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Projections of streamflow intermittence under climate change in European drying river networks

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S1 Prediction of flow intermittence with the random forest model

This section presents some data and results from Mimeau et al. (2024) for the Albarine (FR), Genal (ES), and Lepsämänjoki (FI) DRNs and extends them to the Bükkösdi (HU), Butiznica (HR), and Velicka (CZ) DRNs.

S1.1 Flow intermittence observed data

Observations of the state of flow used to train the RF model come from four main types of datasets:

- Hydrological stations: (i) discharge daily time series from gauging stations (http://leutra.geogr.uni-jena.de/DRYvER). The streams are considered as dry if the measured discharge is equal to 0 m^3/s, and flowing otherwise. (ii) the ONDE network (Observatoire National des Etiages, https://onde.eaufrance.fr): this French network of hydrological stations was specifically developed to monitor intermittent rivers and gives a monthly qualitative information about the state of flow (visible flow, non-visible flow, dry).

- Crowdsourced data from smartphone applications: DRYRivERS (https://www.dryver.eu/app) and CrowdWater (https://crowdwater.ch/en/data/).

- Measurements from field campaigns: phototraps installed during the DRYvER project and conductivity loggers.

- Observations on Google Earth images: the state of flow of the reaches was observed on the images for several dates between 2010 and 2022. The observation with Google Earth images was only possible in the Genal DRN (ES) which has a scarce vegetation.

- Expertise of local DRYvER project partners: some members of the DRYvER project have been studying these DRNs for several years and have a deep understanding or their hydrological behaviours. Their expertise was used to identify reaches characterised by a perennial flow. Those reaches are assumed to be flowing every day during the field campaign period.

Table S1 and Fig S1 show the number of observations available in the six studied DRNs and their temporal and spatial distributions in the river networks.

The Albarine (FR), Bükkösdi (HU), and Velicka (CZ) DRNs are the best-monitored catchments with high total number of observations (Tab. S1) and a fairly even distribution of the observation over time (observations throughout the year) and over space (observations on the four classes of reaches) (Fig.S1). In these three DRNs, drying is observed mostly in late summer (August and September) and in the four classes of reaches, in particular in the Albarine (FR) and Bûkkösdi (HU) where drying events are regularly observed in the main river sections with large drainage areas.

The Butiznica (HR), Genal (ES), and Lepsämänjoki (FI) DRNs have less observed data. For these three DRNs, most of the data come from the gauging stations located on the main river which presents no or few drying events. River sections at the head of the catchments are less monitored with observations collected during field campaign not sufficient to cover the whole year. For the Lepsämänjoki (FI) DRN, drying mostly occurs in the smallest reaches during summer. The absence of observations during the other months of the year does not prevent from characterising the drying pattern in this basin. However, in the Butiznica (HR) and Genal (ES) DRNs, the spatio-temporal pattern of drying seems to be more complex, with observed drying events throughout the year on all types of river sections. Additional data would be needed to better characterise the drying up of rivers in these two basins.

DRN	Data type	Period of available data	Number of observations	Number of reaches	Length of river network [%]
Albarine (FR)	Stations	2005-10-01 to 2021-12-01	10 681	5	1.2
	Crowdsourced	2019-06-26 to 2022-04-23	299	56	14.7
	Field campaign	2018-11-07 to 2022-04-30	5 184	9	2.4
	Expertise	2018-11-07 to 2022-04-30	12 688	10	1.9
	All	*2005-10-01 to 2022-04-30*	*28 852*	*61*	*15.7*
Bükkösdi (HU)	Stations	2005-10-01 to 2019-07-03	38 997	9	0.9
	Crowdsourced	2019-04-15 to 2022-03-20	228	50	16.8
	Field campaign	2021-05-04 to 2022-04-30	6 547	20	11.6
	Expertise	2021-05-06 to 2022-04-30	717	2	0.5
	All	*2005-10-01 to 2022-04-30*	*46 489*	*62*	*23.9*
Butiznica (HR)	Stations	2005-10-01 to 2020-12-31	5 571	1	0.1
	Crowdsourced	2021-11-10 to 2021-11-11	21	21	3.9
	Field campaign	2021-02-23 to 2021-11-19	158	20	5.6
	All	2005-10-01 to 2021-11-19	5 750	28	6.93
Genal (ES)	Stations	2005-10-01 to 2021-10-19	5 845	1	0.3
	Crowdsourced	2021-05-20 to 2022-02-12	88	28	14.0
	Google Earth	2010-10-08 to 2022-04-01	319	98	38.2
	All	*2005-10-01 to 2022-04-01*	*6 252*	*119*	*47.5*
Lepsämänjoki (FI)	Stations	2005-10-01 to 2020-05-26	4 761	1	0.1
	Crowdsourced	2021-06-18 to 2021-11-02	28	19	6.2
	Field campaign	2021-06-17 to 2021-09-26	807	8	2.6
	Expertise	2021-06-17 to 2021-09-26	711	7	1.6
	All	*2005-10-01 to 2021-11-02*	*6 307*	*23*	*7.3*
Velicka (CZ)	Stations	2005-10-01 to 2022-01-01	11 452	2	1.4
	Crowdsourced	2016-01-02 to 2022-04-06	292	54	44.7
	Field campaign	2012-09-01 to 2021-12-13	22 804	33	31.0
	All	*2005-10-01 to 2022-04-06*	*34 548*	*59*	*47.7*

Table S1. Flow observations in the six studied DRNs (from 2005-10-01 to 2022-04-30)

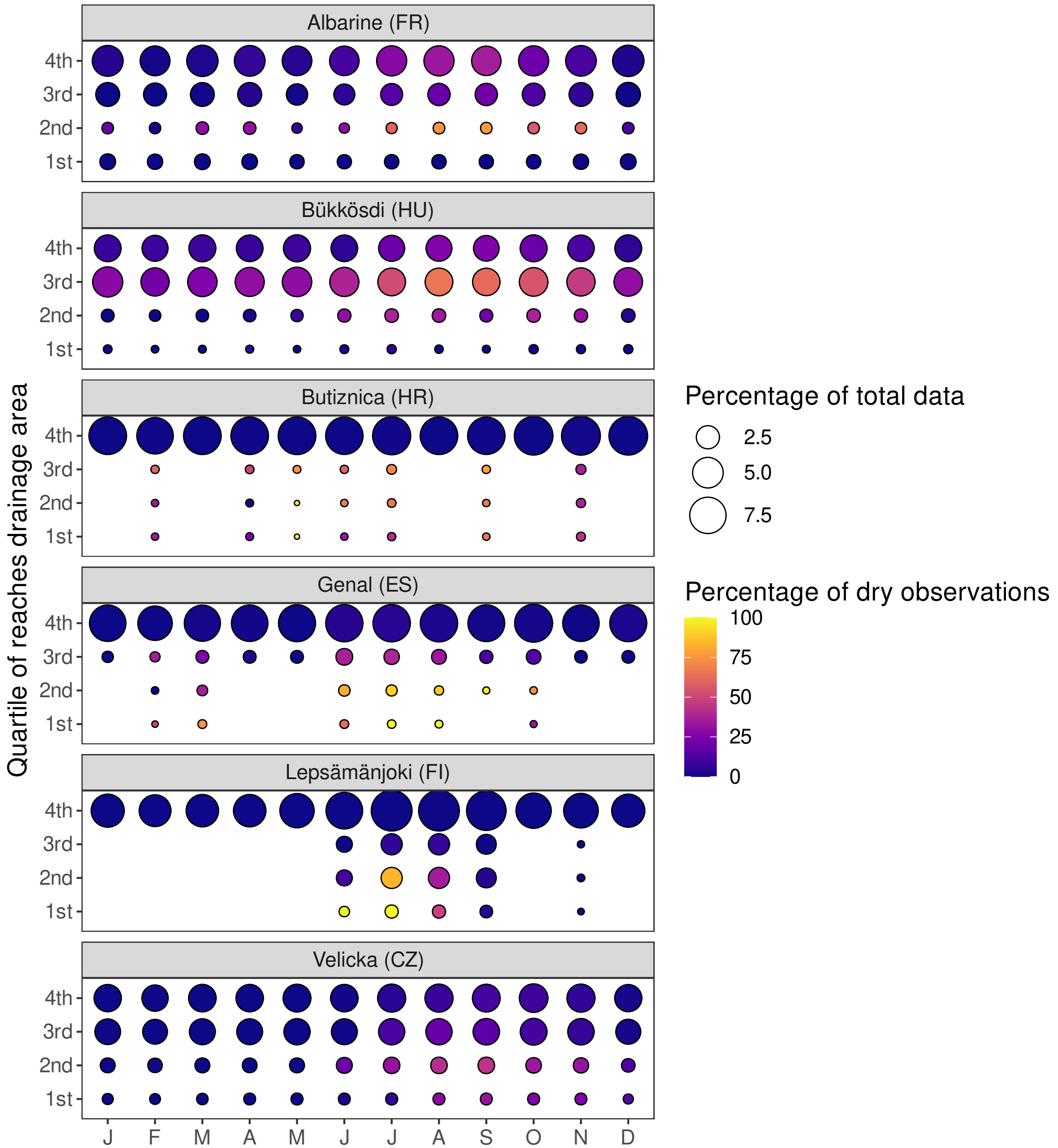

Figure S1. Distribution in space and time of flow state data. The size of the dots indicates the percentage of total available data per month and per class of drainage area and the colour the percentage of dry observations per month and class of drainage area.

S1.2 Sensitivity of the RF model to the training data

Fig S2 shows the simulated seasonal patterns of drying in the DRNs when the RF model is trained with 100 % (black) or 75 % (grey) of the observed data. For the Albarine (FR), Bükkösdi (HU), Lepsämänjoki (FI), and Velicka (CZ) DRNs, the spread of the is fairly narrow showing that the uncertainty related to the training of the RF model is low. However, the simulation of drying pattern is more uncertain in the Butiznica (HR) and Genal (ES) DRNs. The uncertainty related to the hybrid flow intermittence model is discussed in greater detail in Mimeau et al. (2024).

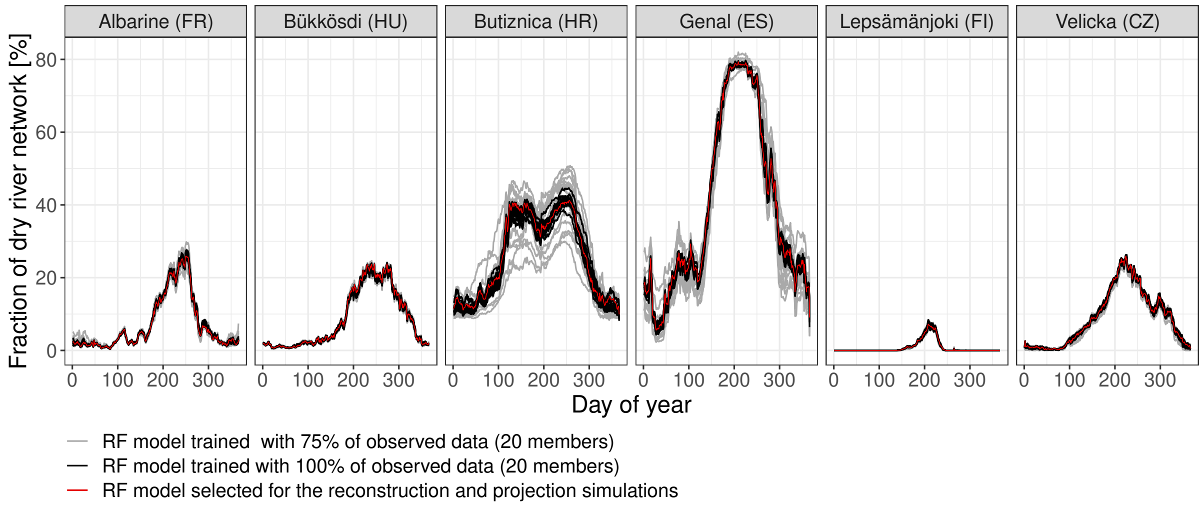

Figure S2. Sensitivity of the simulated length of the dry river network to the size of the training sample: 100% (black) and 75% (grey) of the observed data. The red line show the simulated seasonal pattern of drying for the RF model that was selected for the reconstruction and projection simulations.

S2 Calculation of the flow intermittence indicators

The calculation of the indicators was done by means of a software components of the Java-based environmental modelling framework JAMS Kralisch and Krause (2006), which was also used to do the initial hydrological simulations of the six DRNs. These components allowed to process the NetCDF-files resulting from the hybrid modelling Mimeau et al. (2024), which contain information about the flow condition as well as discharge and the baseflow contribution per day and reach of each DRN. In addition the components utilise attributes of the spatial reach entities, including information about the length and topological connectivity. In a first step, a range of baseline flow metrics were calculated on a daily basis to capture different aspects of flow intermittence, such as start and end day of a drying event within the year. Following, these metrics are then aggregated to create the final flow intermittence indicators, capturing seasonal and annual patterns of flow intermittence. This is done by using three steps: i) **temporal aggregation**, where daily flow states are aggregated to monthly and yearly summaries to capture seasonal and annual patterns of flow intermittence; ii) **spatial aggregation**, to compute the connected length of the entire river network with a certain condition, providing spatial patterns of flow intermittence; and iii) **statistical analysis**, to calculate spatio-temporal signatures including mean, median, frequency analysis, and proportions per reach or the entire river network, as well as per month and year or specific periods. However, one indicator is calculated differently, $PatchC$ (indicator 10 in Table 2). This 'patchiness indicator' computes the spatial variability of flow conditions between adjacent reaches. It reads the flow state of the current reach and its downstream reach to determine whether there is a change in the flow condition (flowing or intermittent). Hence, $PatchC$ indicates whether the flow state of the current reach differs from that of the downstream reach (0 if the same, 1 if different).

S3 Climate and hydrological projections

DRN	Variable	SSP1-2.6	SSP3-7.0	SSP5-8.5
Lepsämänjoki (FI)	T [°C]	2.0	4.6	5.6
	P [%]	1.8	4.4	4.1
	ET [%]	9.0	14.5	16.9
	QA [%]	-10.2	-12.6	-16.7
Velicka (CZ)	T [°C]	1.7	4.0	4.9
	P [%]	2.1	-0.7	-5.2
	ET [%]	9.6	13.4	11.2
	QA [%]	-26.5	-51.1	-63.9
Bükkösdi (HU)	T [°C]	1.8	4.2	5.3
	P [%]	1.2	-6.8	-14.0
	ET [%]	3.5	-2.9	-9.2
	QA [%]	-34.6	-63.6	-74.4
Albarine (FR)	T [°C]	1.4	3.7	4.7
	P [%]	0.1	-7.1	-8.8
	ET [%]	7.9	11.9	12.0
	QA [%]	-5.2	-20.2	-23.2
Butiznica (HR)	T [°C]	1.8	4.2	5.2
	P [%]	0.6	-7.6	-13.8
	ET [%]	7.4	6.3	3.2
	QA [%]	-7.1	-23.3	-32.9
Genal (ES)	T [°C]	1.2	3.2	4.1
	P [%]	-8.8	-25.6	-33.2
	ET [%]	-5.7	-12.1	-17.1
	QA [%]	-11.6	-38.5	-49.1

Table S2. Changes in annual temperature (T), precipitation (P), actual evapotranspiration (ET), and streamflow at the main gauging station (QA) in 2071-2100 compared to 1985-2014 in the 6 DRNs. Results are given as the average of the 5 GCMs.

S4 Location of the gauging stations

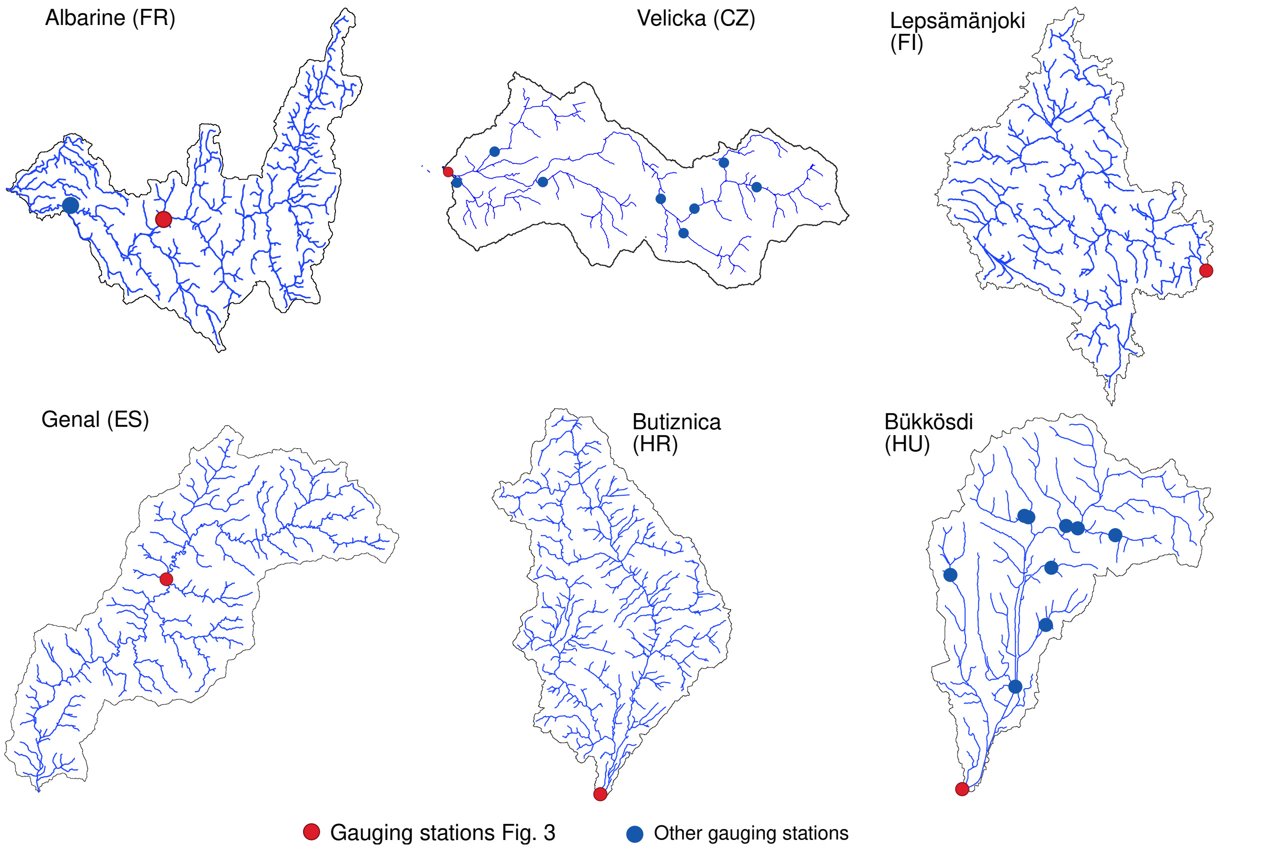

Figure S3. Location of the gauging stations from Fig. 3 (red), and other gauging stations used for the JAMS-J2000 model calibration (blue).

S5 Observed flow intermittence regimes in the DRNs

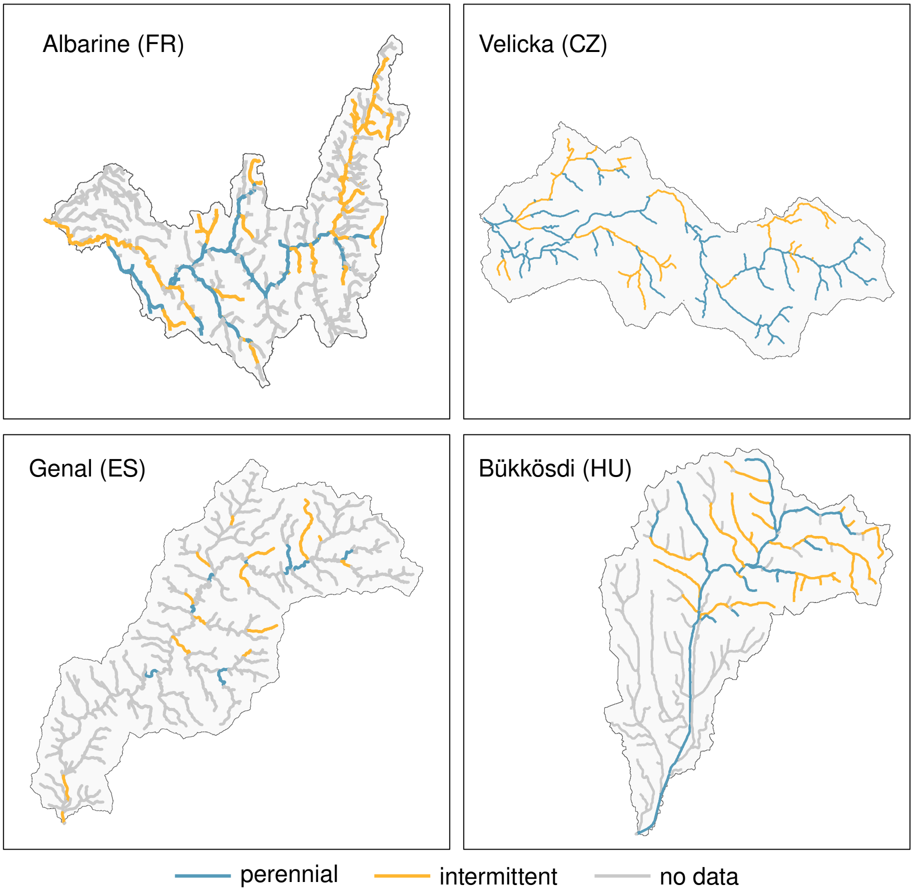

Figure S4. Flow intermittence regimes based on local DRN teams's expertise. blue: the reaches are known to be perennial, orange: the reaches are known to be ephemeral or intermittent (either with observed events of complete drying or pool conditions), grey: flow intermittence regime is unknown. The observation period differs according to the DRNs: the Albarine (FR) and Velicka (CZ) have been observed for more than 10 years by the DRN teams, Bükkösdi (HU) has been observed since 2018 and Genal (ES) since 2020. There is no spatialized data of observed flow intermittence regimes in the Butiznica (HR) and Lepsämänjoki (FI) DRNs.

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Mimeau, L., Künne, A., Branger, F., Kralisch, S., Devers, A., and Vidal, J.-P.: Flow intermittence prediction using a hybrid hydrological modelling approach: influence of observed intermittence data on the training of a random forest model, Hydrology and Earth System Sciences, 28, 851–871, https://doi.org/10.5194/hess-28-851-2024, 2024.