Supplementary Materials

This document contains supporting material for:

A Probabilistic Approach to Mapping the Contribution of Individual Riverine Discharges into Liverpool Bay Using Distance Accumulation Cost Methods on Satellite Derived Ocean-Colour Data

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Contents

Figure S1. Residual current maps for Liverpool Bay

Below are maps for the residual current within the Liverpool Bay river plume. The direction of the current was extracted from the cmems_mod_nws_phy-uv_my_7km-3D_P1M-m dataset from Copernicus (https://doi.org/10.48670/moi-00059) from 2017 to 2021.

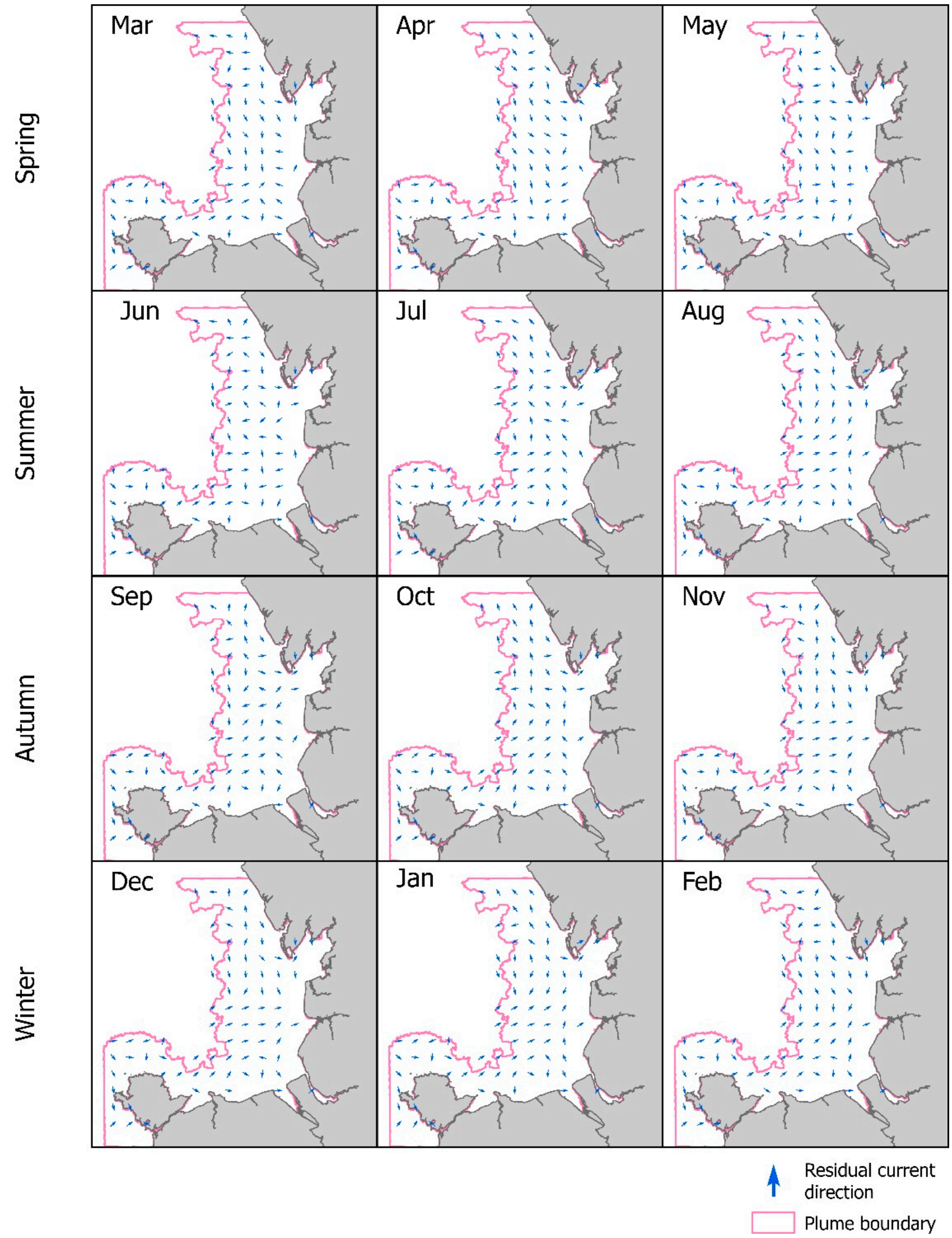


Figure S1. Direction of mean monthly residual current within the river plume boundary for each calendar month between 2017 to 2021.

Figure S2. Correlation of Forel-Ule value and nutrient concentrations

Water quality data were obtained from Environment Agency monitoring stations under the Water framework Directive, and the ICES XXX for the period 01/01/2017 to 31/12/2019 and the data for nitrates and nitrites, and ammonium were extracted. A map of the locations of the data extracted from these datasets is shown in Figure S2.1.

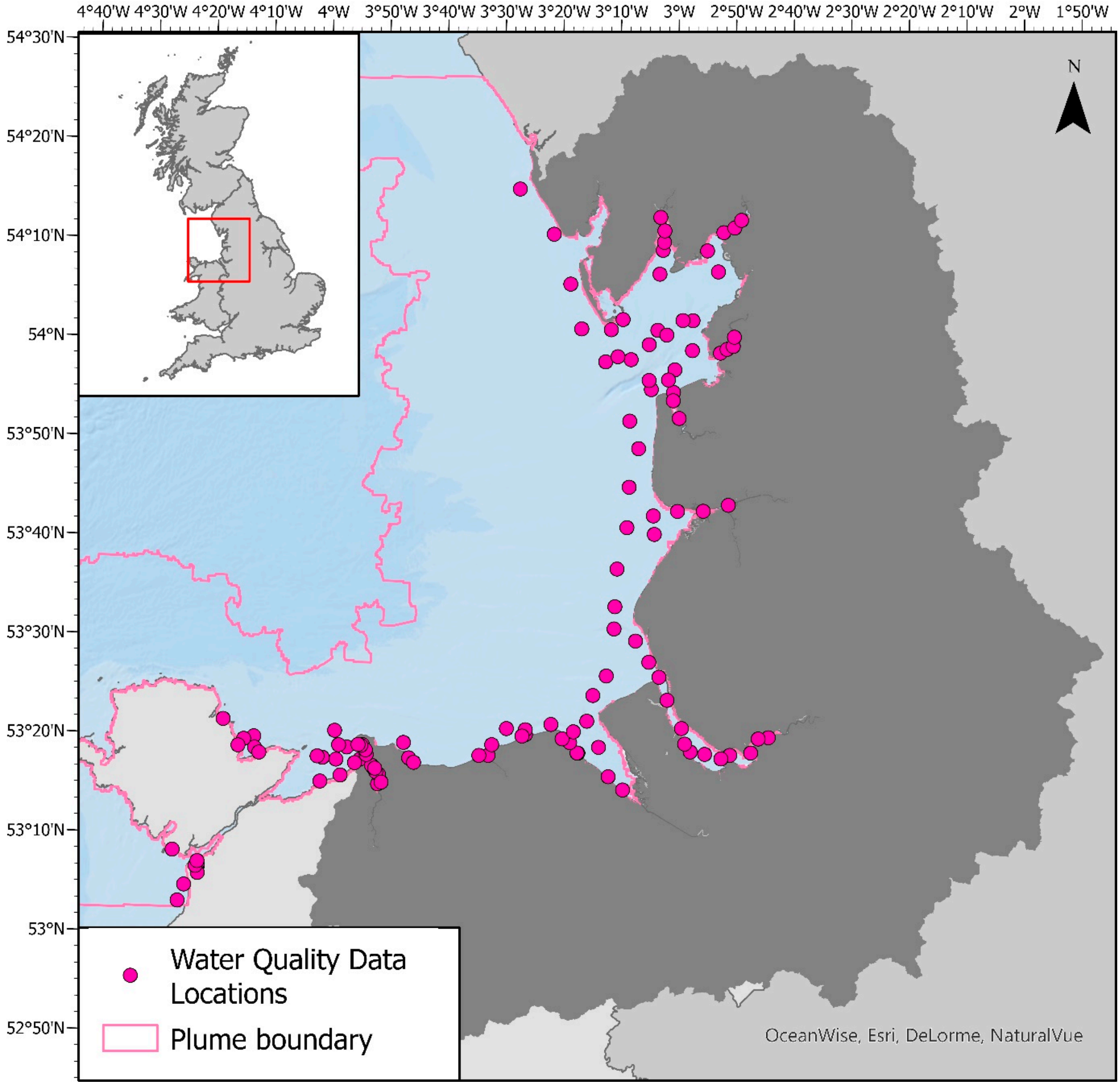
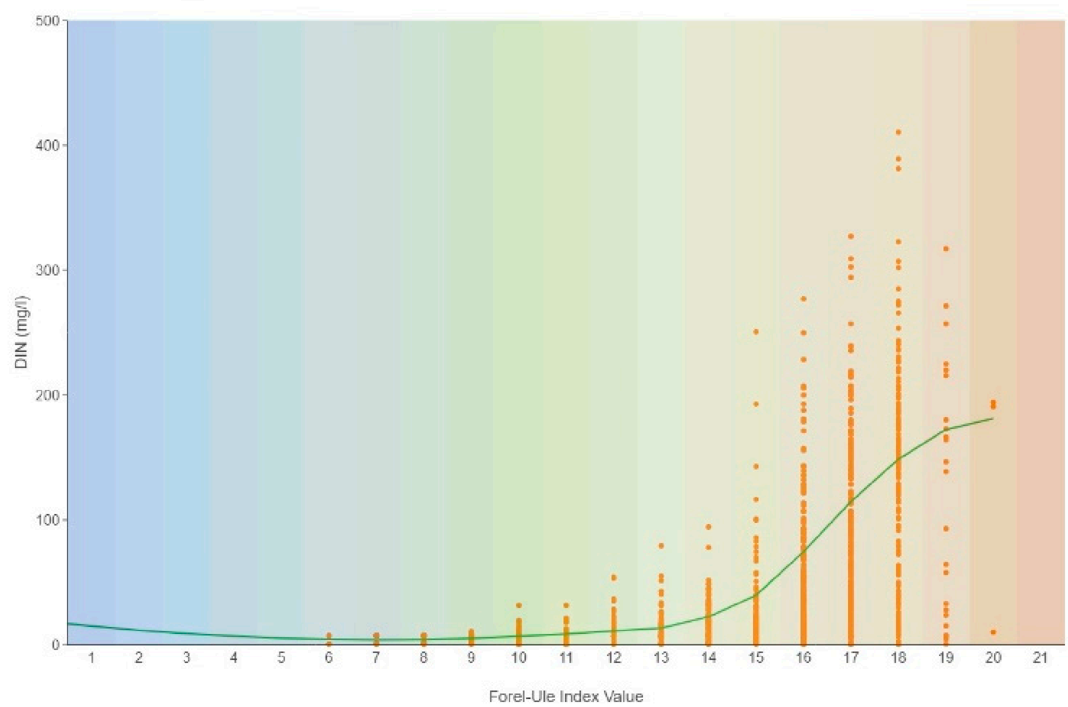


Figure S.2.1. Map of the water quality sample locations extracted from the UK Environment Agency and ICES monitoring programmes for the period 2017 to 2021.

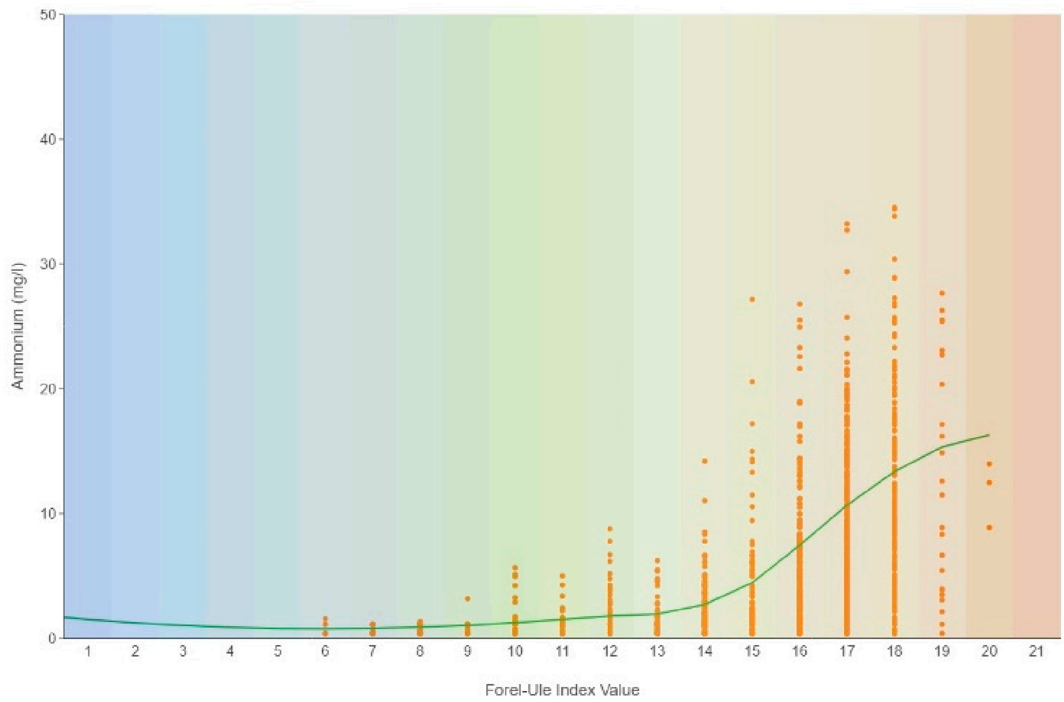
The date of the monitoring sample was used to extract the FUI value from the corresponding data layer. These values were used to obtain a local correlation factor (LOESS), as shown below in Figure S2.2(a) and (b).

To generate a function linking the FUI value and a normalised cost value representing the DIN concentration, all FUI values below 10 were assumed to be open ocean and given a maximal normalised cost of 0.9, and estuarine water (FUI of 21) was given a normalised cost of 0.1. For FUI values between 10 and 21 the LOESS correlation between observed DIN (nitrate, nitrite and ammonium; see above) and FUI values was used to obtain the normalised cost for each FUI value. A graph of the corresponding function is shown in Figure S2.2(c).

(a)



(b)



(c)

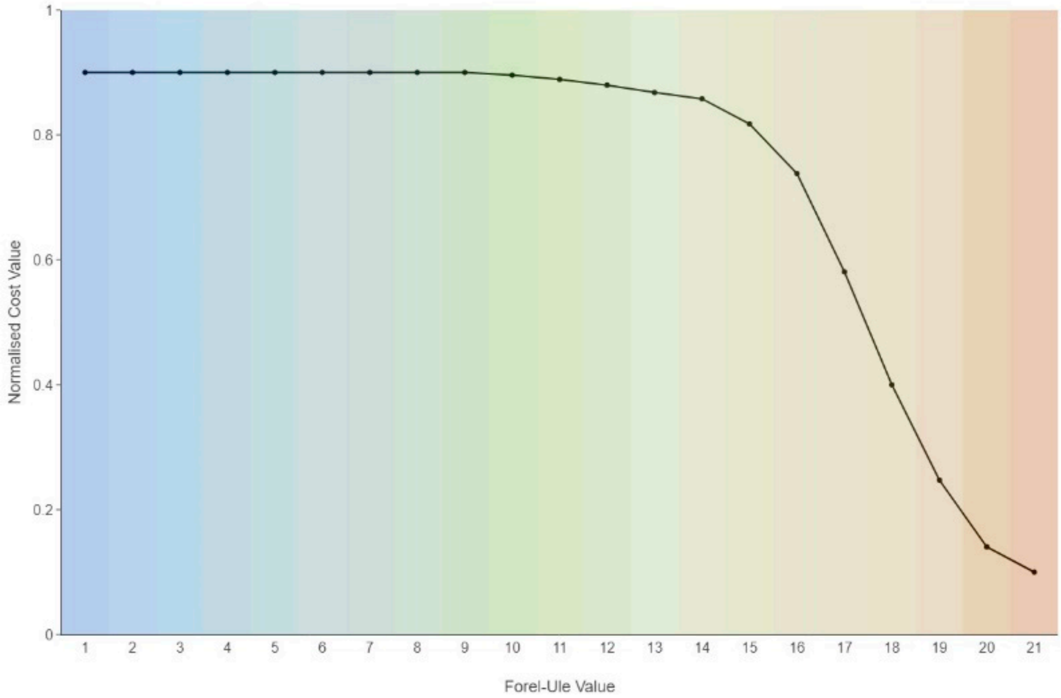


Figure S.2.2. Local correlation factor (LOESS) between the FUI value obtained from the satellite data and the in-situ nitrate and nitrate (a) or ammonium (b) concentration (c) normalised cost value function used to convert Forel-Ule index values to a normalised cost value for DIN exposure.

Figure S3. Liverpool Bay River Plume Monthly Frequency Maps

Median FUI layers for every month from 2017 to 2021 inclusive were reclassified for the presence of river plume (FUI value > 9) and the frequency of the presence of the river plume was calculated for each calendar month. For example, the frequency of the river plume for March was the frequency of the presence of the river plume in March 2017, March 2018, March 2019, March 2020 and March 2021.

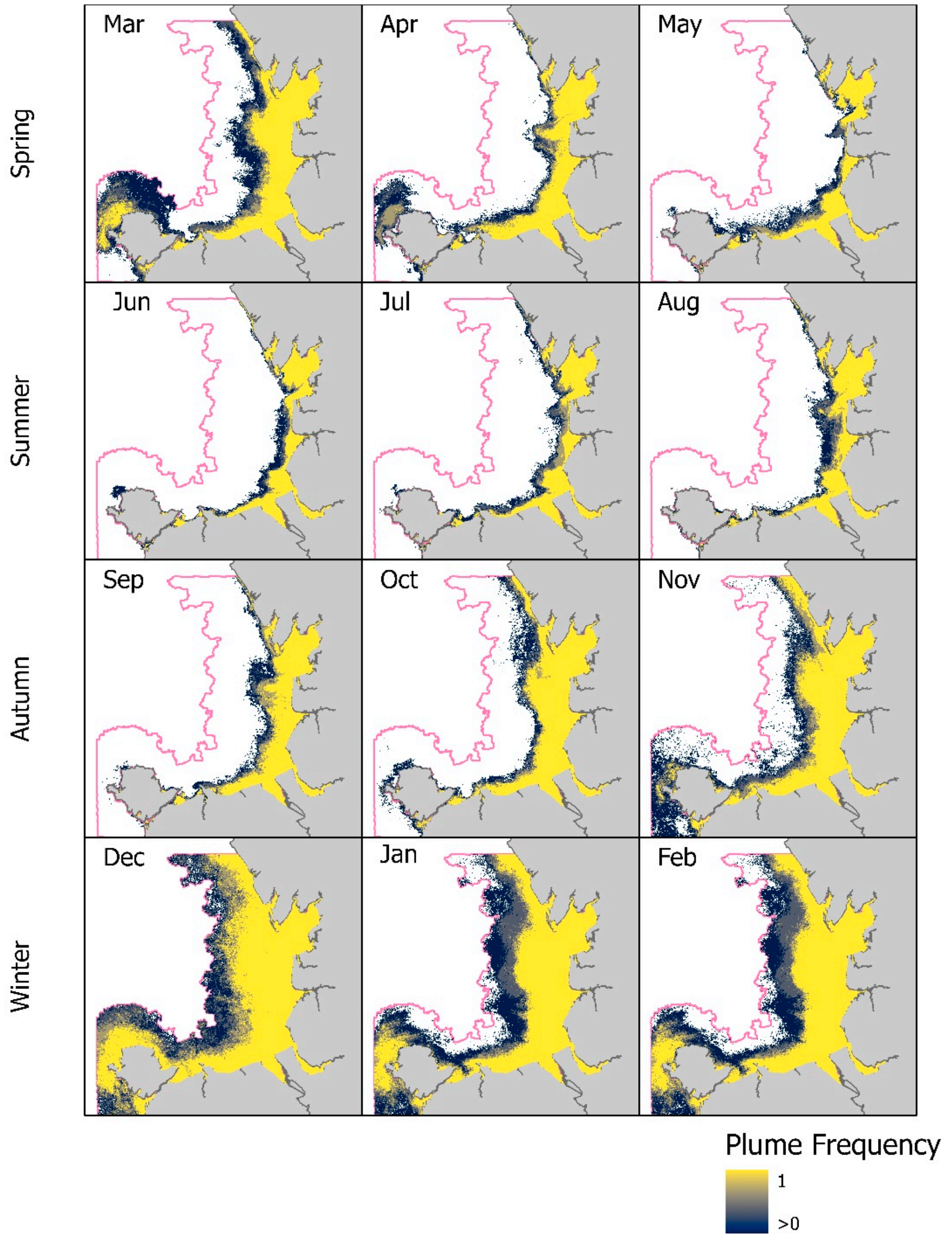


Figure S.3. Frequency of the presence of a river plume as defined by a median FUI value over 9 for each calendar month between 2017 to 2020.

Figure S4. Cost surface maps for DIN in the Liverpool Bay plume

Using the local correlation factor for normalised DIN exposure and FUI value (see Section 0) cost surfaces were generated for each calendar month by reclassification of the mean FUI value for the period 2017 to 2021 with the normalised DIN value. These normalised cost surfaces are shown in the figure below.

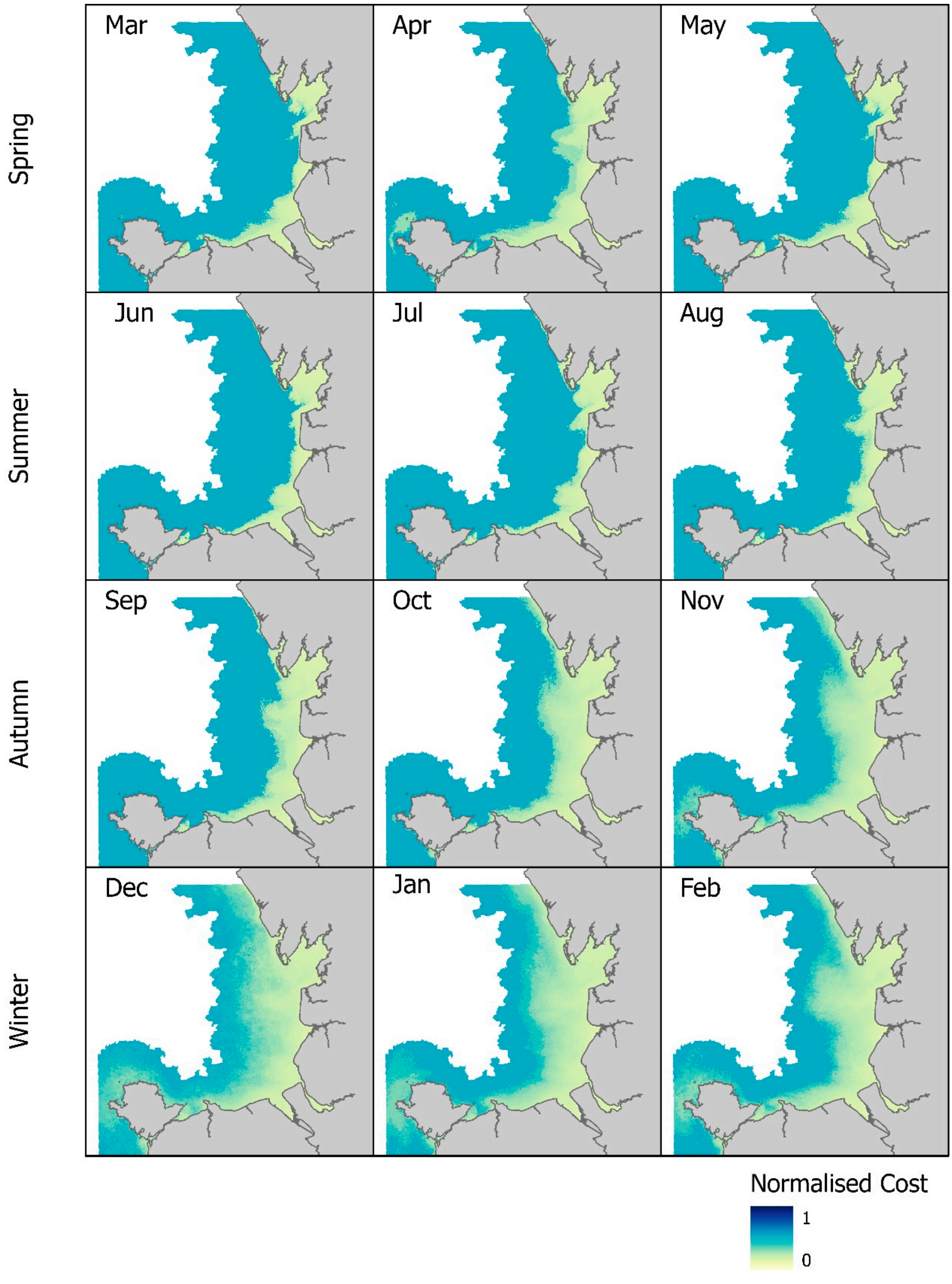


Figure S.4. Normalised cost surfaces for DIN exposure within the Liverpool Bay river plume boundary.

Figure S5. Spatial probability of riverine inputs into Liverpool Bay

A distance-accumulation method was used to determine the probability of riverine discharge reaching locations within the Liverpool Bay river plume. The distance-cost incorporated a horizontal cost based on the direction of the residual current (see Section S1). The probability maps for each river for January are shown below.

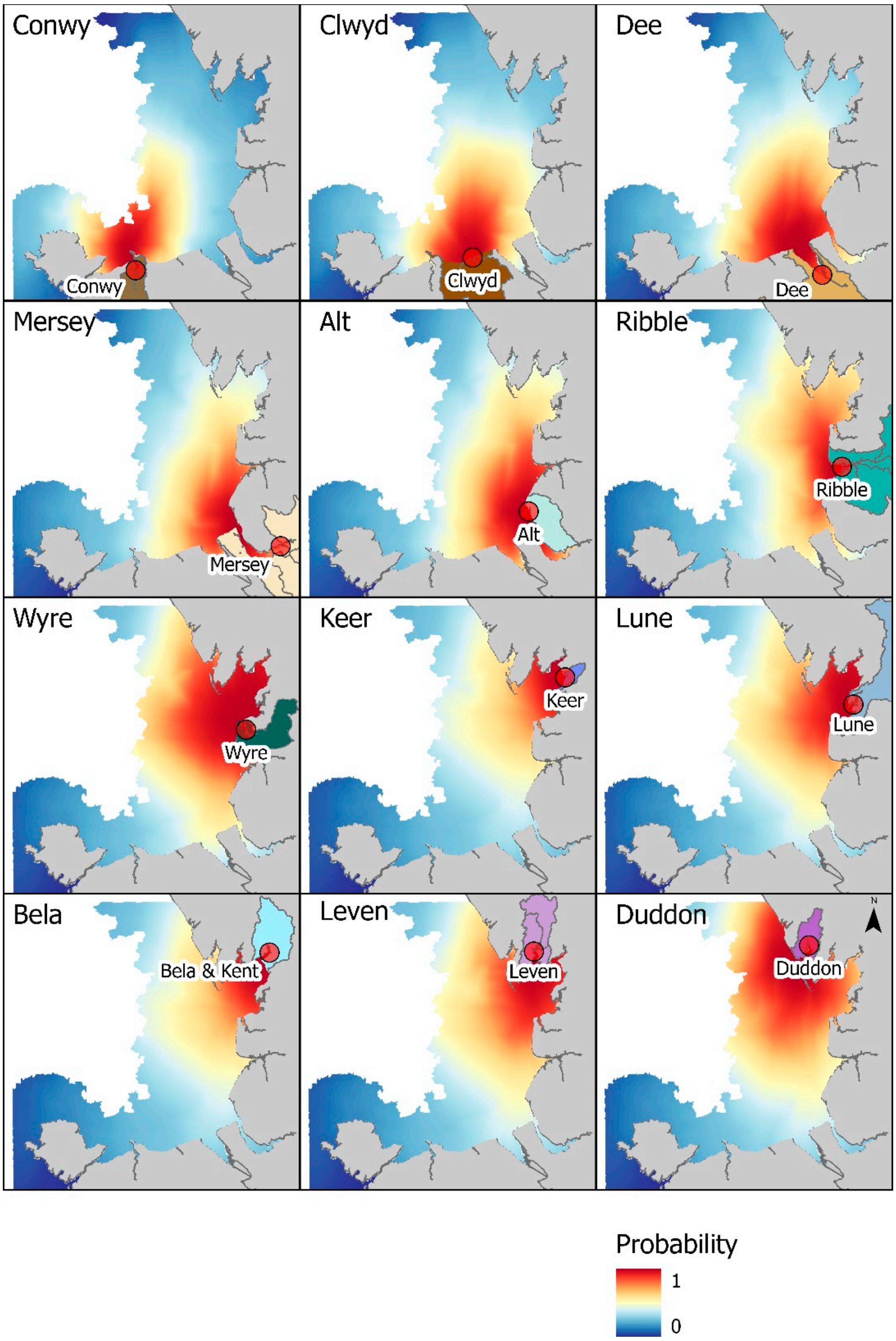


Figure S. 5. Spatial maps of the probability of water from a river reaching a location within the study area river plume. Shown below are the maps for January for all 12 major rivers, using the river mouth as the source location.

Figure S6. Riverine DIN input as a percentage of the cumulative DIN risk

These maps show the percentage contribution of each river to the overall cumulative DIN exposure risk (the probability that a location is exposed to DIN). Shown here are the percentage contributions for the rivers Clwyd, Mersey, Wyre, Dee, Ribble and Leven, for the months of January and July.

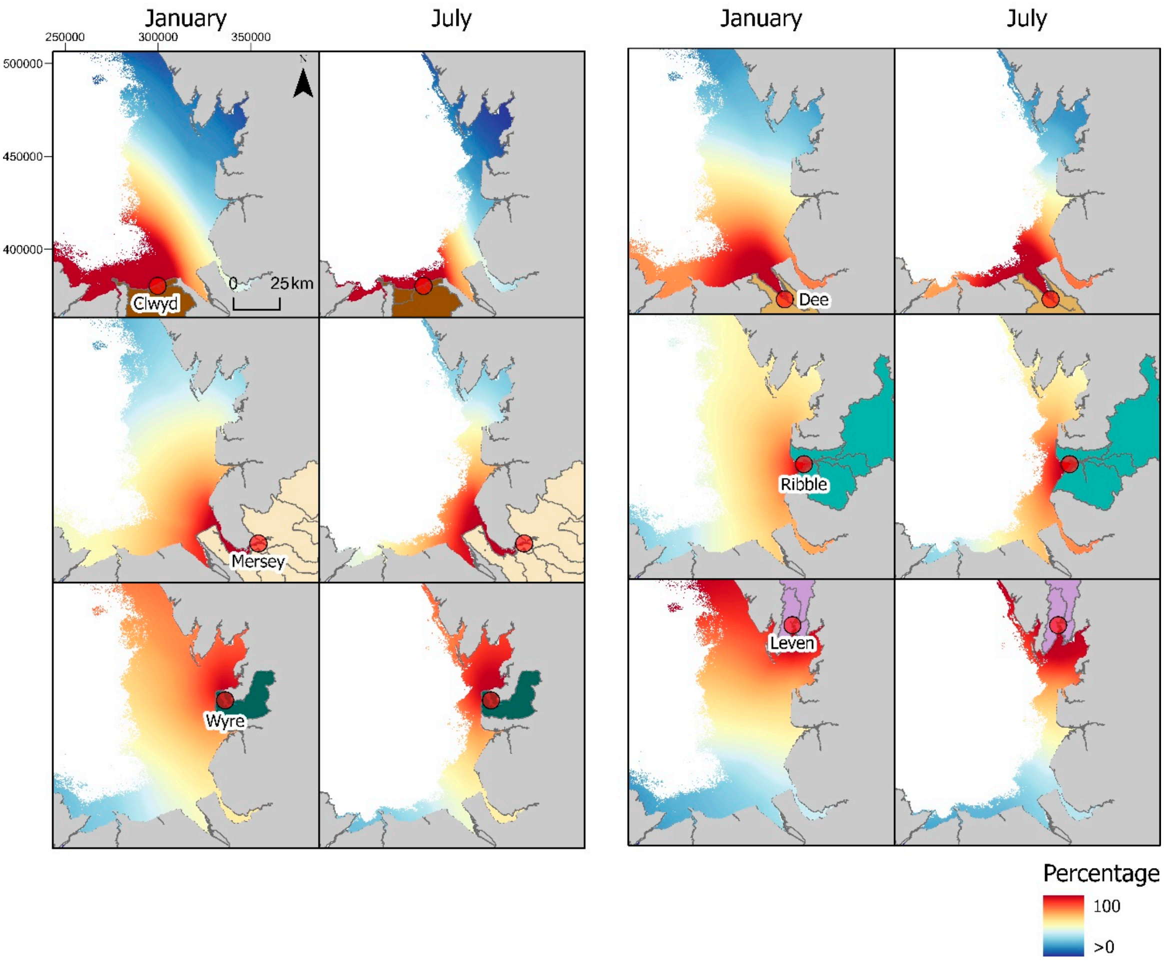


Figure S. 6. Spatial maps of the percentage of the cumulative probability that water from a river reaches a location within the study area river plume. Shown are the maps for January and July for Clwyd, Mersey, Wyre, Dee Ribble, and Leven using the river mouth as the source location.

Table S1. Sources of in situ data for river flow and nutrient inputs for rivers inputting into the Liverpool Bay study area

	Rivers	NRFA Gauge	Water Quality Station
R1	Conwy	Conwy (66011)	S28136[a] S25374[a] S25385[a]
R2	Clwyd (Clwyd and Elwy)	Clwyd (66001) Elwy (66006)	S3560[a] 3622[a] 3559[a]
R3	Dee	Dee – 67001	NW-3[b]
R4	Mersey (Mersey, Gowy, Dane, Weaver, Sanky Brook, Irk, Irwell, Medlock, Glaze, and Bollin)	Mersey (69037) Arrowe Brook - 68021 Gowy (68020) Dane (68003) Weaver (68001) Sanky Brook (69030)	NW-88002829[b] NW-88002640[b] NW-88002710[b] NW-88002762[b] NW-88002769[b] NW-88002770[b] NW-88002811[b] NW-88002822[b]
R5	Alt	Alt (69032)	NW-88002837[b]
R6	Ribble (Ribble, Darwen, Douglas, and Yarrow)	Ribble (71001) Darwen (71014) Douglas (70002) Yarrow (70004)	NW-88003566[b] NW-88003579[b] NW-88003586[b] NW-88003594[b]
R7	Wyre	Wyre (72002)	NW-88003886[b] NW-88003920[b] NW-88003930[b]
R8	Lune (Lune and Conder)	Lune (72004) Conder (72014)	NW-88004078[b]
R9	Keer	Keer (73015)	NW-88004481[b]
R10	Bela (Bela and Kent)	Bela (73008) Kent (73005)	NW-88004435[b] NW-88004397[b]
R11	Leven (Leven and Crake)	Crake (73002) Leven (73010)	NW-88021019[b] NW-88004563[b]
R12	Duddon	Duddon (74001)	NW-88004959[b]

[a] – Water quality data obtained from the EA
[b] – Water quality data obtained from NRW

Table S. 1. Rivers inputting into the Liverpool Bay study area and their associated river gauges and water quality stations.

Table S1. Contribution of Conwy, Clwyd and Dee to the DIN exposure risk along the north Wales coast

To understand the relative contribution of the rivers Conwy, Clwyd and Dee to the DIN exposure risk along the north Wales coast, the scaled risk raster layers for each river over the summer (June, July and August) and winter (December, January and February) months were summed. The area of interest was taken out to 6 nm from the westerly tip of Anglesey to the easterly mouth of the river Dee. The cumulative sum for each river was compared to the cumulative sum of all 3 rivers to obtain the percentage contribution for each river at each grid location. The mean values of these raster layers are presented in the table below.

River	**Mean grid cell percentage contribution to DIN exposure risk**	
	Summer	**Winter**
Dee	66%	58%
Clwyd	33%	41%
Conwy	<1%	<1%

Table S. 2. Contribution of Conwy, Clwyd and Dee to the DIN exposure risk along the north Wales coast.