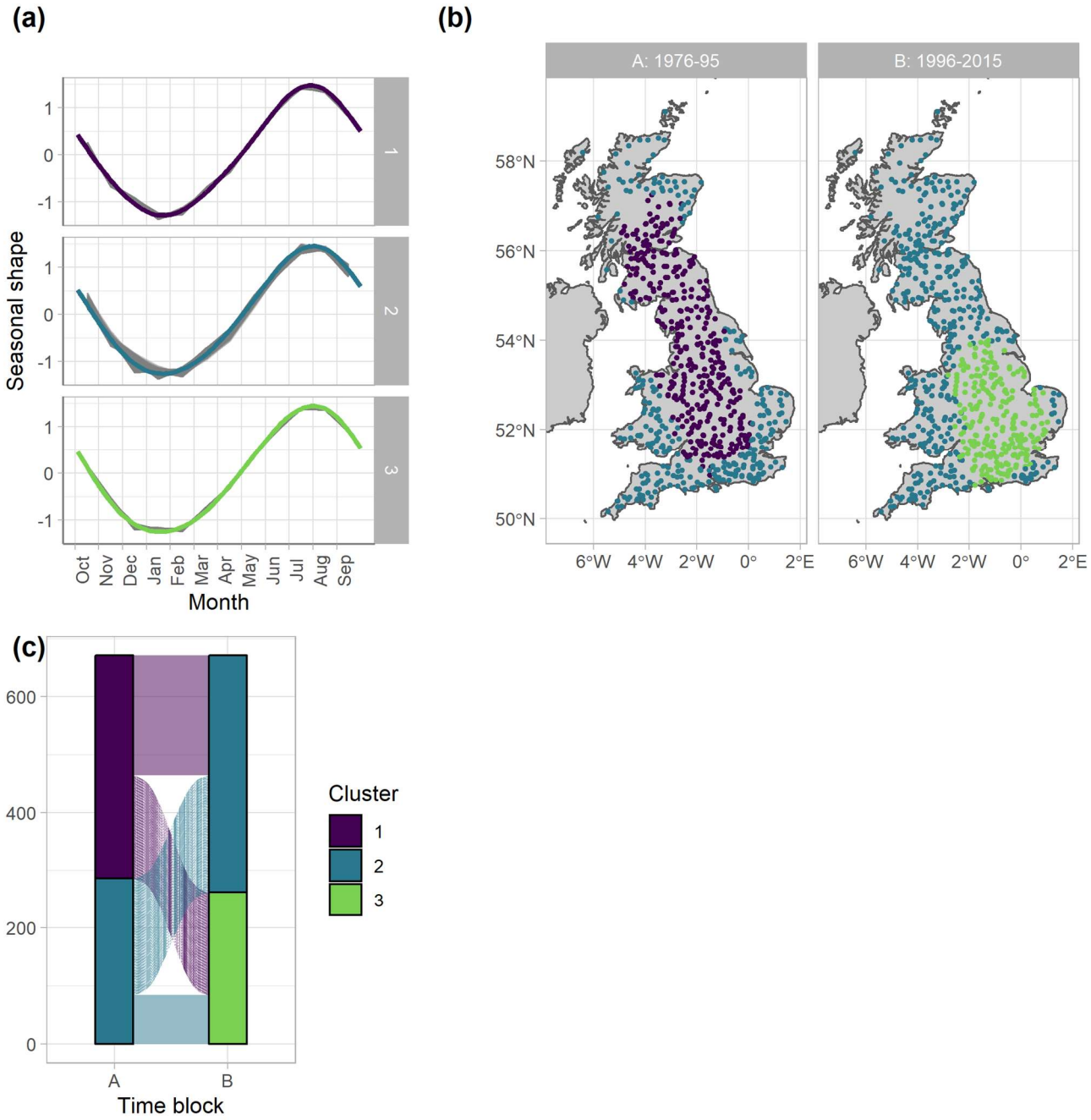

Figure S2: FDA clustering result for temperature (median). (a) Median annual temperature for each location and time block plotted by cluster (grey lines), with the cluster means overlaid (in cluster colour and bold). (b) Cluster membership of each location within each time block. (c) Flow diagram of each location showing cluster membership over the time blocks. Each location is a thin line within the plot. Subplot (d) is not included because the clusters have little difference in seasonal timing.

Cluster	Block A	Block B
1	385	0
2	286	409
3	0	262

Table S2: Number of locations assigned to each temperature cluster within each time block.

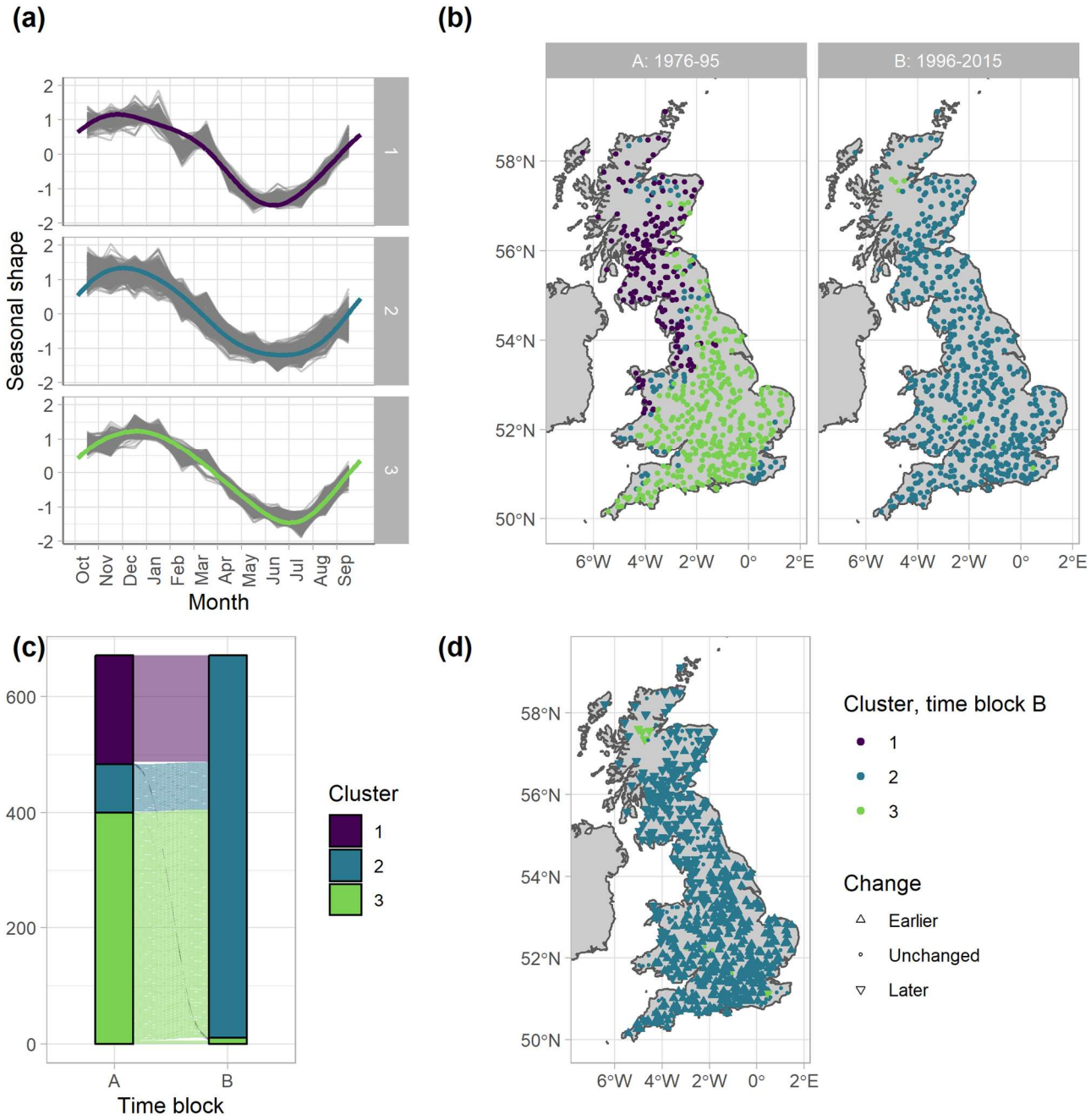

Figure S3: FDA clustering result for effective rainfall (median). (a) Median annual effective rainfall for each location and time block plotted by cluster (grey lines), with the cluster means overlaid (in cluster colour and bold). (b) Cluster membership of each location within each time block. (c) Flow diagram of each location showing cluster membership over the time blocks. Each location is a thin line within the plot. (d) Map showing the cluster membership of each location in time block B (shown by colour), with triangular symbols for those locations in an earlier or later cluster compared to time block A.

Cluster	Block A	Block B
1	188	0
2	83	660
3	400	11

Table S3: Number of locations assigned to each effective rainfall cluster within each time block.

S2 Paired catchments

Three pairs of catchments with different cluster allocations and changes in cluster allocation (one catchment in each pair moves to an earlier baseflow cluster and one does not) are selected to consider the controls on the annual shapes in baseflow and the changes over the time blocks. The three pairs of catchments are: catchments 37008 and 37020, 33020 and 33012, and 45004 and 45005, and are marked on Fig. 1(a). These were chosen based on several principles: (a) adjacent and nearby catchments were preferable; (b) each pair has rather similar catchment attributes in terms of climate (e.g., the differences of annual precipitation and PET should be within 10 %), topography, land cover and geology etc., yet with different cluster memberships over the time blocks; (c) catchment pairs with less human activities (no reservoir and urban percentage < 10 %) or under similar human influences are selected. The key catchment attributes of selected pairs and their cluster allocations over time blocks are presented in Table S4 and the respective pairs of standardised seasonal baseflow curves are shown in Fig. S4. Regardless of whether a catchment in each pair moves to an earlier baseflow cluster or not, both seasonal baseflow curves in each pair are similar in form suggesting that the selection of catchment pairs is adequately robust. However, there are changes in baseflow curves over time in all the catchments that appear to be independent of the range of catchment characteristics sampled by the catchment pairs. Although the pairs are chosen so that one catchment in each pair moves to an earlier functional seasonal cluster and one does not, all catchments exhibit an earlier seasonality when details of the monthly curves are considered (Fig. S4). In the case of one catchment in each pair, these changes are smaller than would result in a change in cluster allocation, and reflect the clustering being a discretisation of the functional space of annual curves. From these observations we infer that: i.) catchment characteristics may not have a first order effect on changes in baseflow seasonality in these catchments (and by extension in the wider population of catchments that move to earlier baseflow seasonality), and ii.) that increased temporal granularity (beyond early-, mid-, and late-season functional clusters) may be useful in exploring controls on changes in baseflow seasonality.

Table S4. Key catchment attributes of selected catchment pairs and their cluster allocations over time blocks.

ID, station	Cluster allocations over time blocks	Area (km^2)	Aridity (-)	BFI (-)	Mean annual precipitation (mm)	Mean annual PET (mm)	Mean elevation (m.a.s.l)	Urban percent (%)	Surface.abs (mm/d)	Ground-water.abs (mm/d)

37008 (Chelmer at Springfield)	Moves from cluster 3 -> 2	190	0.89	0.57	601	532	77	8.0	0.002	0.015
37020 (Chelmer at Felstead)	Stays in cluster 2	133	0.88	0.49	608	533	86	5.5	0.001	0.022
33020 (Alconbury Brook at Brampton)	Moves from cluster 3 -> 2	213	0.92	0.26	582	533	47	4.7	0	0
33012 (Kym at Meagre Farm)	Stays in cluster 2	138	0.88	0.25	606	531	61	2.9	0	0
45004 (Axe at Whitford)	Moves from cluster 2 -> 1	289	0.5	0.49	1052	530	138	2.8	0.026	0.007
45005 (Otter at Dotton)	Stays in cluster 2	202.83	0.53	0.53	1006	529	144	4.61	0.003	0.038

Note: PET denotes potential evapotranspiration. Surface.abs represents the mean surface water abstraction, whereas groundwater.abs denotes the mean groundwater abstraction.

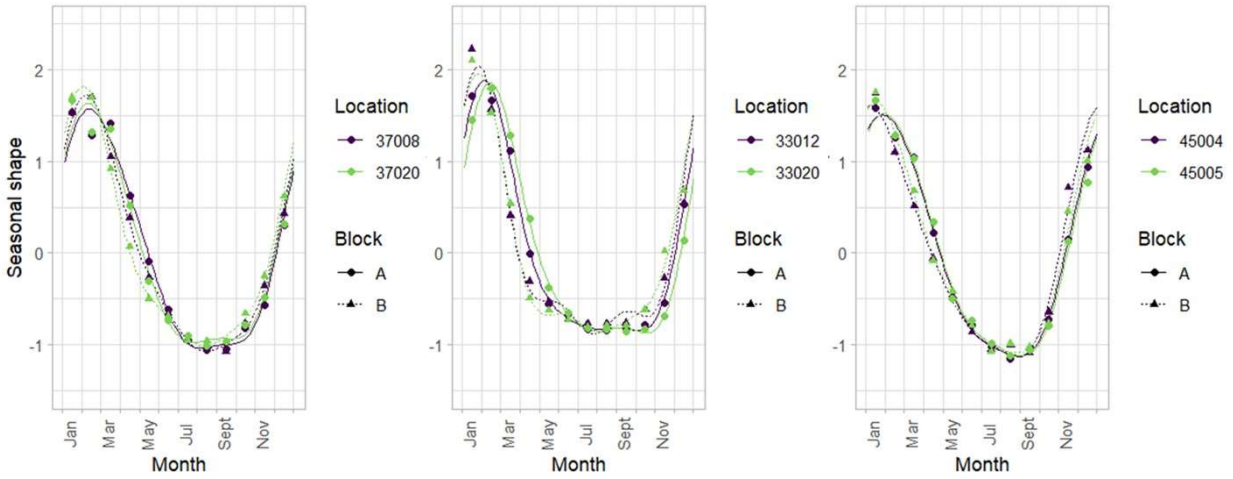

Fig S4 Paired catchments showing the average annual baseflow (points) and fitted curves (lines) over the two time blocks for the paired catchments.

65