Climate Change Mitigation Research Programme Annual Report

2021

IFI/2022/1-4621

Iascach Intíre Éireann
Inland Fisheries Ireland

Climate Change Mitigation Research Programme

Annual Report 2021

Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24

CITATION: Barry, J., Coyne, J., Kelly. S., and Kelly, F.L. (2022) Climate Change Mitigation Research Programme, Annual Report 2021. National Research Survey Programme, Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24.

Cover photo: Lough Currane @ Inland Fisheries Ireland

ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge the help and co-operation of all their colleagues in Inland Fisheries Ireland. The authors would also like to acknowledge the funding provided for the project from the Department of Communications, Climate Action and Environment for 2019. The authors would also like to acknowledge the advice related to initiating a long-term water temperature monitoring network from Iain Malcom and Faye Jackson (Marine Scotland Science).

Table of Contents

1. Introduction

Climate change has been identified by Inland Fisheries Ireland (IFI) as one of the greatest current and future threats facing the wider aquatic environment and fish populations. Considerable uncertainties and research gaps remain in relation to the impacts of climate change on Irish fish species, populations, and habitats. In response to this, IFI established a Climate Change Mitigation Research Programme (CCMRP) in 2019 to build an evidence-based assessment programme to assess the impact of climate change on the Irish fisheries sector in both freshwater and estuarine environments, with the aim to inform and build capacity for fisheries conservation and protection measures.

1.1 Climate change and fish species

Climate change is predicted to cause increases in air temperature, heatwaves, dry periods/droughts, and heavy precipitation events (Nolan and Flanagan, 2020). The main impacts of climate change on fish species are predicted to be on their distribution, abundance, phenology (timing), species composition and community structure and dynamics (Comte *et al*., 2012). The fisheries associated impacts also altered are flow regimes, increases in water temperature (and resulting decrease in oxygen concentration) and loss of habitat (Solheim *et al*., 2020; O' Keefe *et al*., 2018). Food-webs will also be altered with unpredictable consequences for fish production (Cochrane *et al*., 2009). Increasing risks of new invasive species and spreading of water borne diseases provide additional concern (Cochrane *et al*., 2009). Additionally, the effects of existing anthropogenic pressures (e.g., nutrient enrichment, hydro-morphological changes, and invasive species) on freshwater environments and their fish species are likely to interact with climate change associated pressures (e.g., rising temperatures and droughts) and seriously affect freshwater fish species and other aquatic life (Comte *et al*., 2013; Gutowsky *et al*., 2018).

1.1.1 Water temperature

The most prevalent impact of climate change will be on the thermal regime and mostly a warming of water temperatures (Pletterbauer *et al*., 2018). Water temperature is one of the most important factors in aquatic ecosystems. Water temperature has an influence on water chemistry, for example the amount of dissolved oxygen in a waterbody decreases as it gets warmer, and some compounds are more toxic to aquatic life at higher temperatures. Water temperature can also influence water quantity measurements and the types of organisms that live in water bodies. It also applies a major influence on biological activity and growth. Most aquatic organisms have a preferred temperature range and as temperatures rise above or below the preferred range the number of individuals of a species will decrease and eventually die (Pletterbauer *et al*., 2018).

Water temperature plays an important role in almost every aspect of fish life and adverse temperatures can affect fish behaviour, growth, survival, and disease resistance (e.g., Jonsson and Jonsson, 2010; Pletterbauer *et al*., 2018). Fish response to increasing temperature will vary according to their thermal tolerances and life stage; however, a negative response is expected for cold-water species (e.g., Arctic char, Atlantic salmon, and brown trout/sea trout), while warm water species (e.g., roach) and cool-water species (e.g., pike and perch) are likely to be positively affected to varying degrees (Mohsenie *et al*, 2003; Pletterbauer *et al*., 2018). Thermal stress that incurs growth and feeding limitations will begin to occur for brown trout when water temperatures are >19°C (Elliot and Elliot, 2010). It is important to identify where these limits may occur in stream and rivers during summer droughts (and during other seasons), identify risk areas and mitigate if necessary. Changes in water temperature are primarily influenced by the depth of the water and the amount of solar radiation received at a site. High water temperatures, low flow and low dissolved oxygen in combination can be catastrophic and cause fish kills.

1.2 Objectives

The primary objective is to build an evidence-based assessment programme to assess the impact of climate change on the Irish fisheries sector in both freshwater and estuarine environments, with the aim to inform and build capacity for fisheries conservation and protection measures. The work will be carried out through a series of work packages, including the establishment of a long-term fish, water temperature and other environmental variables monitoring network, developing species distribution models, undertaking a vulnerability assessment for key fish species in Ireland and assessing mitigation strategies. The project will use advanced mapping tools to model stream temperature and other variables and identify waterbodies at risk from climate change impacts. The lakes network of the project will continue to evolve with key limnological measurements such as dissolved oxygen, wind speed, direction and solar radiation being added to the programme in the coming years. The combination of these metrics will ensure that lakes can be investigated using a wide variety of limnological modelling tools. The aim is to investigate the effects of climate derived changes on lakes such as intensified storms and droughts on fish movements, life history changes and potential constrictions of available habitat.

This report summarises the progress of the IFI Climate Change Mitigation Research Programme in 2021. Preliminary findings from the fish species vulnerability assessment and the national water temperature (T_w) monitoring network in rivers and lakes are presented.

2. Methods

2.1 Vulnerability assessment of fish species to climate change in Ireland

Fish species vulnerability to climate change was assessed based on three principal metrics developed by Foden *et al*. (2013): (i) exposure, (ii) sensitivity, and (iii) adaptive capacity. The exposure metric identifies how climate factors will affect the species in their current habitat range. The sensitivity metric reflects a species' ability to persist through changes in the environment and sensitive species will have limited resistance to climate change. Adaptive capacity refers to the ability species have to disperse to suitable habitats or tolerate changing habitat ability to undertake behavioural changes. Expert's knowledge facilitated through an online questionnaire survey presented a unique mechanism to characterise the vulnerabilities of Irelands freshwater fish species. An initial pool of twenty-two experts was identified and potential participants contacted and asked to take part in the vulnerability questionnaire. Considered experts consisted of research scientists from government agencies, conservation groups, and academia, all having extensive research experience with freshwater fishes in Ireland. All experts have adequate knowledge of the study species including their population dynamics, current management practices and local level threats to the species. The participants accessed the online questionnaire through a cloud-based tool for analysing survey data.

The questionnaire was designed into three sections. In the first section, experts assessed the projected changes in water temperature and precipitation for Ireland. Experts were required to provide numerical values of 1 to 5 for each vulnerability indicator, the scoring bins were attributed values corresponding to low = 1, low-moderate = 2. moderate = 3, moderate-high=4 and high = 5. The higher the exposure and sensitivity index for a species the higher its overall climate change vulnerability. Adaptive capacity has an inverse relationship with vulnerability, the higher the adaptive capacity index meant lower vulnerability to climate change, the numerical values attributed to the scoring scale were reversed for indicator scoring. We followed existing fish specific climate-change vulnerability frameworks (Olusanya and van Zyll de Jong, 2018) based on online questionnaires. The final vulnerability score was calculated by adding scores for exposure, sensitivity, and adaptive capacity.

2.2 Index catchment monitoring network

The approach taken to design a large-scale long term national index catchment monitoring network, within which a range of variables (e.g., water temperature, flow velocity) and biota (e.g., fish) expected to respond to climate change will be measured was adapted for Ireland from that developed for Scottish streams (Jackson *et al*., 2016). The purpose of the index catchment network is to document changes in lake, river and estuarine ecosystems that occur in response to different land use and climate pressures. The data collected will inform risk assessment, mitigation measures and future policy.

Traditional monitoring (e.g., low-frequency spot sampling) cannot resolve or provide the necessary information to understand the processes driving many aspects of river, lakes or estuaries because the water body properties can be completely altered by short-term weather-related physical disturbances. High-frequency water temperature data will be collected in all index catchments and additional data will be collected in a subset of these. Other environmental data (e.g., dissolved oxygen) will be collected at selected sites in each index catchment and habitat assessments will also be undertaken.

2.2.1 Index catchment selection

An index catchment approach was chosen as this provides numerous benefits, such as reduction of costs and ease of planning (Jackson *et al*., 2016). The methods used to select index catchments and sites are described below.

Index catchments were chosen to represent the range of landscape variables controlling Irish freshwater waterbodies to provide an understanding of spatial variability and long-term change. For more information on the site selection process see Barry *et al*. (2021).

A total of nine near natural index catchments were selected with a good representation across Ireland of N, S, E W. Monitoring sites were then chosen using appropriate landscape covariates and a site selection and validation process. The selected index catchments include: Gweebara, Co. Donegal; Erriff, Co. Mayo; Doonbeg, Co. Clare; Ilen Co. Cork; Cummeragh/Currane, Co. Kerry; Nore, Counties Kilkenny, Laois and Tipperary; Vartry and Dargle, Co. Wicklow and Dodder, Co. Dublin (Fig. 2.1 and Appendix 1). Three additional catchments were selected as part of a collaborative project between IFI and Office of Public Works (Kelly *et al*., 2022) (Fig. 2.1).

2.2.2 Meteorological data

Automatic weather stations were strategically located at three sites close to or within index catchments (IFI Glenties, Co. Donegal; IFI National Salmonid Index Catchment (Erriff) (Co. Galway); Duiske catchment (River Barrow catchment) (close to River Nore, Co. Kilkenny) (Fig. 2.1)) where monitoring sites are not close to Met Eireann's national monitoring network. Each weather station has an integrated sensor suite and records air temperature, wind speed and direction, precipitation and barometric pressure data every 30 minutes. This data is downloaded by IFI staff once a month and is also visible via a free online application (www.weatherlink.com).

Met Eireann weather station data at Dublin Airport and Valentia Observatory is available for the remaining catchments (Fig. 2). These data are used in conjunction with the CCMRP Tw network (Section 3.3) where a national model is being developed which will establish the relationship between air temperature (Ta) and stream temperature (Tw) and how this relationship is modified by landscape covariates including elevation, channel orientation and riparian woodland (see Barry *et al*., 2021 for more information). In addition, the support of high-quality weather data at Valentia Observatory will support the limnological analysis on Lough Currane as part of the lakes network.

2.3 National climate change index monitoring network (rivers and lakes)

2.3.1 River monitoring network

A total of 213 water temperature (T_w) data loggers have been deployed to date in rivers within nine catchments between September 2019 and present (Table 2.1). (See Kelly *et al*., 2022 for information related to three additional drained catchments – OPW Climate resilience Project datalogger distribution). A standardised deployment method was developed (Barry *et al*., 2021). Each T_w data logger was anchored using rebar and was shielded using 10mm white pvc drainpipe to prevent exposure to direct sunlight. An alternative deployment method was used for deep sites (Barry *et al*., 2021; Kelly *et al*., 2022). Each data logger was programmed to record T_w every 30 minutes (reporting resolution 0.2 °C). Field deployed dataloggers were calibrated against an internal reference logger which was in turn calibrated by a certified laboratory instrument. Each data logger is downloaded every 6-12 months and replaced by a calibrated unit.

Table 2.1. Summary details of number and location of river Tw data loggers in the national index catchment network (IFI OPWCRP information also included) Note: * indicates IFI OPWCRP catchments

Region	Catchment	No. Tw data loggers
East	Dargle	21
	Dodder	17
	Vartry	13
	Boyne*	46
Midlands	Inny*	16
Northwest:	Gweebarra	28
Southeast	Nore	46
Southwest	Ilen	25
	Cummeragh/Currane	17
West	Erriff River (NSIC)	35
	Doonbeg	11
	Moy*	53

2.3.2 Lake monitoring network

Lake ecosystems are important indicators of catchment modification and can quickly respond to climate driven forces. The delivery of quality temperature and limnological data is a key objective of the programmes research deliverables. The CCMRP lakes network has been established since June 2019. At present the network comprises of five lakes within four catchments (Fig. 2.2).

Thermistor chains were deployed over the deepest part of four lakes in the Gweebarra, Erriff and Currane/Cummeragh catchments. A total of 58 T_w data loggers have been deployed in the four lakes (Table 2.2). In parallel a real time data buoy was initiated to monitor water temperature on Lough Sheelin through the OPW CRP project during summer 2021 (Kelly *et al.*, 2022). T_w monitoring in the four lakes is provided using a design structure fitted with an array of water temperature data loggers in 2m increments located at the deepest point of each lake. Data loggers record T_w in 30 minute intervals. The thermistor arrays are maintained by 30-40kg weight and kept stable by a submerged tension buoy with an additional signal buoy at the water surface (Barry *et al.*, 2021). A preliminary investigation of dissolved oxygen (D.O.) consumption was conducted in 2021 using a similar design structure in the same location fitted with an array of dissolved oxygen data loggers. These were based in increments dividing the lake max depth between “surface”, “middle” and “bottom”. Where maximum depth was less than 20m, only two D.O. data loggers were deployed (surface and bottom only).

Table 2.2. Summary details of number and location of data loggers in the index lakes

Region	Catchment	Lake name	No. data loggers	
			Tw	D.O.
Northwest	Gweebarra	Barra	7	2
Midlands	Inny	Sheelin*	7	2
Southwest	Cummeragh/Currane	Currane	19	3
		Derriana	19	0
West	Erriff (NSIC)	Tawnyard	13	3

Note: * indicates IFI/OPWCRP catchment

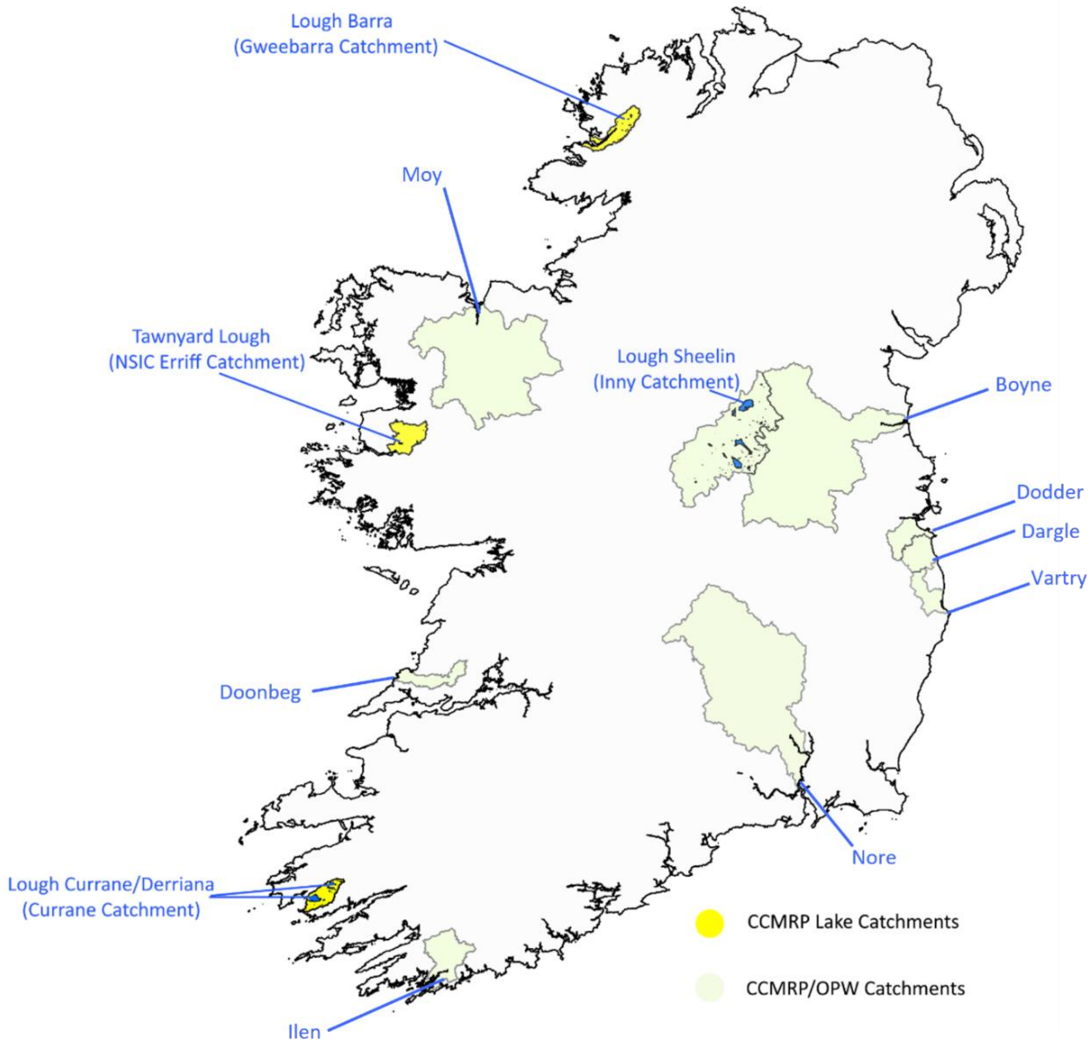

Fig. 2.1. Location of IFI's national temperature monitoring network. IFI CCMRP catchments and OPW catchments are highlighted in light green. CCMRP catchment with lake monitoring are highlighted in yellow. IFI Weather stations are located in Gweebarra, Nore and Inny catchments.

2.3.4 Thermal metrics

The thermal regime for each catchment was summarised by calculating eight thermal metrics (Isaak *et al*., 2018). The eight metrics included 1) Mean Winter Tw; 2) Mean Summer Tw; 3) Maximum weekly average Tw; 4) Maximum daily Tw; 5) Minimum daily Tw; 6) Number of days >20°C; 7) Number of days <2°C and 8) Maximum Tw recorded. Meteorological seasons were used (Winter = December, January, February; Spring= March, April, May; Summer= June, July, August; Autumn = September, October, November).

2.3.4 Spatial statistical network models

A spatial statistical network model was applied to the temperature logger data recorded on the Erriff catchment. Water temperature in unmonitored sites was predicted from observed T_w logger sites using autocovariance functions that allow inclusion of Euclidean as well as flow-connected and flow-unconnected spatial correlation structures (see Peterson and Ver Hoef (2010)). By explicitly incorporating spatial weights associated with stream attributes (e.g., drained watershed area) and topological relationships (e.g., flow-directionality at confluences) the spatial correlation structures included in the model are valid for usage in stream network systems. A variety of models were fit comparing different autocovariance structures and using upstream catchment area and percentage of upstream area comprising lake area as explanatory variables. Model selection was based on AIC values and model predictive skill (LOOCV).

2.3.5 Lake data

Preliminary analysis of the physical properties of each lake were analysed using the rLake Analyzer package (Read *et al*., 2021, Winslow *et al*., 2019). Lake Analyzer is a set of open-source tools that allows users to calculate common indices for lake physical states, such as Schmidt stability. These indices are calculated according to established literature with a time series output format. The Lake Analyzer programme was created for the rapid analysis of large volumes of high-frequency data collected from instrumented lake buoys (Read *et al*., 2011; Winslow *et al*., 2019).

2.4 Data management

It is essential that all the data is traceable and quality controlled, therefore a data management plan has been drafted and will be developed further as the project evolves. A centralised database is currently being developed which will incorporate ArcGIS Survey123 and dashboard capabilities for standardised on site data collection and tracking the data logger deployment and turnover.

3. Results

3.1 Climate change vulnerability assessment

Ten experts from a panel of twenty-two persons responded to the climate change vulnerability questionnaire for Irish freshwater species. Nine of the participants were classified as scientists and one as scientist/manager, four left the category blank. The overall species vulnerability scoring (cumulative exposure, sensitivity, and adaptive capacity index scores) grouped one species to be of high (class 5) vulnerability to climate change (i.e. Arctic char), twenty species of moderate to high (class 4) vulnerability, seven species of moderate (class 3) vulnerability, ten species of low to moderate (class 2) vulnerability, while no species were classified as having a low (class 1) overall vulnerability to climate change (Table 3.1) (Barry *et al*., submitted for publication).

Plate 3.1. Arctic char from Lough Melvin.

Table 3.1 Irelands freshwater fish climate change vulnerability ranking (after Barry *et al.*, submitted for publication). (Migratory species have been included and some species that enter freshwater for short periods of their life cycle).

Common Name	ScientificName	Risk category (survey)	Vulnerability score
Arctic char	*Salvelinus alpinus*	High	13.0
Salmon	*Salmo salar*	Moderate to high	10.8
Pollan	*Coregonus pollan*	Moderate to high	10.5
Gillaroo trout	*Salmo stomachicus*	Moderate to high	10.4
Killarney shad	*Alosa fallax killarnensis*	Moderate to high	10.3
Sonaghen trout	*Salmo nigripinnis*	Moderate to high	10.1
Ferox trout	*Salmo ferox*	Moderate to high	9.9
Sea trout	*Salmo trutta*	Moderate to high	9.1
Brook lamprey	*Lampetra planeri*	Moderate	9.0
Sea lamprey	*Petromyzon marinus*	Moderate	8.8
Brown trout	*Salmo trutta*	Moderate	8.6
European eel	*Anguilla anguilla*	Moderate	8.6
Twaite shad	*Alosa fallax*	Moderate	8.2
Allis shad	*Alosa*	Moderate	8.0
River lamprey	*Lampetra fluviatilis*	Moderate	7.9
Minnow	*Phoxinus phoxinus*	Moderate	7.4
Smelt	*Osmerus eperlanus*	Moderate	7.3
Gudgeon	*Gobio*	Moderate	7.0
Bream	*Abramis brama*	Moderate	7.0
9.sp stickleback	*Pungitius pungitius*	Moderate	6.7
Stone loach	*Barbatula barbatula*	Moderate	6.5
Tench	*Tinca tinca*	Moderate	6.5
Flounder	*Platichthys flesus*	Moderate	6.5
Rudd	*Scardinius erythrophthalmus*	Moderate	6.3
Rainbow trout	*Oncorhynchus mykiss*	Moderate	6.2
Perch	*Perca fluviatilis*	Moderate	6.2
Carp	*Cyprinus carpio*	Moderate	6.1
Pike	*Esox lucius*	Moderate	6.1
3.sp stickleback	*Gasterosteus aculeatus*	Low to moderate	5.9
Dace	*Leuciscus*	Low to moderate	5.6
Chub	*Squalius cephalus*	Low to moderate	4.8
Roach	*Rutilus*	Low to moderate	4.7

3.2 Meteorological data

Many areas across Ireland were dominated by a heatwave (definition: air temperature exceeds 25°C for ≥ 5 days or more) in mid-late July 2021 with air temperatures exceeding 30°C and many stations were above their long-term average temperature for the month (Met Éireann, 2021). Maximum temperatures in July varied throughout the country (Met Éireann, 2021). The highest air temperature observed at IFI stations was recorded at Glenties, Co. Donegal (30.7°C). The lowest air temperature was recorded at IFI Duiske station (-6.4°C). The highest annual temperature range (max-min) among IFI stations was observed at the Duiske weather station in Co. Kilkenny (35.5°C). Drought conditions were also observed in many areas during 2021 (e.g., Duiske catchment, August to September 2021) (Table 3.2).

Table 3.2. IFI weather station statistics for 2021. Data from two Met Éireann stations are also included.

Weather station	Source	Air Temperature -High (°C)	Air Temperature – Low (°C)	Total rainfall (mm)	Total rain days (≥0.2)	Yellow rainfall event (≥30mm)	Drought events 2021 (no. of days ≤ 0.1mm rainfall)
Glenties	IFI	**30.7**	-4.6	1306	240	2	NA
Duiske	IFI	29.1	-6.4	951	172	5	23rd August to 7th September (n=16)
NSIC Erriff	IFI	30.1	-4.3	**1989**	**256**	4	NA
Dublin Airport	Met Éireann	26.8	-5.9	666	159	0	29th May to 13th June (n=16)
Valentia	Met Éireann	28.3	-2.1	1548	241	2	22nd August to 7th September **(n=17)**

Plate 3.2. Weather station at NSIC Erriff, Co. Galway

3.3 National monitoring network: T_w in rivers

3.2.1 Gweebarra catchment

The highest water temperature recorded in the catchment during the sampling period was 28.4°C at site GA003 in July 2021 (Table 3.3). The range in maximum water temperatures across the catchment was 12.4°C (16.0 to 28.4°C). Since deployment of T_w data loggers in July 2019 twelve monitoring sites within the Gweebarra catchment recorded mean daily T_w exceeding 20°C (cumulative across 12 sites n=77days). Site GA003 recorded 12 days followed by sites GBA002 and GBA003 (ten and nine days respectively (Table 3.3 and Plate 3.3). The number of days the mean daily temperature exceeded 20°C in the catchment ranged from 1 to 12 (Table 3.3). The mean winter 2019 T_w across all sites in the catchment (mean=5.35 °C; 91 day sampling period) was higher than winter 2020 T_w (mean=4.61 °C; 91 day sampling period). In general, sites in the lower catchment had higher water temperatures as indicated by the number of days T_w exceeded 20°C (Fig. 3.3 and Table 3.3).

Table 3.3. Summary of selected thermal metrics for the Gweebarra catchment T_w monitoring sites, July 2019 to 2021.

Site code	Mean Tw	Mean winter Tw 2019	Mean winter Tw 2020	Mean summer Tw 2020	Max weekly avg Tw	Max daily Tw	Min daily Tw	No. of days mean daily Tw >20°C	No. of days mean daily Tw <2°C	Max record Tw
GBA001	10.6	5.6	5.0	15.6	20.3	21.7	1.6	7	4	23.4
GBA002	10.6	5.6	4.6	15.7	21.7	22.7	0.3	10	9	26.9
GBA003	10.6	5.5	4.6	15.7	22.5	24.8	0.3	12	9	**28.4**
GBA004	10.5	5.5	4.6	15.5	21.4	22.3	0.3	9	8	26.6
GBA005	9.2	5.8	4.9	13.3	15.7	16.9	2.7	0	0	17.2
GBA006	9.7	4.9	4.5	14.4	20.6	21.8	0.8	4	11	23.9
GBA007	12.8	NA	NA	12.8	13.0	13.6	11.7	0	0	16.0
GBA008	9.5	4.9	4.2	14.3	20.2	21.4	0.1	3	16	26.4
GBA009	9.1	4.5	3.8	13.8	19.2	19.7	0.1	0	27	23.9
GBA010	8.4	4.2	3.5	12.9	16.8	17.2	0.1	0	39	19.8
GBA012	9.9	NA	4.6	15.7	19.6	20.5	1.0	4	6	24.7
GBA013	9.6	5.5	4.7	13.9	18.0	19.7	0.5	0	7	21.7
GBA014	9.0	5.8	5.1	12.6	14.7	15.6	2.0	0	0	16.7
GBA015	10.1	5.3	4.5	15.0	19.3	19.8	0.6	0	7	22.9
GBA016	9.5	5.0	4.4	14.2	17.5	18.3	1.0	0	13	22.2
GBA017	10.3	5.2	4.4	15.6	21.2	22.5	0.7	6	5	27.4
GBA018	9.1	5.7	5.0	12.8	15.7	16.5	0.9	0	4	18.9
GBA019	8.9	5.7	5.0	12.4	14.2	15.3	1.6	0	1	16.1
GBA020	10.2	5.6	4.7	14.9	19.7	20.8	0.4	4	9	22.5
GBA021	9.9	5.5	4.8	14.5	17.6	18.7	1.6	0	3	20.1
GBA022	10.0	5.5	4.7	14.7	19.7	20.4	0.2	3	10	24.6
GBA023	9.7	NA	4.9	15.1	17.5	18.4	0.9	0	6	20.4
GBA024	9.4	6.2	5.5	13.0	14.5	15.8	3.3	0	0	17.2
GBA025	9.9	5.5	4.7	14.5	19.7	20.5	0.3	3	9	25.6
GBA026	9.6	5.5	4.7	14.1	18.1	18.9	0.6	0	8	22.7
GBA027	9.1	5.2	4.5	13.6	17.5	18.1	0.6	0	8	21.5
GBA028	8.9	4.7	4.0	13.3	18.3	20.0	0.5	1	11	23.5

***Note**: Winter 2019: 91 days (1st Dec 2019 to 29th Feb 2020); Summer 2020: 92 days (1st Jun 2020 to 31st Aug 2020); Winter 2020: 90 days (1st Dec 2020 to 28th Feb 2021). Mean Tw is average annual temperature.*

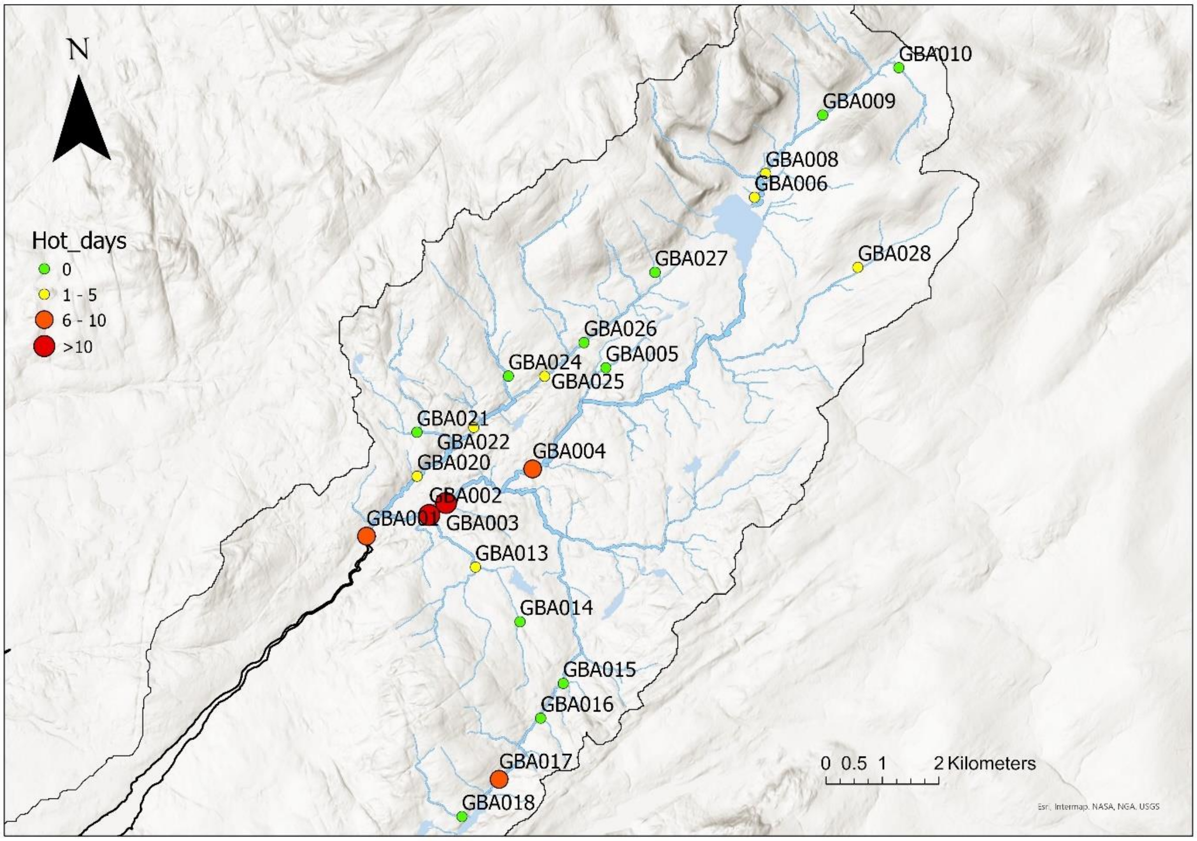

Fig. 3.1 Number of days the average daily Tw of 20°C was exceeded in the Gweebarra catchment (0 days (green circle), 1-5 days (yellow circles), 6-10 days (orange circles) and >10 days (red circles).

Plate 3.3. Monitoring locations on the Gweebarra River (Sites GA003 (left), GBA002 (middle) and GBA004 (right)).

3.2.2 Erriff catchment

The highest temperature in the Erriff network in the sampling period was 26°C at site ERF024 (Table 3.4 and Appendix 1). The range in maximum water temperatures across the catchment was 8.8°C (Table 3.4). Five sites (14.7%) within the Erriff network recorded mean daily T_w exceeding 20°C (cumulative across five sites n=15 days) (Table 3.4). The number of days the mean daily temperature exceeded 20°C in the catchment ranged from 1 to 6. The mean Winter 2019 Tw across all sites (mean=6.05 °C) was higher than Winter 2020 Tw (mean=5.6 °C).

Table 3.4 Summary of selected thermal metrics for the Erriff catchment Tw monitoring sites, 2019-2020

Site code	Mean Tw	Mean winter Tw 2019	Mean winter Tw 2020	Mean summer Tw 2020	Max weekly avg Tw	Max daily Tw	Min daily Tw	No. of days Mean daily Tw >20°C	No. of days Mean daily Tw <2°C	Max record Tw
ERF001	9.5	NA	5.7	15.1	15.7	17.2	0.9	0	5	17.6
ERF002	10.3	6.3	5.7	15.2	19.3	20.8	1.0	**6**	5	22.9
ERF003	9.2	5.9	5.3	13.9	17.3	18.3	0.2	0	9	21.0
ERF004	9.6	6.0	NA	NA	17.5	18.6	2.5	0	0	21.7
ERF005	9.8	5.9	5.5	14.1	17.2	18.3	0.1	0	5	23.2
ERF006	10.8	6.2	5.7	15.6	19.1	20.3	1.0	3	6	23.8
ERF007	11.1	6.4	6.0	16.0	19.2	19.9	3.1	0	0	21.5
ERF008	9.8	7.0	6.7	12.7	15.6	16.4	2.2	0	0	19.9
ERF009	10.1	6.0	5.4	14.4	18.0	19.0	0.5	0	6	24.0
ERF010	8.4	NA	5.0	13.6	14.0	15.8	0.0	0	**11**	19.3
ERF011	10.6	6.2	5.7	15.4	19.0	20.2	1.0	2	6	23.7
ERF012	10.6	6.2	5.6	15.4	18.9	20.0	0.9	0	6	22.7
ERF013	10.6	6.1	5.6	15.4	18.9	20.0	0.8	1	6	23.0
ERF014	10.6	6.1	5.5	15.4	19.1	20.2	0.6	3	9	23.6
ERF015	10.2	6.1	NA	NA	18.0	18.6	3.0	0	0	20.2
ERF016	9.9	5.7	5.4	14.2	17.2	18.2	0.4	0	6	21.1
ERF017	8.3	NA	5.0	13.6	14.3	15.9	0.2	0	5	18.2
ERF018	9.9	5.9	5.4	14.6	17.1	18.4	0.7	0	4	21.9
ERF019	10.3	6.0	5.5	14.8	17.5	18.3	0.5	0	8	20.0
ERF020	10.1	6.2	5.7	14.3	16.7	17.5	1.1	0	4	21.8
ERF021	9.9	6.2	5.9	13.9	16.2	17.5	1.0	0	2	22.0
ERF022	9.8	5.8	5.6	14.1	16.6	17.9	1.1	0	2	20.6
ERF023	10.2	6.0	5.5	14.7	17.7	18.6	0.4	0	8	22.3
ERF024	10.0	6.3	5.8	13.9	16.6	17.7	0.7	0	3	**26.0**
ERF025	9.7	5.8	5.5	13.8	16.9	17.9	0.9	0	4	23.6
ERF026	10.1	6.0	6.4	14.0	16.5	17.9	2.1	0	0	20.5
ERF027	10.3	6.1	5.5	14.9	17.4	18.3	1.2	0	5	20.4
ERF029	9.9	6.7	6.3	13.3	15.2	16.4	0.8	0	1	17.2
ERF030	10.3	5.9	NA	NA	17.7	18.5	3.0	0	0	22.3
ERF031	10.2	5.8	5.3	14.9	18.1	19.3	0.2	0	4	23.5
ERF032	10.0	5.9	5.5	14.5	17.8	19.0	0.6	0	3	22.7
ERF033	10.3	5.9	NA	NA	17.7	19.2	2.4	0	0	21.9
ERF034	10.1	5.8	5.2	14.7	17.4	19.0	0.6	0	9	21.7
ERF035	10.3	5.9	5.3	15.0	17.7	19.1	0.6	0	8	23.1
ERF036	9.8	5.5	NA	NA	16.5	17.8	1.8	0	1	21.7

***Note**: Winter 2019: 91 days, (1st Dec 2019 to 29th Feb 2020); Summer 2020: 92 days (1st Jun 2020 to 31st Aug 2020); Winter 2020: 90 days (1st Dec 2020 to 28th Feb 2021). Mean Tw is average annual temperature.*

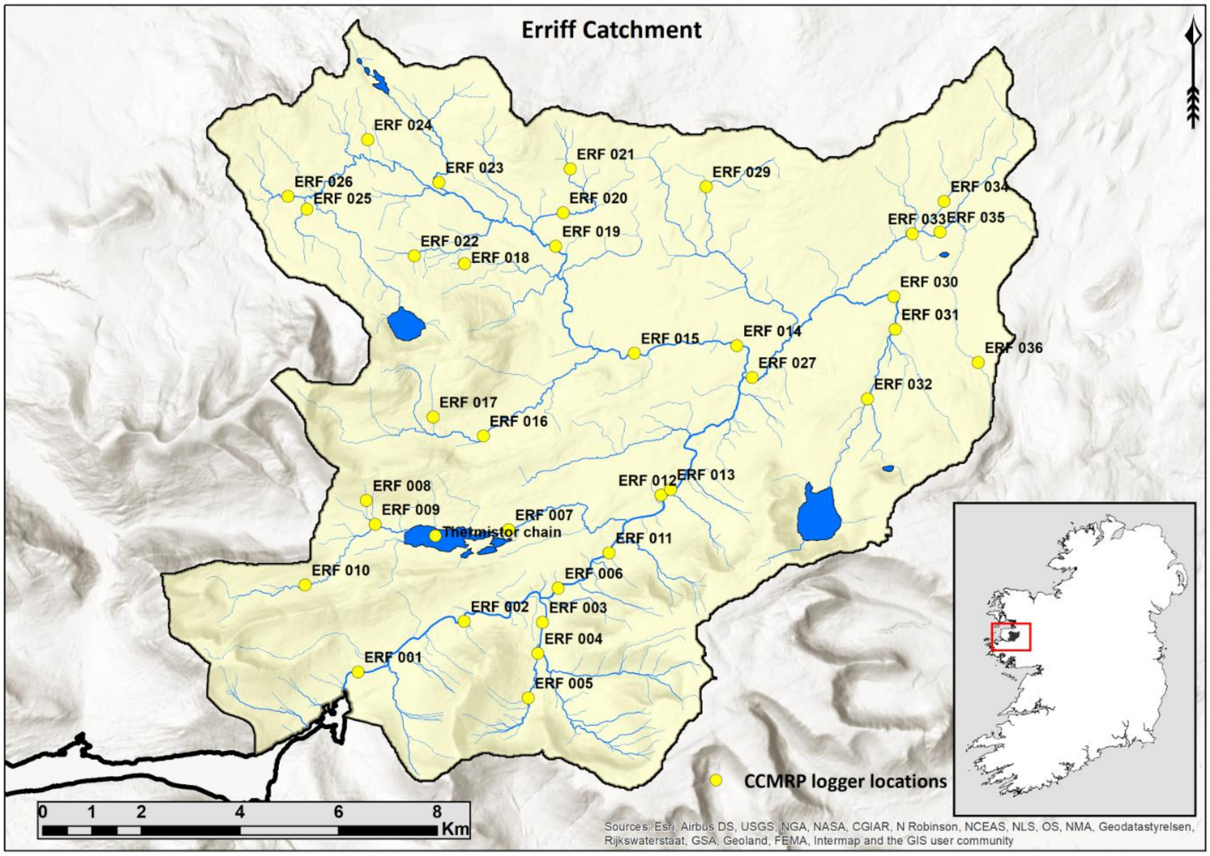

Fig. 3.2 Erriff catchment indicating locations of CCMRP Tw monitoring sites

3.2.2.3 Erriff Stream Network Model

Results from the stream network model developed for the Erriff catchment revealed that during a seven-day period in 2019, highest water temperatures were reached throughout downstream sections of the river basin, including the main channel (Fig. 3.3). In contrast, high elevation headwater streams typically remained cooler than 19.5 °C and may provide important thermal refuges for salmonids in the system during warm weather. Additionally, river sections immediately downstream of lakes within the catchment (i.e., rivers with a large proportion of upstream catchment area comprising lakes) had warmer temperatures compared to rivers with similar sized catchment areas, but not draining lakes (Fig. 3.3).

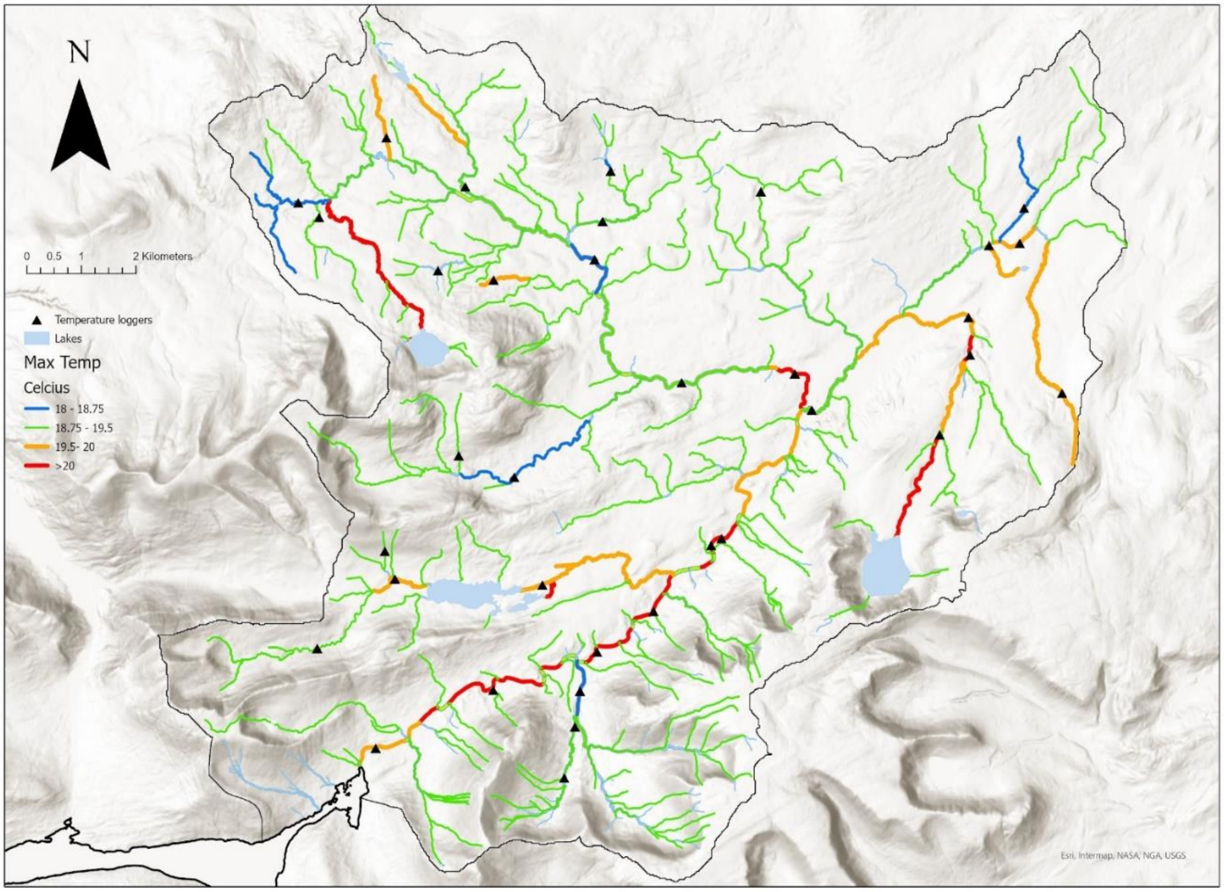

Fig. 3.3 Stream network model of maximum seven-day rolling mean daily water temperature recorded in the Erriff catchment, July 2019.

3.2.3 Doonbeg catchment

The highest Tw recorded in the catchment during the sampling period was 25.2^{o}C at site DBG0158 (Table 3.5). The range in maximum Tw was 7.8^{o}C (Table 3.5). Five sites (45.5%) within the Doonbeg network recorded mean daily Tw exceeding 20°C (cumulative across 5 sites n=57 days) (Table 3.5 and Fig. 3.3). The number of days the mean daily temperature exceeded 20^{o}C in the catchment ranged from 9 to 18 (Table 3.5). In general, sites in the lower catchment had higher water temperatures as indicated by the number of days Tw exceeded 20^{o}C (Fig. 3.3 and Table 3.5).

Table 3.5 Summary of selected thermal metrics for the Doonbeg catchment Tw monitoring sites, July 2020 - August 2021

Site	Mean Tw	Mean winter Tw 2020	Mean summer Tw 2020**	Max weekly avg Tw	Max daily Tw	Min daily Tw	No. of days Mean daily Tw >20°C	No. of days Mean daily Tw <2°C	Max record Tw
DBG0043	11.3	5.8	*15.6*	21.7	23.2	1.3	10	5	24.4
DBG0114	11.6	6.3	*15.8*	21.7	23.1	2.5	10	0	24.6
DBG0116	11.9	5.5	*18.0*	21.9	23.0	1.5	18	6	24.2
DBG0128	11.0	7.4	*14.3*	16.7	17.5	4.9	0	0	18.2
DBG0133	11.0	5.7	*15.2*	21.5	23.1	1.3	9	4	24.6
DBG0140	10.8	6.8	*15.0*	17.3	18.4	3.5	0	0	20.6
DBG0158	11.8	6.2	*16.1*	22.4	23.7	2.3	10	0	25.2
DBG0196	10.6	5.8	*14.9*	19.0	19.9	2.0	0	1	22.5
DBG0227	10.0	5.4	*14.3*	18.1	19.5	1.3	0	4	22.3
DBG0272	9.6	5.4	*13.9*	15.4	16.2	1.7	0	1	17.4
DBG0284	9.6	5.2	*15.3*	16.9	18.0	2.1	0	0	18.4

Note: *Winter 2020: 90 days (1st Dec 2020 to 28th Feb 2021); **Summer 2020:* ***46 days****, Jul 17th 2020 to 31st Aug 2020. Mean Tw is average annual temperature.*

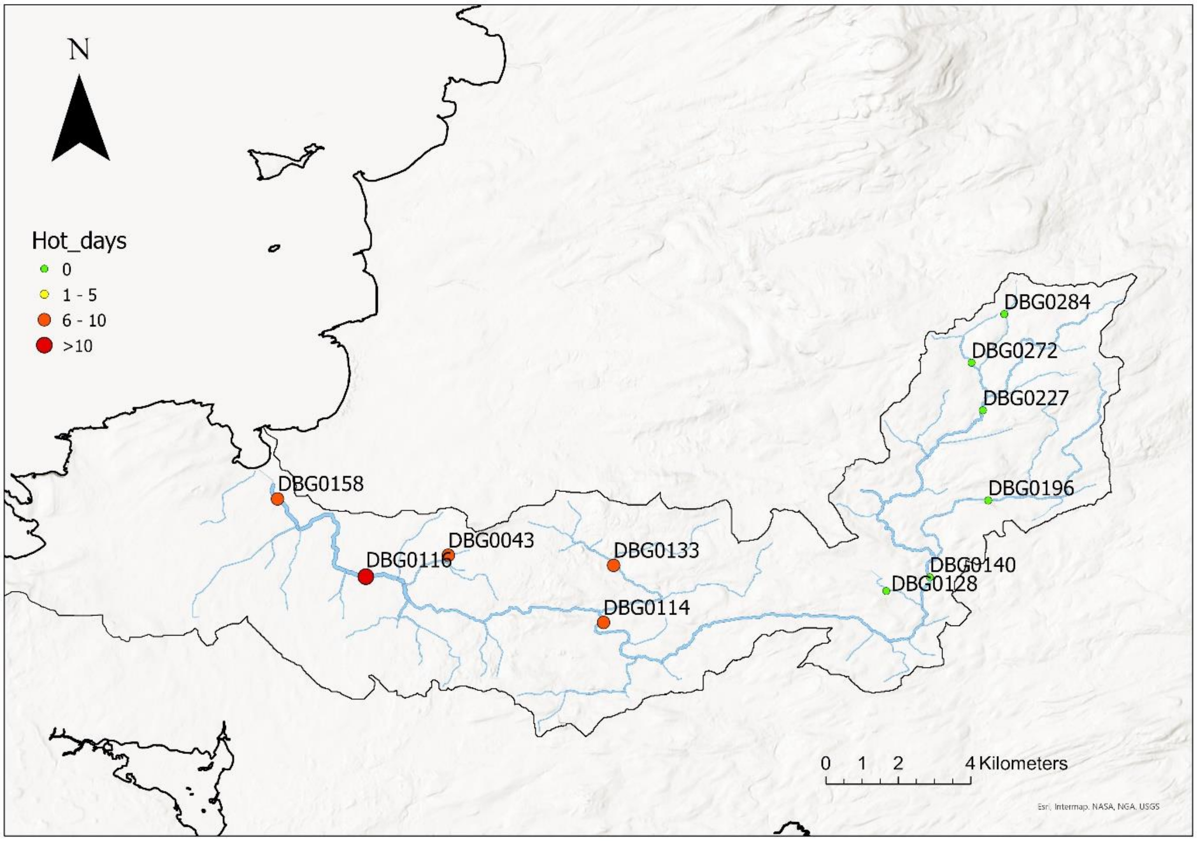

Fig. 3.4 Number of days the average daily Tw of 20^{o}C was exceeded in the Doonbeg catchment, 0 days (green circle), 1-5 days (yellow circles), 6-10 days (orange circles) and >10 days (red circles).

3.2.4 Currane Catchment

The maximum Tw recorded within the Currane network was 27.4ºC at site CUR0299 (Table 3.6 and Fig. 3.5 and plate 3.4). The range in maximum water temperatures across the catchment was 9.9ºCºC (Table 3.6). Eight sites (57.14%) associated with lake outflows recorded mean daily Tw exceeding 20°C (cumulative across 8 sites n=90 days) (Table 3.6). The number of days the mean daily temperature exceeded 20ºC in the catchment ranged from 7 to 20 (Table 3.6).

Table 3.6 Summary of selected thermal metrics for the Currane catchment Tw monitoring sites, June 2020-2021

Site	Mean Tw	Mean winter Tw 2020	Mean summer Tw 2021	Max weekly avg Tw	Max daily Tw	Min daily Tw	No. of days Mean daily Tw >20°C	No. of days Mean daily Tw <2°C	Max record Tw
CUR0027	10.9	7.2	14.2	17.6	18.8	3.2	0	0	19.9
CUR0028	11.0	7.7	13.8	16.2	17.5	4.9	0	0	19.7
CUR0089	11.2	6.6	14.7	18.2	19.8	2.5	0	0	21.7
CUR0109	12.5	6.7	18.3	22.9	24.4	2.2	16	0	25.6
CUR0110	12.7	7.0	17.6	22.4	23.3	4.7	12	0	24.9
CUR0184	11.3	8.8	13.0	14.6	15.6	6.7	0	0	17.5
CUR0187	11.1	7.5	13.7	16.4	16.6	4.4	0	0	18.4
CUR0232	10.6	6.8	16.7	21.0	21.8	3.7	7	0	23.5
CUR0299	12.8	6.3	18.3	22.6	24.2	2.4	20	0	27.4
CUR0316	10.4	5.6	15.5	20.8	22.6	1.5	9	0	25.1
CUR0317	12.1	6.8	16.6	21.3	22.9	4.5	10	0	25.1
CUR0320	10.5	6.8	16.6	21.1	22.4	4.6	9	0	26.3
CUR0326	11.7	5.9	16.1	20.0	20.7	-1.0	7	0	23.3
CUR0347	11.1	7.3	13.7	15.9	16.5	4.4	0	0	19.4

***Note**: Winter 2020: 90 Days (1st Dec 2020 to 28th Feb 2021); Summer 2021: 92 days (1st Jun 2021 to 31st Aug 2021)*

Plate 3.4. Monitoring location on the Currane catchment (site CUR0326)

Fig. 3.5 Number of days the average daily temperature exceeded 20ºC in the Currane catchment 0 days (green circle), 1-5 days (yellow circles), 6-10 days (orange circles) and >10 days (red circles).

3.2.5 Ilen Catchment

The maximum Tw recorded between August 2020 and 2021within the Ilen Tw monitoring network was 23.4°C at site ILN0344 (Table 3.7, Figure 3.6 and Plate 3.5). The range in maximum water temperatures across the catchment was 7.3°C (Table 3.7). Site ILN0027 was the only site to record mean daily Tw exceeding 20°C (n=6 days) (Table 3.7). The highest mean summer Tw and max daily Tw was also recorded at this site (Table 3.7).

Table 3.7. Summary of selected thermal metrics for the Ilen catchment Tw monitoring sites, August 2020-2021

Site code	Mean Tw	Mean winter Tw 2020	Mean summer Tw 2021	Max weekly avg Tw	Max daily Tw	Min daily Tw	No. of days Mean daily Tw >20°C	No. of days Mean daily Tw <2°C	Max record Tw
ILN0027	11.4	7.3	15.9	19.6	20.8	3	6	0	21.3
ILN0029	11	6.8	15.5	18.6	19.8	1.8	0	1	20.2
ILN0058	11.1	6.9	15.4	18.6	19.9	2.2	0	0	21.6
ILN0074	10.7	7.3	13.9	15.9	17	3.3	0	0	17.5
ILN0196	11	7.2	15.1	18.6	19.8	3.3	0	0	21.2
ILN0216	11	7.3	15.1	18.7	19.8	3.4	0	0	21.4
ILN0231	9.8	6.2	13.5	16.1	16.6	1.7	0	1	17.6
ILN0344	10.6	6.8	14.9	18.5	19.6	3.1	0	0	23.4
ILN0361	11.1	7.8	14.6	17.7	18.8	4.6	0	0	20.7
ILN0372	9.5	6.2	12.7	14.7	15.7	2.2	0	0	16.6
ILN0382	10.8	6.7	15.3	18.8	19.5	1.5	0	1	21.6
ILN0413	11	7	15.2	18.3	19.5	2.5	0	0	20.3
ILN0421	10.6	8.3	12.4	14.5	15.5	6.1	0	0	16.1
ILN0449	10.6	7.1	14.1	16.5	17.6	3.5	0	0	19.2
ILN0518	10.6	7	14.5	17.7	18.9	3.2	0	0	20.1
ILN0525	10.8	7.1	14.3	16.3	17	3.8	0	0	18.0
ILN0589	9.5	6.2	13.0	15.3	16.6	1.9	0	1	17.2
ILN0651	10.3	6.6	14.0	17.3	18.4	2.8	0	0	21.5
ILN0683	10.2	7.2	13.3	16.1	17.1	4.4	0	0	19.6
ILN0692	10.3	5.9	14.8	18.3	18.9	1.4	0	1	20.7

***Note**: Winter 2020: 90 day (1st Dec 2020 to 28th Feb 2021); Summer 2021: **85 days** (1st Jun to 24th Aug).*

Plate 3.5. Monitoring locations on the Ilen River (sites ILN0344 (left) and ILN0027 (right)).

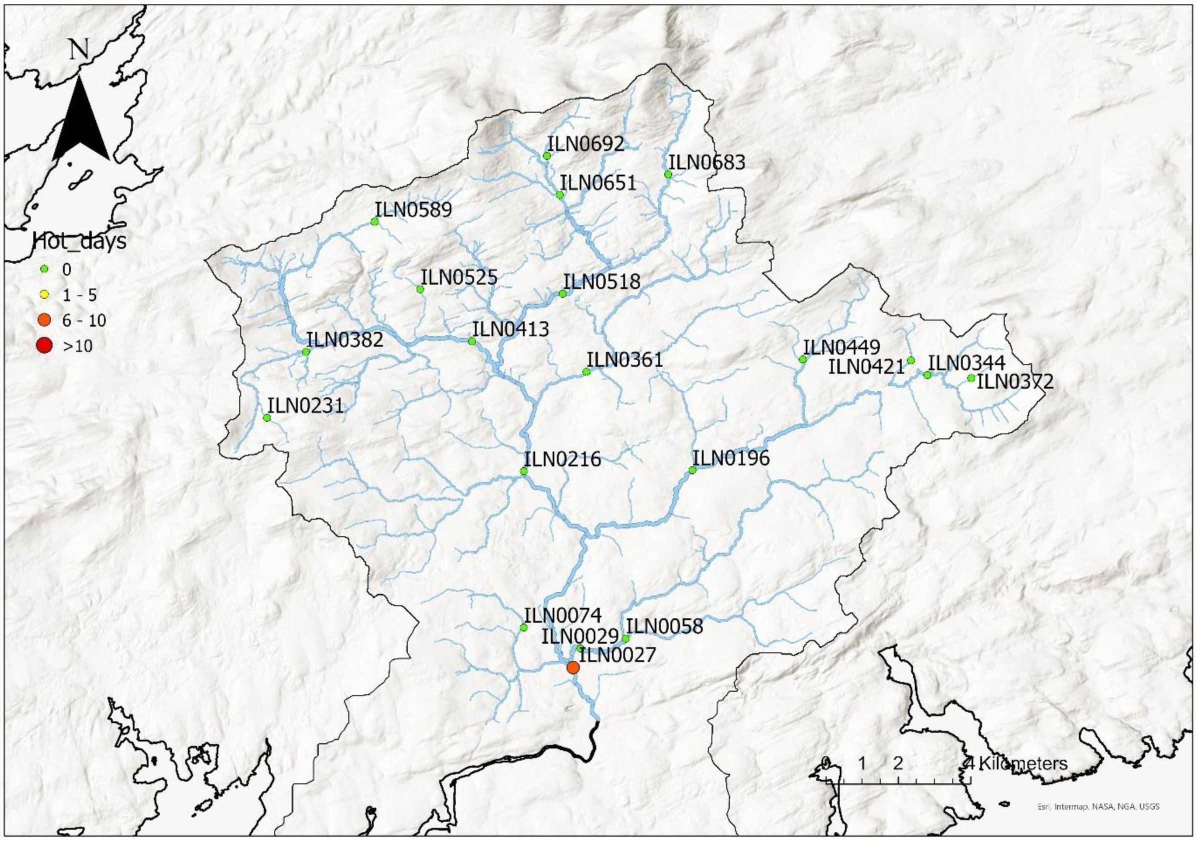

Fig. 3.6 Number of days the average daily temperature exceeded 20°C in the Ilen catchment 0 days (green circle), 1-5 days (yellow circles), 6-10 days (orange circles) and >10 days (red circles)

3.2.6 Nore catchment

The maximum Tw recorded within the Nore monitoring network was 21.5°C at site NOR0289 (Kings River) between June 2020 and July 2021 (Table 3.8 and Fig. 3.7). The range in maximum water temperatures across the catchment was 8.1°C (Table 3.8). None of the 41 sites recorded mean daily Tw exceeding 20°C during the monitoring period (Table 3.8). The highest mean summer 2020 Tw was 16.7°C at NOR0214 (River Nore, main channel) and the highest mean winter 2020 Tw was 9.6°C, recorded at site NOR1704 on the Nuenna River (Table 3.8 and Fig. 3.7).

Table 3.8. Summary of selected thermal metrics for the Nore catchment Tw monitoring sites, June 2020 to July 2021

Site code	Mean Tw	Mean winter Tw 2020*	Mean summer Tw 2020*	Max weekly avg Tw	Max daily Tw	Min daily Tw	No. of days Mean daily Tw >20°C	No. of days Mean daily Tw <2°C	Max record Tw
NOR0059	10.0	7.9	14.5	15.9	16.4	4.8	0	0	18.8
NOR0077	9.8	6.8	14.8	16.1	16.9	3.0	0	0	17.3
NOR0214	**11.2**	6.5	**16.7**	18.4	18.9	3.4	0	0	19.6
NOR0289	10.9	7.1	16.2	18.1	19.0	3.7	0	0	**21.6**
NOR0358	10.6	6.6	15.2	17.3	18.2	2.7	0	0	18.8
NOR0427	11.1	7.8	15.6	17.1	17.7	5.1	0	0	18.3
NOR0463	11.1	6.4	16.4	18.1	18.6	3.4	0	0	19.6
NOR0599	10.7	7.6	14.6	16.0	16.5	4.8	0	0	18.5
NOR0815	10.1	6.9	14.0	15.6	16.4	4.1	0	0	18.2
NOR0866	10.3	5.9	15.3	17.5	18.3	1.6	0	1	19.6
NOR0976	9.9	7.7	12.5	13.4	14.1	6.3	0	0	14.9
NOR1118	9.5	6.0	13.7	15.9	16.5	2.6	0	0	17.3
NOR1163	10.2	6.5	15.1	17.3	18.2	3.1	0	0	19.6
NOR1215	9.2	5.9	13.2	15.2	15.8	2.3	0	0	16.4
NOR1418	9.7	6.4	14.2	16.4	17.2	2.7	0	0	18.6
NOR1513	10.2	6.8	14.3	16.1	16.7	3.4	0	0	18.1
NOR1659	10.9	6.1	16.0	17.8	18.5	3.0	0	0	19.0
NOR1699	11.0	5.9	16.3	18.9	19.8	1.6	0	1	20.4
NOR1704	10.4	9.6	11.3	11.6	12.0	8.9	0	0	13.5
NOR2005	11.0	6.1	15.9	17.9	18.6	2.9	0	0	19.3
NOR2019	10.1	5.4	15.2	17.5	18.4	1.1	0	2	20.6
NOR2293	10.9	7.3	15.0	16.3	17.1	4.7	0	0	18.7
NOR2367	9.2	4.9	13.5	15.8	16.5	0.0	0	9	18.2
NOR2523	9.1	6.0	12.8	14.0	14.4	3.2	0	0	16.3
NOR2578	11.2	8.1	15.3	17.1	17.9	4.3	0	0	18.7
NOR2616	10.3	6.2	14.6	16.4	17.2	2.0	0	0	18.3
NOR2656	10.0	5.5	14.7	17.1	18.1	1.1	0	1	19.9
NOR2683	11.0	6.4	15.6	17.1	18.0	3.4	0	0	18.7
NOR2691	10.7	6.3	15.6	17.3	18.3	2.6	0	0	20.1
NOR2873	10.0	6.5	14.0	15.5	16.0	3.5	0	0	18.1
NOR2935	10.3	6.3	15.0	17.0	17.9	2.1	0	0	20.1
NOR3169	9.1	4.9	13.6	16.0	16.7	0.5	0	8	17.6
NOR3249	10.6	6.3	14.6	15.7	16.5	3.0	0	0	17.9
NOR3637	9.2	6.1	12.3	13.7	14.3	3.0	0	0	15.2
NOR3686	10.1	6.3	14.1	15.6	16.2	2.5	0	0	18.1
NOR3766	10.3	6.0	14.7	16.8	17.6	2.6	0	0	18.6
NOR3853	9.0	5.2	13.2	15.4	16.0	1.2	0	3	16.9
NOR3859	10.2	6.1	14.6	16.5	17.2	2.7	0	0	18.9
NOR4009	8.9	6.0	12.1	13.1	13.7	3.9	0	0	14.3
NOR4178	9.1	6.5	12.0	13.3	13.8	4.4	0	0	14.5
NOR4244	8.9	5.1	13.1	15.0	15.7	1.3	0	1	16.4

Note: * Summer 2020: **76 days** (18th Jun 2020 to 31st Aug 2020); Winter 2020: 90 days (1st Dec 2020 to 28th Feb 2021).

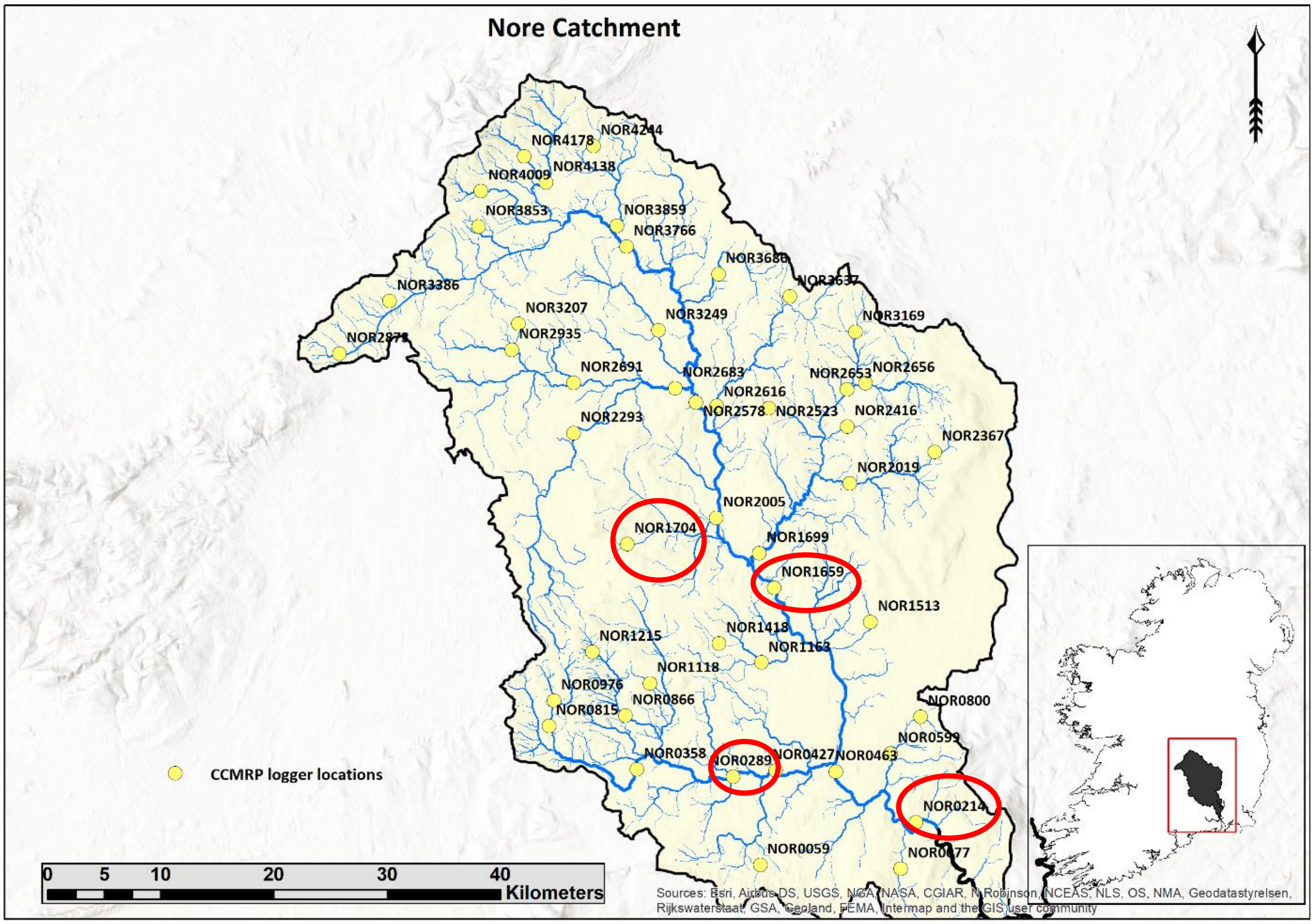

Fig. 3.7. Location of Tw monitoring sites in the Nore catchment

<u>3.2.7 Vartry catchment</u>

The maximum T_w recorded within the Vartry network was 23°C at site VRT012 in Summer 2020 (Table 3.9 and Fig. 3.8). The range in maximum water temperatures across the catchment was 7.0°C (Table 3.9). None of the 13 sites recorded mean daily Tw exceeding 20°C (Table 3.9). Mean winter temperatures varied across the sampling years with the highest mean winter temperatures being recorded in 2021 (6.5±0.71 °C) in comparison to 2020 (5.8±0.71 °C) and 2019 (6.2±0.61 °C). Mean summer temperatures also varied across the sampling years with the highest mean summer temperatures being recorded in 2021 (14.4±1.7 °C) in comparison to 2020 (14±1.2 °C) and 2019 (13.9±1.29 °C). The highest maximum weekly average Tw and minimum daily Tw were recorded at VRT007 and VRT009 temperatures on the main channel downstream of Vartry reservoir (Fig. 3.8).

Table 3.9. Summary of selected thermal metrics for the Vartry catchment Tw monitoring sites, May 2019 to March 2021

Site	Mean Tw	Mean winter Tw 2019	Mean winter Tw 2020	Mean winter Tw 2021	Mean summer Tw 2019	Mean summer Tw 2020	Mean summer Tw 2021	Max weekly avg Tw	Max daily Tw	Min daily Tw	No. of days Mean daily Tw >20°C	No. of days Mean daily Tw <2°C	Max record Tw
VRT001	10.5	6.3	5.8	6.9	14.8	14.7	15.2	17.5	17.9	3.3	0	0	19.7
VRT002	10.3	6.3	5.7	6.7	14.7	14.6	15.1	17.4	17.7	3.0	0	0	19.1
VRT003	9.9	7.0	6.7	7.2	12.9	13.0	13.1	14.9	15.5	4.2	0	0	16.7
VRT004	10.0	7.3	6.9	NO DATA	13.2	13.2	NO DATA	15.4	16.1	4.1	0	0	17.2
VRT005	10.2	5.8	5.2	6.3	14.6	14.5	15.3	17.7	18.1	2.3	0	0	19.2
VRT006	10.2	5.7	5.2	6.2	14.7	14.7	15.5	18.0	18.3	2.3	0	0	20.2
VRT007	10.6	5.4	4.8	5.9	15.7	15.8	16.4	19.3	19.6	2.3	0	0	23.7
VRT008	9.4	6.2	5.9	6.5	13.2	13.3	13.2	15.7	16.4	2.8	0	0	19.1
VRT009	10.8	5.3	4.6	5.7	16.2	16.2	16.9	19.2	19.4	2.4	0	0	20.8
VRT010	9.5	6.9	6.6	7.3	12.4	12.6	12.6	14.1	14.5	4.6	0	0	16.8
VRT011	9.6	6.8	6.3	6.9	12.3	13.2	13.0	15.9	16.6	4.1	0	0	19.4
VRT012	9.7	6.1	5.8	6.4	13.7	13.9	14.2	17.8	18.0	3.2	0	0	23.1
VRT013	9.3	6.4	6.1	6.8	12.4	12.5	12.3	14.0	15.1	3.2	0	0	17.5

Note: Summer 2019: 92 days (1st Jun 2019 to 31st Aug 2019); Winter 2019: 91 Days (1st Dec 2019 to 29th Feb 2020); Summer 2020: 92 days (1st Jun 2020 to 31st Aug 2020); Winter 2020: 90 Days (1st Dec 2020 to 28th Feb 2021); Summer 2021: 92 days (1st Jun 2021 to 31st Aug 2021); Winter 2021: 90 Days (1st Dec 2021 to 28th Feb 2022)

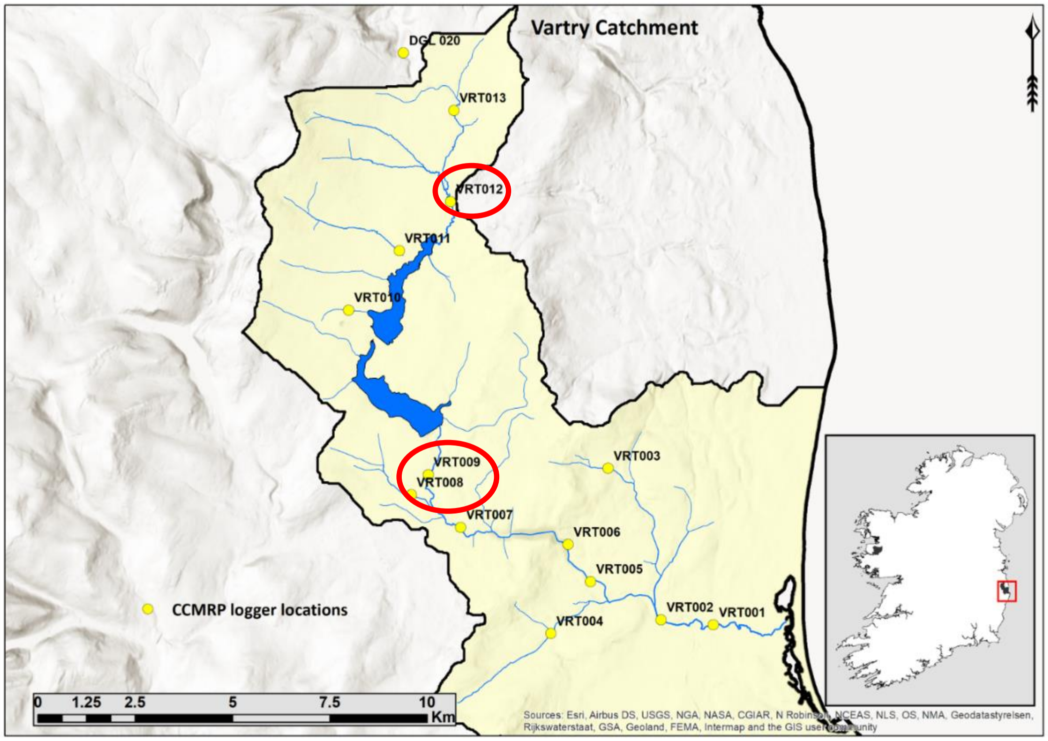

Fig. 3.8. Location of Tw monitoring sites in the Vartry catchment.

3.2.8 Dargle Catchment

The maximum Tw recorded within the Dargle network between May 2019 and April 2021 was 21.6°C at site DGL013 (Table 3.10 and Fig. 3.9). The highest maximum weekly average Tw and minimum daily Tw was recorded at DGL015 (Fig. 3.8). The range in maximum temperatures was 5.4°C (Table 3.10). None of the 15 sites recorded mean daily Tw exceeding 20°C. Mean winter temperatures varied across the sampling years with the highest average winter temperatures being recorded in 2021 (6.2±0.48 °C) in comparison to 2020 (5.5±0.7 °C) and 2019 (4.9±1.3 °C). Mean summer temperatures also varied across the sampling years with the highest mean summer temperatures being recorded in 2021 (13.7±0.8 °C) in comparison to 2020 (13.1±10.7 °C) and 2019 (13.4±0.7 °C) (Table 3.10).

Table 3.10. Summary of selected thermal metrics for the Dargle catchment Tw monitoring sites, May 2019 to April 2021

Site	Mean Tw	Mean winter Tw 2019	Mean winter Tw 2020	Mean winter Tw 2021	Mean summer Tw 2019	Mean summer Tw 2020	Mean summer Tw 2021	Max weekly avg Tw	Max daily Tw	Min daily Tw	No. of days Mean daily Tw >20°C	No. of days Mean daily Tw <2°C	Max record Tw
DGL001	9.9	3.4	5.8	6.5	14.0	13.8	14.3	16.7	17.2	2.6	0	0	18.1
DGL002	9.9	2.4	7.1	7.4	12.6	12.6	12.6	14.1	15.3	4.8	0	0	16.6
DGL003	9.6	3.2	5.8	6.4	13.4	13.2	13.6	15.9	16.4	3.1	0	0	17.4
DGL004	9.5	3.6	5.3	6.1	13.8	13.5	14.2	17.9	18.1	2.5	0	0	20.7
DGL005	9.1	3.3	5.3	6.1	13.0	12.7	13.2	16.7	16.9	2.7	0	0	20.8
DGL006	8.5	3.4	4.6	5.6	12.4	12.1	12.8	15.8	16.2	1.5	0	5	17.1
DGL007	9.7	NO DATA	6.0	6.7	NO DATA	13.4	13.4	15.5	15.9	2.4	0	0	17.0
DGL008	9.7	6.2	5.6	6.3	14.3	13.7	14.3	17.1	17.6	2.4	0	0	18.6
DGL009	9.6	6.1	5.6	6.3	14.1	13.6	14.1	16.8	17.2	2.4	0	0	18.2
DGL010	9.6	5.9	NO DATA	6.1	14.0	NO DATA	14.3	17.2	17.5	3.5	0	0	18.9
DGL011	9.7	5.8	NO DATA	6.0	14.1	NO DATA	14.5	17.7	18.1	3.3	0	0	19.7
DGL012	9.4	5.7	5.1	6.0	14.0	13.5	14.3	17.8	18.2	1.7	0	1	21.2
DGL013	9.3	5.5	5.0	6.0	13.7	13.4	14.2	17.7	18.1	1.8	0	1	21.6
DGL014	8.9	5.5	5.1	6.0	12.6	12.3	12.7	15.1	15.6	2.3	0	0	17.1
DGL015	9.4	5.0	4.6	5.5	14.2	13.8	14.8	19.1	19.8	2.5	0	0	21.4
DGL016	8.8	NO DATA	4.3	5.3	NO DATA	13.0	13.8	17.3	17.5	0.9	0	8	18.9
DGL018	9.5	6.2	NO DATA	6.4	12.6	NO DATA	14.0	16.8	17.1	3.7	0	0	19.0
DGL019	9.5	6.1	5.7	6.3	13.5	13.4	13.8	16.8	17.0	3.0	0	0	19.5
DGL020	9.0	6.8	6.5	6.9	11.6	11.3	11.6	12.7	13.5	3.8	0	0	16.2
DGL021	10.1	NO DATA	6.0	6.7	NO DATA	13.9	14.4	16.9	17.2	3.1	0	0	19.6

Note: Summer 2019: 92 days (1st Jun 2019 to 31st Aug 2019); Winter 2019: 91 Days (1st Dec 2019 to 29th Feb 2020); Summer 2020: 92 days (1st Jun 2020 to 31st Aug 2020); Winter 2020: 90 Days (1st Dec 2020 to 28th Feb 2021); Summer 2021: 92 days (1st Jun 2021 to 31st Aug 2021); Winter 2021: 90 Days (1st Dec 2021 to 28th Feb 2022).

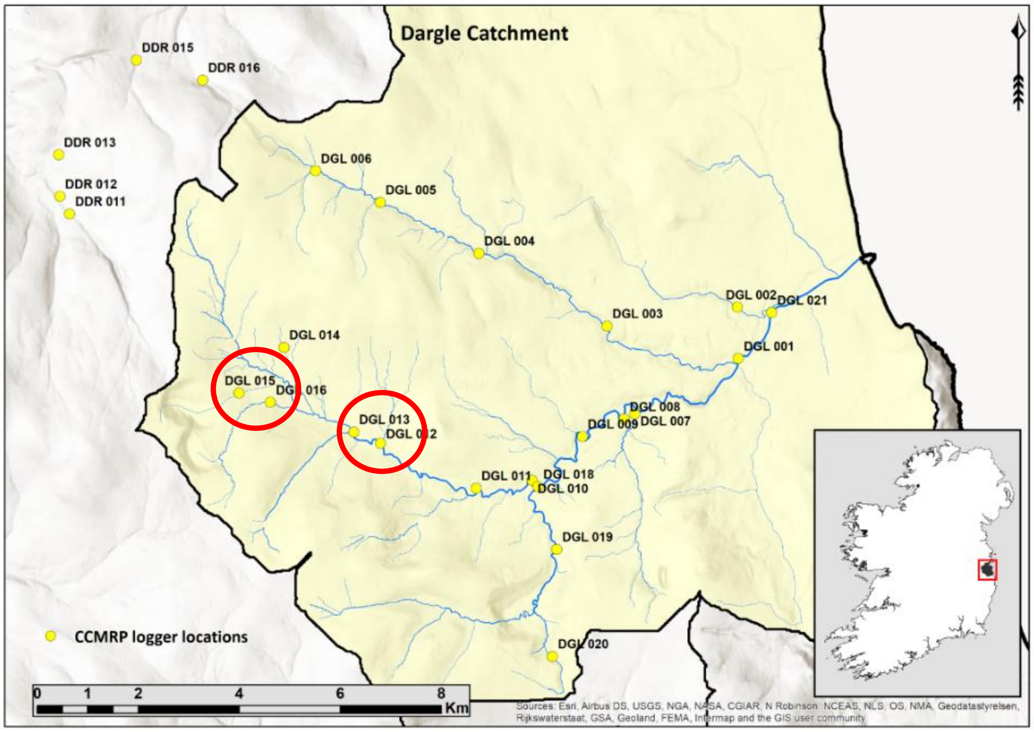

Fig. 3.9 Location of Tw monitoring sites in the Dargle catchment

3.2.9 Dodder Catchment

The maximum T_w recorded within the Dodder network was 20.8°C at site DDR002 on the River Dodder main channel (Fig. 3.10). The range in maximum temperatures was 6.7°C (14.1-20.8°C). None of the 16 sites recorded mean daily Tw exceeding 20°C (Table 3.11). The highest maximum daily Tw was recorded at site DDR003 (Table 3.11). Mean winter temperatures varied across the sampling years with the highest mean winter temperatures being recorded in 2021 (6.4±0.49 °C) in comparison to 2020 (5.6±0.63 °C) and 2019 (6.1±0.5 °C). Mean summer temperatures also varied across the sampling years with the highest average summer temperatures being recorded in 2019 (14.01±1.4 °C) in comparison to 2020 (13.3±1.1 °C) and 2021 (13.9±1.3 °C). In general sites in the lower catchment and downstream of Bohernabreena reservoir had higher Tw as indicated by max daily Tw and max weekly average Tw (Table 3.11).

Table 3.11. Summary of selected thermal metrics for the Dodder catchment Tw monitoring sites, June 2019 to March 2021

Site	Mean Tw	Mean winter Tw 2019	Mean winter Tw 2020	Mean winter Tw 2021	Mean summer Tw 2019	Mean summer Tw 2020	Mean summer Tw 2021	Max weekly avg Tw	Max daily Tw	Min daily Tw	No. of days Mean daily Tw >20°C	No. of days Mean daily Tw <2°C	Max record Tw
DDR002	14.1	NO DATA	NO DATA	NO DATA	15.3	NO DATA	NO DATA	17.6	18.8	9.2	0	0	20.8
DDR003	10.7	6.7	6.2	7.0	15.4	14.6	15.4	18.4	18.9	3.2	0	0	20.2
DDR004	10.5	6.6	6.1	6.9	15.2	14.5	15.2	18.1	18.5	3.4	0	0	19.7
DDR005	10.5	6.5	6.0	6.7	15.3	14.5	15.2	18.1	18.6	3.0	0	0	20.6
DDR006	10.3	6.4	6.5	7.2	14.7	14.0	14.4	16.7	17.6	4.1	0	0	19.5
DDR007	10.0	6.3	5.6	6.5	14.5	13.8	14.5	16.8	17.4	2.9	0	0	19.3
DDR008	10.0	5.9	5.4	6.2	15.0	14.0	14.9	17.6	18.1	2.6	0	0	20.5
DDR009	10.1	5.9	5.3	6.2	15.0	14.1	15.0	17.6	18.1	2.5	0	0	20.5
DDR010	10.1	5.6	5.0	6.0	15.4	14.3	15.5	18.6	19.0	2.0	0	0	20.5
DDR011	8.9	5.1	4.6	5.6	13.5	12.8	13.8	17.3	17.6	0.8	0	7	19.4
DDR012	9.3	5.9	5.3	6.3	13.0	12.9	13.2	15.1	15.6	1.8	0	1	16.8
DDR013	8.8	5.9	5.3	6.1	12.1	12.0	12.3	13.8	14.3	2.7	0	0	15.3
DDR014	9.7	6.7	6.2	6.8	13.4	12.9	13.4	15.7	16.3	3.2	0	0	18.5
DDR015	8.4	5.8	5.3	6.0	11.5	11.3	11.5	13.3	13.8	2.8	0	0	14.1
DDR016	8.3	5.8	5.3	6.0	11.4	11.2	11.3	12.7	13.4	3.2	0	0	14.5
DDR017	10.0	7.3	7.0	7.2	13.5	13.0	13.5	15.7	16.5	4.4	0	0	18.2

Note. Summer 2019: **85 days** (8th Jun 2019 to 31st Aug 2019); Winter 2019: 91 Days (1st Dec 2019 to 29th Feb 2020); Winter 2020: 90 Days (1st Dec 2020 to 28th Feb 2021); Summer 2020: 92 days (1st Jun 2020 to 31st Aug 2020); Winter 2021: 90 Days (1st Dec 2021 to 28th Feb 2022); Summer 2021: 92 days (1st Jun 2021 to 31st Aug 2021).

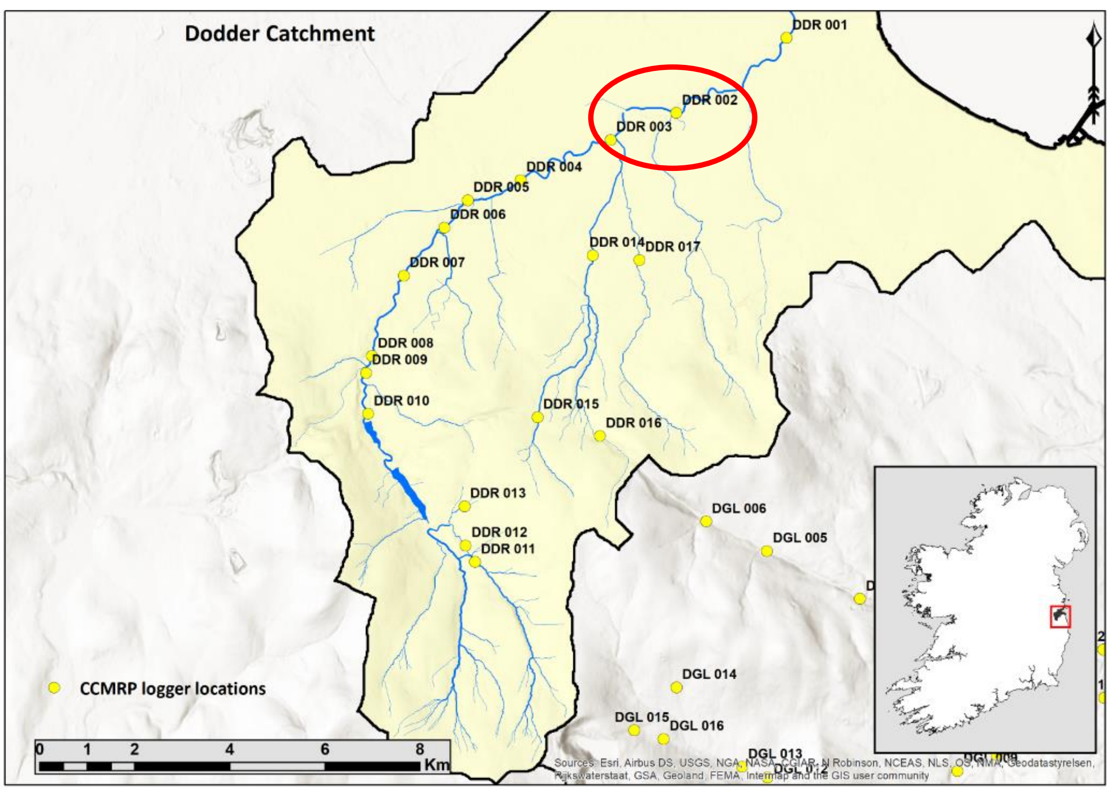

Fig. 3.10 Location of Tw monitoring sites on the Dodder catchment.


Plate 3.6 River Dodder Tw monitoring sites (DDR002 (left) and DDR003 (right))

3.2.10 Tw inter-catchment variation

At this stage of the project, it is not possible to conduct a full comparison of thermal metrics across all catchments as T_w data loggers were deployed and turned over on a phased basis. However, it is possible to compare metrics from certain seasons for selected catchments (Table 3.12). The highest mean winter 2019 Tw was recorded in the Vartry catchment, while the lowest was in the Dargle (Table 3.12). In 2020 the highest mean winter T_w in 2020 was observed in the Currane and Ilen catchments, while the lowest was in the Gweebarra. Mean winter T_w was higher in 2021 then 2019 and 2020 in the three eastern catchments. In general winter T_w followed a south to north gradient within the network. The highest average winter T_w being recorded on the most southerly index catchments (Ilen and Currane) and the lowest on the most northerly catchment (Gweebarra) (Table 3.12).

In 2019 the highest mean summer T_w was observed in the Dodder catchment, followed by the Vartry and Dargle catchments respectively (Table 3.12). The highest mean summer 2020 T_w was recorded in the Doonbeg catchment and the lowest was observed in the Dargle catchment (Table 3.12). In summer 2021, the mean summer T_w was highest in the Currane catchment and lowest in the Dargle catchment (Table 3.12).

Table 3.12. Mean seasonal (winter and summer) T_w (°C) (and standard deviation) in each index catchment

Catchment	Winter 2019	Winter 2020	Winter 2021	Summer 2019	Summer 2020	Summer 2021	Region
Gweebarra	5.4 (0.5)	4.6 (0.4)	-	-	14.2 (1.1)	-	Northwest
Erriff NSIC	6.1 (0.3)	5.6 (0.4)	-	-	14.5 (0.8)	-	West
Doonbeg	-	6.0 (0.7)	-	-	15.3 (1.1)	-	West
Currane	-	6.9 (0.8)	-	-	-	15.6 (1.8)	Southwest
Ilen	-	6.9 (0.6)	-	-	-	14.4 (1.0)	Southwest
Nore	-	6.4 (0.9)	-	-	14.4 (1.3)*	-	Southeast
Vartry	6.3 (0.6)	5.8 (0.7)	6.6 (0.5)	13.9 (1.3)	14.0 (1.2)	14.4 (1.5)	East
Dargle	4.9 (1.4)	5.5 (0.7)	6.2 (0.5)	13.4 (0.8)	13.1 (0.7)	13.7 (0.8)	East
Dodder	6.2 (0.6)	5.7 (0.6)	6.4 (0.5)	14.0 (1.4)	13.3 (1.1)	13.9 (1.4)	East

*Note: * Summer 2020 on Nore catchment =76 days only.*

Annual mean Tw ranged from 9.4 to 11.4°C. The highest mean annual water temperature was observed in the Currane catchment, while the lowest was recorded in the Dargle catchment (Table 3.13). The highest maximum T_w (28.4°C) observed was in the Gweebarra catchment during July 2021; however sites in all catchments exceeded the temperature threshold of 20°C for brown trout (i.e. thermal stress occurs in brown trout at or above this temperature) on at least one occasion. Interestingly the range in maximum T_w varied from 12.4°C in the Gweebarra to 5.4°C in the Dargle (Table 3.13).

In total there were 234 days, at 31 sites, where the mean daily water temperature exceeded 20°C across the Tw monitoring network. This phenomenon was not evenly spread across the catchments; Currane had the greatest number (90 days across eight sites), followed by Gweebarra (70 days across 12 sites), Doonbeg 57 days (across five sites), Erriff (15 days across five sites) and Ilen (6 days at one site) (Table 3.13). The four remaining catchments recorded 0 days where average daily water temperature exceeded 20°C (Table 3.13).

Table 3.13: Selected thermal metrics for each catchment (Note: dates of deployment differ, and number of logging days are higher for some catchments due to a phased deployment and turnover; therefore, data from heatwave events (e.g., July 2021) are not included for certain catchments).

Catchment	Mean Tw (+SD) (°C)	Range in max weekly avg Tw (°C)	Range in max daily Tw (°C)	No. days mean daily Tw>20°C (total number)	No. days mean daily Tw<2°C (total number)	Range in Max record Tw (no. sites >20°C) (°C)	Region
Gweebarra (06/07/2019-23/07/2019-data from 748 days logging)	9.8 (0.8)	13-22.5 (9.5)	13.6-24.8	12 (66) (44% sites)	39 (230)	16.0-28.4 (range=12.4) (74% sites)	Northwest
Erriff NSIC (22/06/2019-16/07/2021-data from 755 days logging)	10.0 (0.6)	14.0-19.3	15.8-20.8	6 (15) (14% sites)	11 (151)	17.2-26.0 (range=8.8) (83% sites)	West
Doonbeg (1/07/2020 to 17/08/2021) 396 days logging	10.8 (0.8)	15.4-22.4	16.2-23.7	18 (57) (45% sites)	6 (21)	17.4-25.2 (range=7.8) (73% sites)	West
Currane (01/06/20 to 01/06/21) 365 days logging	11.4 (0.8)	14.6-22.9	15.6-24.4	20 (90) (57% sites)	0	17.5-27.4 (range=9.9) (64% sites)	Southwest
Ilen (14/08/2020 to 24/08/21) 375 days logging	10.6 (0.5)	14.5-19.6	15.5-20.8	6 (6) (5% sites)	1 (4)	16.1-23.4 (range =7.3 (50% sites)	Southwest
Nore (17/06/20 to 17/07/21) 390 days logging)	10.1 (0.7)	11.6-18.9	12-19.8	0	9 (12)	13.5-21.6 (range=8.1) (12% sites)	Southeast
Vartry (29/05/2019 to 19/03/2021) 660 days logging	10.0 (0.5)	14-19.3	14.5-19.6	0	0	16.7-23.7 (range=7.0) (31% sites)	East
Dargle (31/05/19 to 01/04/21) 671 days logging	9.4 (0.4)	12.7-19.1	13.5-19.8	0	8 (10)	16.2-21.6 (range=5.4) (21% sites)	East
Dodder (08/06/2019 to 16/03/2021) 647 days logging	10.0 (1.3)	12.7-18.6	13.4-19.0	0	7 (8)	14.1-20.8 (range=6.7) (29% sites)	East

3.4 National monitoring network: Lakes

The lakes Tw monitoring network was initiated in June 2019. Phase one was developed to evaluate Tw throughout the water column using offline dataloggers, but additional metrics such as water level, air temperature, wind speed and direction have been added in subsequent years. In addition, an online data buoy was established on Lough Sheelin in July 2021 (Kelly *et al*., 2022).

Results from two lakes in 2021 show the effects of an intense heatwave between 17th-25th July with surface (0.5m) lake temperatures on both Tawnyard Lough and Lough Barra exceeding 26°C (Table 3.14). Maximum surface summer temperatures in 2021 on both lakes were almost 5°C higher than 2020 (Table 3.14), revealing a similar pattern to maximum air temperatures recorded in 2020 vs 2021 (e.g., NSIC Erriff weather station (2020 – max Ta=25.9°C) vs 2021 – Max Ta=30.1°C).

Mean surface summer T_w on Tawnyard Lough in 2021 were over 1.5°C higher than 2020 (Table 3.12). Despite the high T_w recorded at the surface during the summer of 2021 on Tawnyard Lough (peak of 26.7°C, mean 17.5°C), mean summer T_w at depth were lower than the previous year, with the lake bottom T_w at 23m averaging two degrees lower in 2021 (11.3°C) than in 2020 (13.0°C). A low standard deviation (±0.25) at 23m recorded in 2021 also shows evidence of a consistent and stable water temperature at this depth during the study period(Table 3.14).

The CCMRP lake network has revealed T_w variances between monitored lakes as well as occurrence of stratification events over the three-year period. Length of the stratification period on Tawnyard Lough appeared to be stronger in 2021 than 2019 and 2020. This occurred in conjunction with high air temperatures exceeding 30°C at the NSIC Erriff weather station. Water column stability was also strongest in 2021 on Tawnyard Lough as indicated by the Schmidt stability score (J m^{-2}) (Fig. 3.12).

Table 3.14. Summary lake Tw (°C ±SD) metrics 2019-2021 for Lough Barra, Co. Donegal and Tawnyard Lough, Co. Mayo. (Winter: December 1st to February 28-29th/ Summer: June 1st to August 31st, only calculated when data from a full season available).

Lake	Year	Mean summer Tw 0.5m (°C)	Mean summer Tw bottom (°C)	Mean winter Tw 0.5m (°C)	Mean winter Tw bottom (°C)	Max Tw (0.5m) (°C)	Max stratified duration (no. days)
Lough Barra (deployed July 2019) (bottom=12m)	2019	-	-	-	-	19.1*	**
	2020	15.9 ± 2.04	14.2 ± 1.24	5.4 ± 1.15	5.3 ± 1.07	21.7	53
	2021	-	-	4.5 ± 1.60	4.5 ± 1.50	26.4	**
Tawnyard Lough (deployed June 2019) (bottom=23m)	2019	16.7 ± 1.50	12.95 ± 0.85	-	-	20.7	**
	2020	16.0 ± 1.78	13.0 ± 1.19	6.5 ± 0.67	6.4 ± 0.67	21.2	58
	2021	17.5 ± 3.01	11.3 ± 0.25	6.2 ± 0.99	6.1 ± 0.97	26.7	**

Note: *Not a full season.
**Only included if full years data available

Plate 3.7. Tawnyard Lough (photo taken from northern side of lake looking southeast)

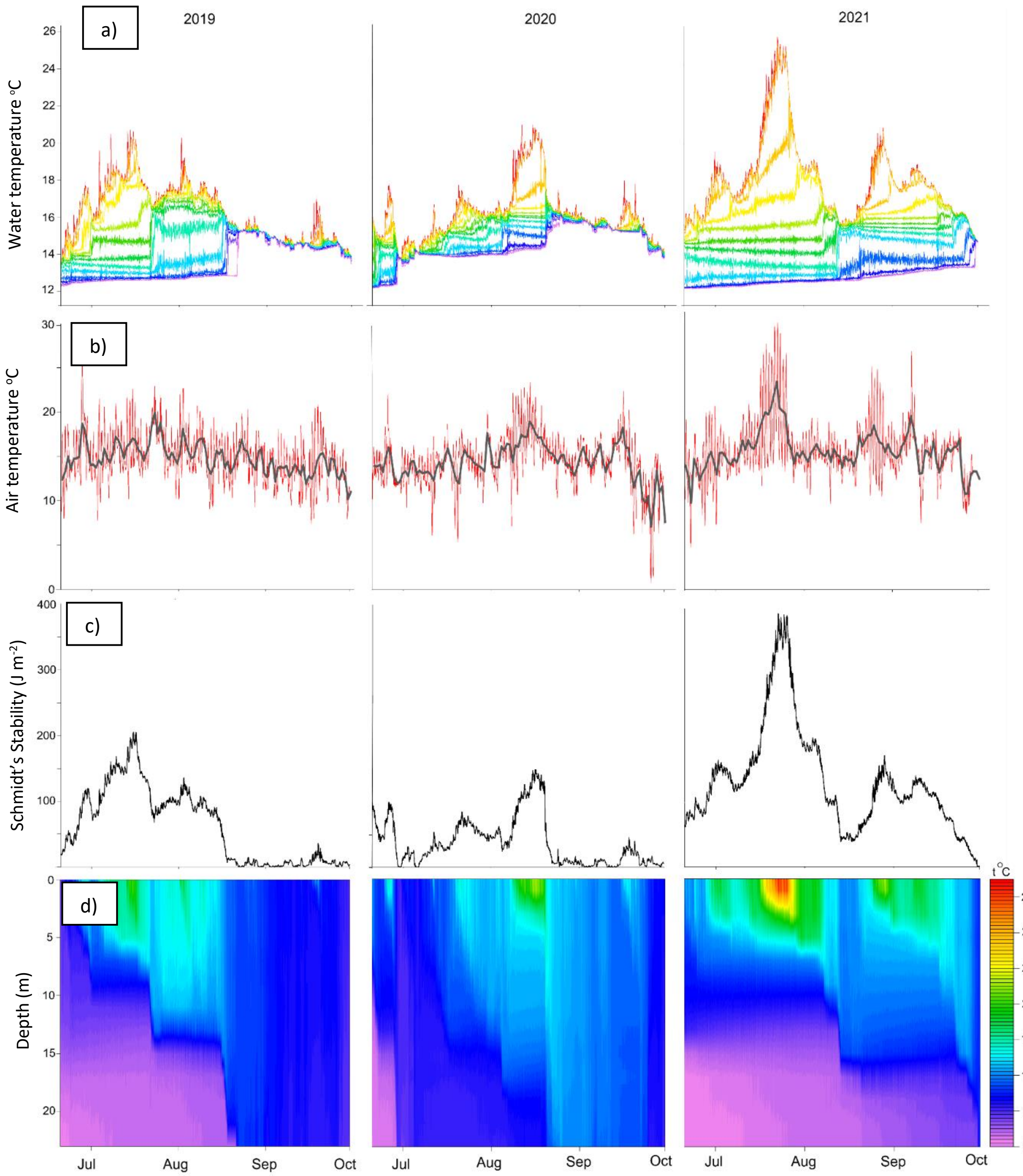

Figure 3.12 Tawnyard Lough, NSIC Erriff Catchment, Co. Mayo, (a) individual Tw data loggers deployed at 2m intervals, (b) Mean (black line) and range (red) of daily Ta from IFI weather station at NSIC Erriff, (c) Schmidt's stability and (d) temperature contours. (Data displayed is from June 20th to October 1st for 3 consecutive years (2019-2021)).

4. Summary

Climate change impacts on fish species may manifest directly (e.g., through physiological stress) or indirectly (e.g., species interactions). It is predicted that cold water species will likely shift towards higher latitudes or altitudes and may become locally extinct at the warmest edge of their current distribution ranges. Some species will undoubtedly experience net benefits and others net losses which is important to understand from a fisheries management perspective. Given the geographic location of Ireland and the unique freshwater fish community present on the island, considerable uncertainties and research gaps remain in relation to the impact climate change will have on populations and habitats. In 2019 IFI's climate change mitigation research programme (CCMRP) was initiated to address some of these research gaps.

The climate change species vulnerability assessment was undertaken via an expert-based questionnaire and a trait-based assessment to assign specific species to vulnerability categories. The expert-based questionnaire assigned one species (3%), namely Arctic char the rank of high vulnerability, thirteen species (40.5%) were assigned moderate to high vulnerability, fourteen species (44%) were assigned moderate vulnerability, and four species (12.5%) were allocated low to moderate vulnerability, while no species were classified as having a low vulnerability to climate change based on an expert panel. The results provide a vulnerability ranking for Ireland's freshwater fish and offer insight into the factors that increase susceptibility to climate-induced changes (Barry *et al*., submitted for publication). This information is significant to inform policy, decision-makers and other stakeholders engaged in managing freshwater fish resources.

IFI's long-term national climate change index catchment monitoring network which has been established in rivers and lakes across nine catchments represents the range of landscape variables in near natural catchments across Ireland. To date a total of 213 river T_w data loggers and 58 lake T_w data loggers have been deployed in nine catchments via the CCMRP programme (Barry *et al*., 2021) and an additional 115 Tw data loggers in drained rivers via the collaborative OPW/IFI climate resilience project (OPWCRP) (Kelly *et al*., 2022). A state-of-the-art data monitoring buoy was also installed on Lough Sheelin in July 2021 as part of the latter project (Kelly *et al*., 2022)

Temperatures of flowing waters control many physicochemical processes and affect the ecology of aquatic organisms and communities. Description of thermal regimes in flowing waters is key to understanding physical processes, enhancing predictive abilities, and improving bioassessments. Thermal regimes of rivers and streams in the nine index catchments will identify important drivers of thermal regimes in the varying river systems (lake fed, spring fed, spate etc.). The drivers of these thermal metrics will be further investigated through stream network modelling.

The highest T_w recorded in the Gweebarra catchment during the sampling period (July 2019 to 2021) was 28.4°C, recorded on 22/07/2021. The highest Tw in the Erriff network in the sampling period was 26°C on 01/06/2020. The highest Tw recorded in the Doonbeg catchment during the sampling period was 25.2 °C on 23/07/2021. The highest Tw recorded in the Currane/Commeragh catchment during the sampling period was 27.43 ° C on 25/07/2021. The highest Tw recorded in the Ilen catchment during the sampling period was 23.4 ° C on 22/07/2021. The highest Tw recorded in the Nore catchment during the sampling period was 21.6 ° C on 16/07/2020. The highest Tw recorded in the Varty catchment during the sampling period was 23 ° C on 25/06/2020. The highest Tw recorded in the Dargle catchment during the sampling period was 23.7°C on 23/07/2019. The highest Tw recorded in the Dodder catchment during the sampling period was 20.8°C on 23/07/2019.

At this stage of the project, it is not possible to conduct a full comparison of thermal metrics across all catchments and undertake modelling of T_w at a national level as T_w data loggers were deployed and turned over on a phased basis. However, it was possible to compare selected thermal metrics across some catchments. In general, sites in the lower sections of each catchment, in addition to river stretches below lakes or reservoirs had highest water temperatures as indicated by the number of days Tw exceeded 20°C. Results from the stream network model developed for the Erriff catchment revealed that during a seven-day period in 2019, highest water temperatures were reached throughout lower catchment (including the main channel) and river sections immediately downstream of each lake. In contrast, high elevation headwater streams typically remained cooler than 19.5 °C and may provide important thermal refuges for salmonids in the system during warm weather.

In total there were 234 days at 31 sites throughout the network where the mean daily Tw exceeded 20°C across the monitoring network. These events were not evenly spread across the catchments; Currane had the greatest number (90 days across 8 sites), followed by Gweebarra (66 days across 12 sites), Doonbeg (57 days across five sites), Erriff (15 days across five sites) and Ilen (6 days at one site) (Table 3.13). The Gweebarra and Erriff systems flow type is characterised as surface water dominated (flashy and highly reliant on rain). The days exceeding mean daily Tw 20°C in these catchments were recorded during low water drought events. It is likely that may be increasing water residence time and therefore the Tw recorded at these sites will be further investigated (see catchment summary table for site specific breakdown). The Ilen exceedances all came from the lowest site the Ilen network. The four remaining catchments (Dodder, Dargle, Vartry and Nore) recorded 0 days where average daily water temperature exceeded 20°C. These catchments have all groundwater dominated flow paths which exhibit medium to high minimum base flow (Webster *et al*., 2015). Groundwater has been shown to buffer stream temperatures providing thermal and climate refugia (Kaandorp *et al*., 2019) which are important for cold water fish species, e.g salmonids.

The CCMRP lake network has revealed Tw variances between monitored lakes as well as occurrence of stratification events over the three-year period. The results from the lake monitoring network have indicated that T_w conditions are buffered from surface influences by stratification over the analysed period as opposed to 2020. Conditions that create such a thermal barrier in lakes are often formed during the commencement of high-pressure air systems during the summer, with benign wind speeds and high solar radiation driving up surface temperatures. If those conditions are persistent, the consistent band of cool water at lower depths will continue for a longer duration, hence the lower average bottom water temperature for 2021. A counter to that is that a greater effort in the form of storms or high wind would be required to mix the water column.

Next steps - 2022

T_w monitoring will continue in all index catchments. Tw data loggers in rivers will be turned over and additional stream network models will be compiled for the Gweebarra and East coast rivers (Dargle Dodder and Vartry).

Monitoring the extent of dissolved oxygen consumption during stratification events will be a major component of the programme in 2022 in four lakes (Barra, Currane, Tawnyard and Sheelin).

Further data analysis will take place in 2022 incorporating meteorological measurements such as site, air temperature, dissolved oxygen concentrations, solar radiation, wind speed and direction. This in turn will allow for the analysis of past and present temperature data through limnological modelling.

In parallel a fish monitoring programme has been initiated in each catchment. Monitoring will continue in 2022.

5. References

Adrian, R., O' Reilly, C.M., Zagarese, H., Baines, S.B., Hessen, D.O., Keller, W., Livingstone, D.M., Sommaruga, R., Straile, D., Van Donk, E., Weyhenmeyer, G.A. and Winder, M. (2009) Lakes as sentinels of climate change. *Limnology and Oceanography*, **54 (6)**, 2283-2297.

Barry, J., Coyne, J., Connor, L., Purves, K, and Kelly, F.L. (2021) Climate Change Mitigation Research Programme, Annual Report 2020. National Research Survey Programme, Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24.

Barry, J., Radinger.J., Coyne, J., Connor, L., Kelly, S., and Kelly, F.L. (submitted) The vulnerability of Irelands Freshwater Fish to Climate Change.

Bond, N.R., Lake, P.S. and Arthington, A.H. (2008) The impacts of drought on freshwater ecosystems: An Australian perspective. *Hydrobiologia*, **600**, 3-16.

Cochrane, K.; De Young, C.; Soto, D.; Bahri, T. (eds). (2009) *Climate Change Implications for Fisheries and Aquaculture: Overview of Current Scientific Knowledge*. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. 2009. 212p.

Comte, L., Buisson, L., Daufererne, M. and Grenouillet, G. (2012) Climate-induced changes in the distribution of freshwater fish: observed and predicted trends. *Freshwater Biology*, **58 (4)**, 625-639.

Elliott, J. and Elliott, J. A. (2010) Temperature requirements of Atlantic salmon *Salmo salar*, brown trout *Salmo trutt*a and Arctic charr *Salvelinus alpinus*: predicting the effects of climate change. *Journal of Fish Biology***, 77**, 1793-1817.

Gutowsky, L.F.G., Giacomini, H.C., De Kerckhove, D.T., Mackereth, R., McCormick, D. and Chu, C. (2018) Quantifying multiple pressure interactions affecting populations of a recreationally and commercially important freshwater fish. *Global Change Biology*, **25 (3)**, 1049-1062.

Issak, D.J., Luce, C.H., Chandler, G.L., Horan, D.L. and Wollrab, S. (2018) Principal components of thermal regimes in mountain river networks. *Hydrology and Earth System Sciences*, **22**, 6225-6240.

Jackson, F.L., Malcolm, I.A. and Hannah, D.M. (2016) A novel approach for designing large-scale river temperature monitoring networks. *Hydrology Research*, **47**, 569-590.

Jonsson, B. and Jonsson, N. (2010) A review of the likely effects of climate change on anadromous Atlantic salmon *Salmo salar* and brown trout *Salmo trutta*, with particular reference to water temperature and flow. *Journal of Fish Biology*, **75 (10)**, 2381-2447.

Kaandorp, V.P., Doornenbal, P.J., Kooi, H., Broers, H.P. and de Louw, P.G., 2019. Temperature buffering by groundwater in ecologically valuable lowland streams under current and future climate conditions. Journal of Hydrology **3**, p.100031.

Kelly, S., Moore, T.N., de Eyto, E., Dillane, M., Goulon, C., Guillard, J., Lasne, E., McGinnity, P., Poole, R., Winfield, I.J., Woolway, R.I. and Jennings, E. (2020a). Warming winters threaten peripheral Arctic charr populations of Europe. *Climatic Change*, **163**, 599–618.

Mohsenie, O., Stefan, H.G. and Eaton, J.G. (2003) Global warming and potential changes in fish habitat in U.S. streams. *Climate Change*, **59**, 389-409.

Met Eireann (2021) *Climate Statement for July 2021*. https://www.met.ie/climate-statement-for-july-2021.

Nagel, D., Peterson, E., Isaak, D., Van der Hoef, J. and Horan, D. (2016) *National Stream Internet Protocol and User Guide*. Boise, Idaho, USA.

Nolan, P. and Flanagan, J. (2020) *High-Resolution Climate Projections for Ireland – A Multi-Model Ensemble Approach*. EPA Research Report, No. 339.

O' Keeffe, J., Piniewski, M., Szczesniak, O., Parasiewicz, p. and Okruszko, T. (2018) Index based analysis of climate change impact on streamflow conditions important for Northern pike, chub and Atlantic salmon. *Fisheries Management and Ecology*. https://doi.org/10.1111/fme.12316

Olusanya, H.O. and van Zyll de Jong, M., 2018. Assessing the vulnerability of freshwater fishes to climate change in Newfoundland and Labrador. *PloS one*, 13(12), p.e0208182.

Peterson, E.E., Hoef, J.M.V., 2010 A mixed-model moving-average approach to geostatistical modeling in stream networks. *Ecology*, **91**, 644–651.

Pletterbauer, F., Graf, W. and Melcher, A. (2018) Climate Change Impacts in Riverine Ecosystems. In: Schmutz, S. and Sendzimir, J. (eds) *Riverine Ecosystem Management*. Aquatic Ecology Series 8, pp. 203-223.

Poff, N. L. and Zimmerman, J.K.H (2009) Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. *Freshwater Biology*, **55 (1)**, 194-205.

Read, J.S., Hamilton, D.P., Jones, I.D., Muraoka, K., Winslow, L.A., Kroiss, R., Wu, C.H. and Gaiser, E. (2011) Derivation of lake mixing and stratification indices from high-resolution lake buoy data. *Environmental Modelling and Software*, **26**, 1325-1336.

Solheim, A.L., Austnes, K., Eriksen, T.E., Seifert, I. and Holen, S. (2010) *Climate Change Impacts on Water Quality and Biodiversity*. Background report for EEA European environment State and Outlook Report 2010. ETC Water and technical Report 1/2010.

Webster, K, Tedd, K, Coxon, C and Donohue, I, 2015, *Environmental flow assessment for Irish rivers: a literature review*. Unpublished report submitted to the EPA.

Winslow, L., Read, J., Woolway, R., Brentrup, J., Leach, T., Zwart, J. and Collinge, D. (2019). *Package 'rLakeAnalyzer'*.

Appendix 1

Catchment descriptions

3.4.1 Gweebarra catchment

The Gweebarra River catchment is located in County Donegal within the Northwestern River Basin District and covers an area of approximately 122 km^2. The River Barra rises between the Glendowan and Derryveagh mountains and flows for approximately 32km in a southwesterly direction through Lough Barra. The catchment has one relatively large lake present, Lough Barra (Fig. 2.1). This catchment's geology is mixed between granite, slate, shale and schist, with rough pasture and blanket bog as the dominant land uses.

The annual average rainfall in the contributing catchment is 1791mm (EPA GeoPortal https://gis.epa.ie/EPAMaps/); 39% of the soils in the contributing catchment are classified as being poorly drained and 58% of the subsoils in the catchment are classified as being organic/peat in nature (EPA GeoPortal https://gis.epa.ie/EPAMaps/). The Gweebarra catchment has a FARL (Flow Attenuation from Reservoirs and Lakes measured between 0-1) value of 0.91, indicating attenuation from lakes within the system (EPA GeoPortal https://gis.epa.ie/EPAMaps/).

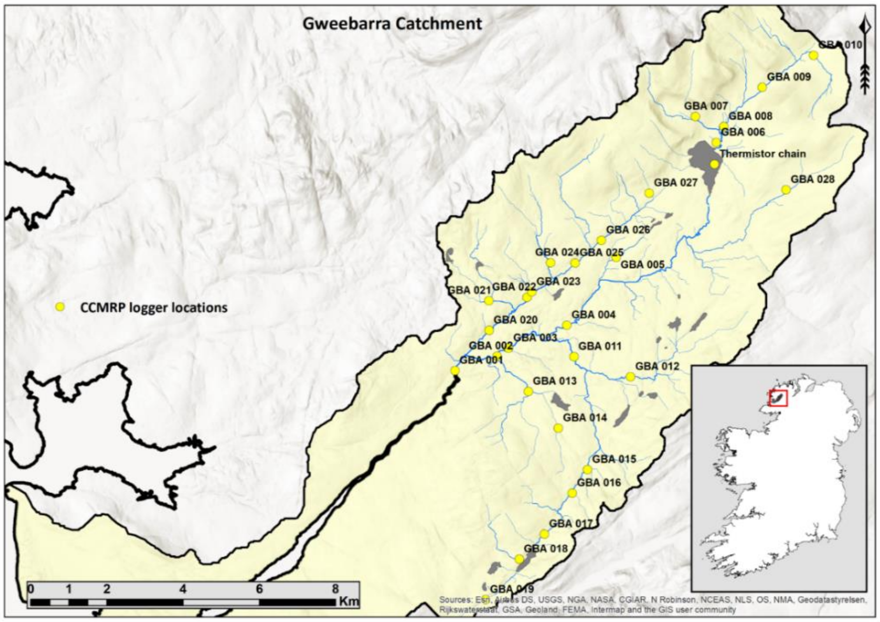

Fig. A1 Gweebarra catchment indicating CCMRP monitoring sites on rivers and lakes

2.3.4.2 Erriff catchment

The Erriff catchment in Co. Mayo is designated by IFI as the National Salmonid Index Catchment (NSIC) and covers an area of approx. 166 km^2. A dedicated research station is located at Aasleagh Falls at the mouth of the River Erriff and supports a wide range of scientific research and monitoring activities on salmon, sea trout and brown trout. There are several lakes on the catchment, most notably Tawnyard Lough, a small upland lake (elevation 64m), (maximum depth 24.3m), small sized lake (0.54km^2) (WFD, 2000). Its outflow is home to one of the main traps in the system and ensures that several major scientific studies of anadromous smolts on an annual basis.

The annual average rainfall in the contributing catchment is 2152mm; 66% of the soils in the catchment are classified as being poorly drained and 20% of the subsoils in the catchment are classified as being organic/peat in nature (EPA GeoPortal https://gis.epa.ie/EPAMaps/). The Erriff catchment has a FARL (Flow Attenuation from Reservoirs and Lakes) value of 0.96, indicating low attenuation from lakes within the system. The catchment includes many mountainous areas, all of which are underlain by assorted metamorphic rocks.

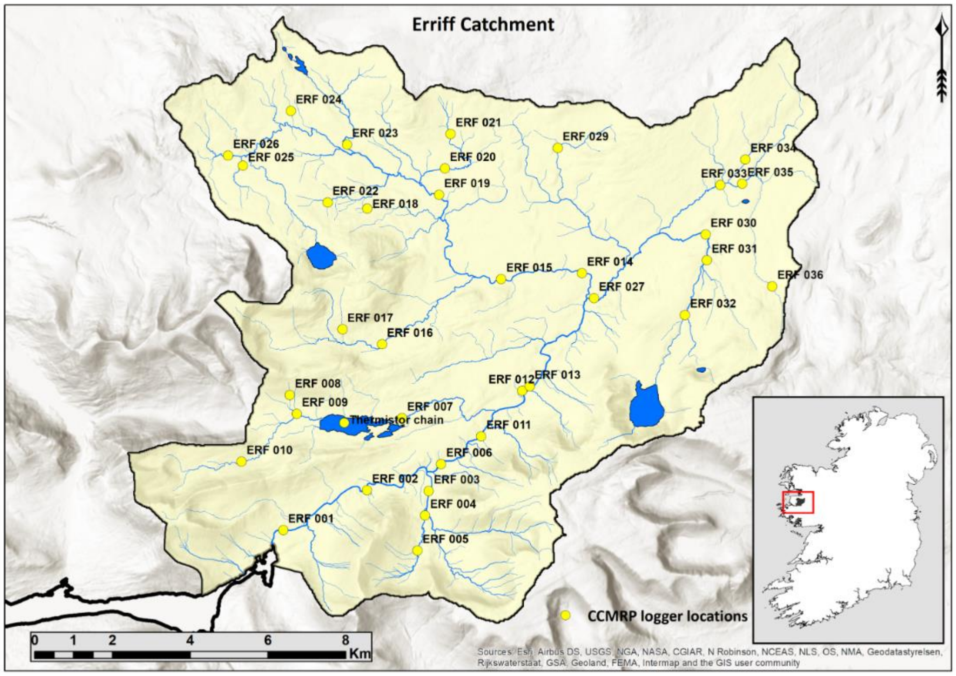

Fig. A2 Erriff catchment indicating locations of CCMRP Tw monitoring sites

2.3.4.3 Doonbeg catchment

The Doonbeg River catchment is located in County Clare within the Shannon River Basin District and covers an area of approximately 112 km^2. This catchment's geology is mixed between sandstone and grey siltstone. The flow type on the Doonbeg is characterised as groundwater dominated (Webster et al. 2015). The annual average rainfall in the contributing catchment is 1144 mm; 24% of the soils in the contributing catchment are classified as being poorly drained and 51% of the subsoils in the catchment are classified as being organic/peat in nature (EPA GeoPortal https://gis.epa.ie/EPAMaps/). The Doonbeg catchment has a FARL (Flow Attenuation from Reservoirs and Lakes) value of 0.96 indicating low attenuation from lakes within the system.

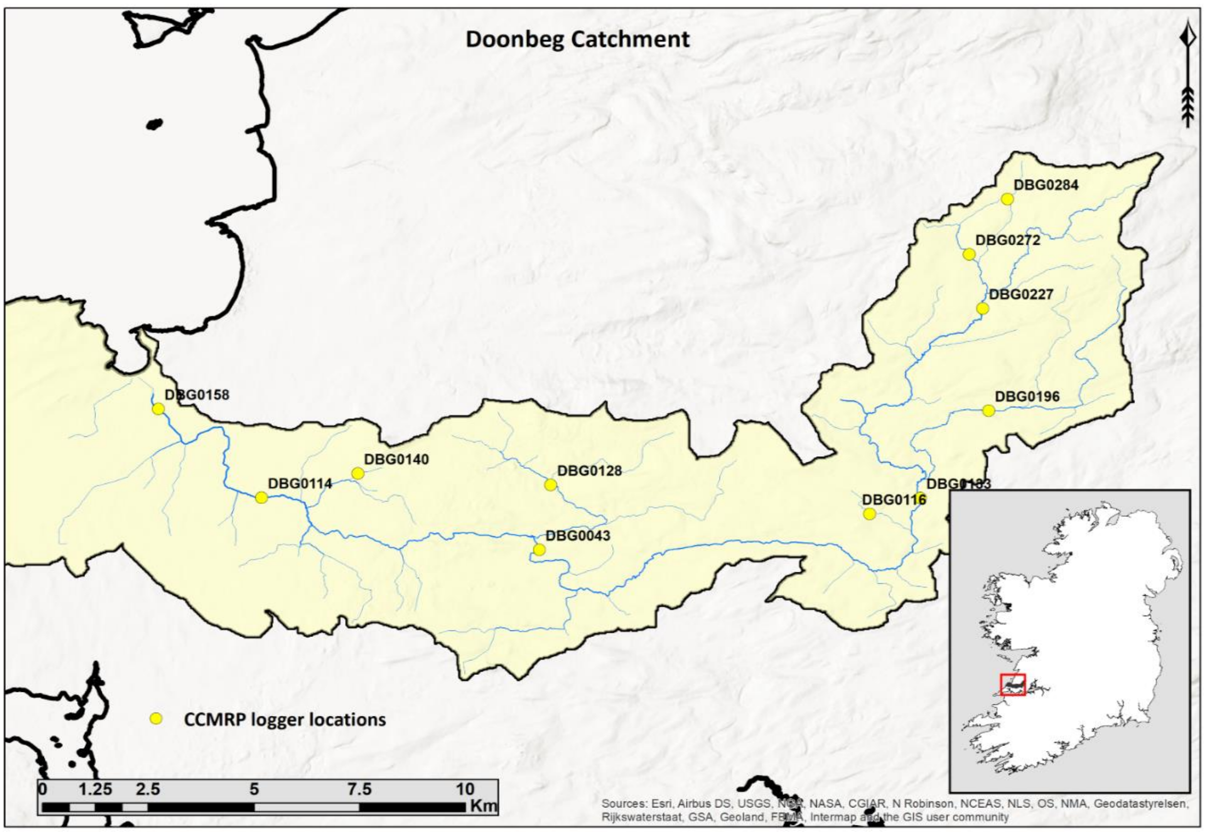

Fig. A3 Doonbeg catchment showing locations of CCMRP monitoring sites

2.3.4.4 Cummeragh/Currane catchment

The Cummeragh/Currane catchment is located in Co. Kerry in the Southwest River Basin District, adjacent to the town of Waterville. The catchment is dominated by Lough Currane, a large lake in the lower reaches of the catchment (Fig. A4). The two main rivers that flow into Lough Currane, the Cummeragh river (draining an area of 48km^2) to the Northeast and Isknagahiny (draining an area of 20km^2) to the Northwest of the lake. The Finglas river enters below the lake draining an area of 12km^2 (Fig. A4). The underlying geology is dominated by red sandstone. The flow type on the rivers in the Currane catchment and major tributaries vary from lake dominated (Cummeragh river) to surface water dominated (Finglas river).

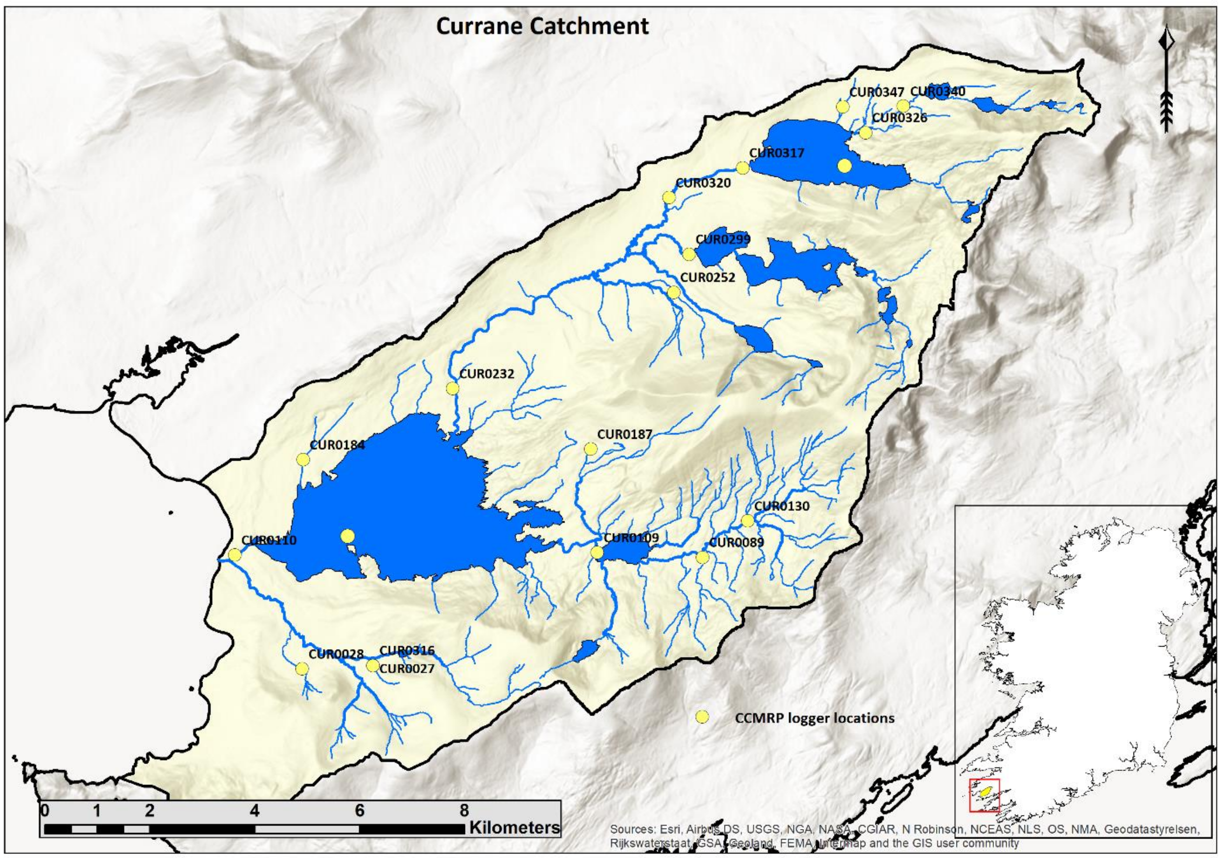

Fig. A4 Currane catchment showing locations of CCMRP monitoring sites

2.3.4.5 Ilen Catchment

The Ilen River catchment is in County Cork within the Southwest River Basin District and covers an area of approx. 240 km^2. The annual average rainfall in the contributing catchment is 1582 mm (EPA GeoPortal https://gis.epa.ie/EPAMaps/); 42% of the soils in the contributing catchment are classified as being poorly drained and 4% of the subsoils in the catchment are classified as being organic/peat in nature (EPA GeoPortal https://gis.epa.ie/EPAMaps/). The Ilen catchment has a FARL (Flow Attenuation from lakes) value of 1, meaning no lakes influence flow on the river. This catchment's geology is mixed between old red sandstone and mudstones.

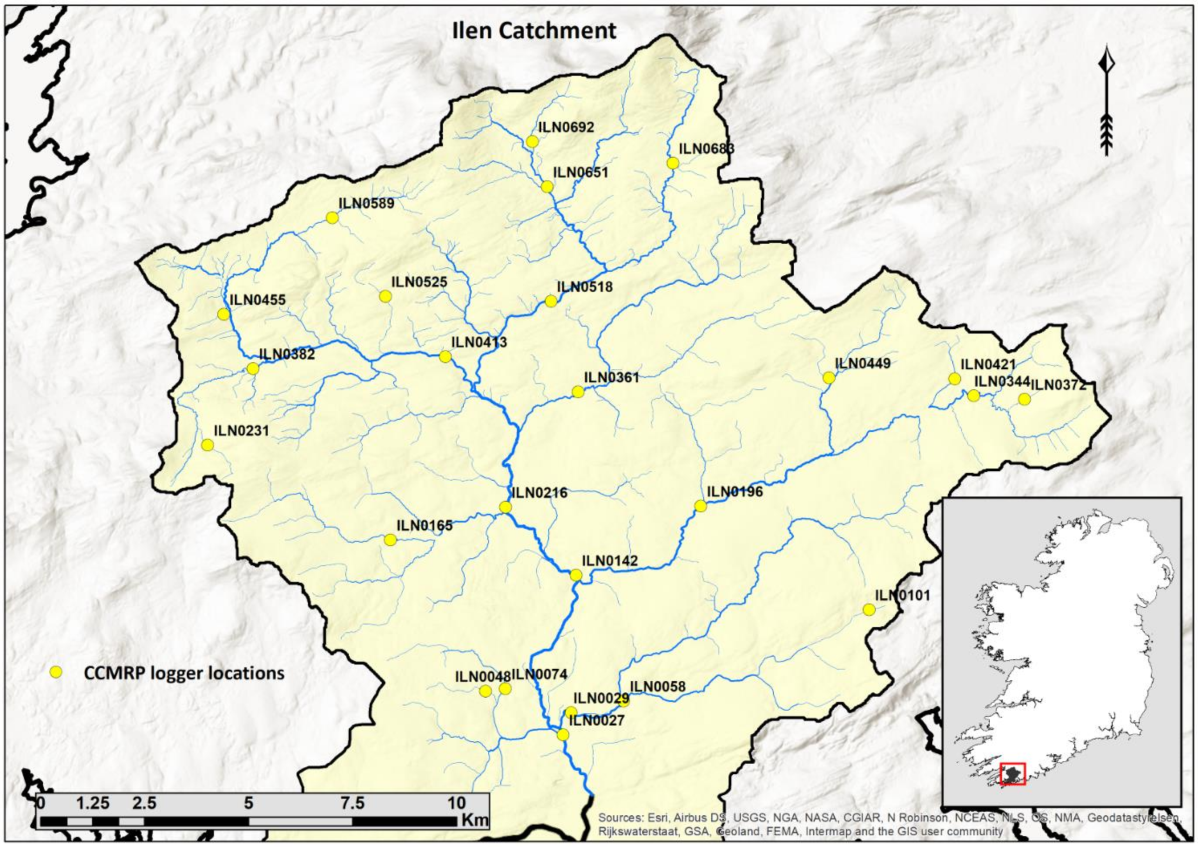

Fig. A5 Ilen catchment showing locations of CCMRP monitoring sites

2.3.4.6 Nore catchment

The River Nore is located within the Southeast River Basin District. The catchment drains an area of 2,597km² and the river is approximately 134km in length from source to sea flowing through counties Tipperary, Laois. It then flows southeast to County Kilkenny, before joining the River Barrow just north of New Ross.

The annual average rainfall in the contributing catchment is 965 mm; 35% of the soils in the contributing catchment are classified as being poorly drained and 7% of the subsoils in the catchment are classified as being organic/peat in nature. The Nore catchment has a FARL (Flow Attenuation from lakes) value of 1, meaning no lakes influence flow on the river. This catchment's geology is mixed between limestone, sandstone, and shale. The flow type on the Nore would be characterised as groundwater dominated, however certain tributaries would be heavily reliant on surface water (Webster *et al*., 2015).

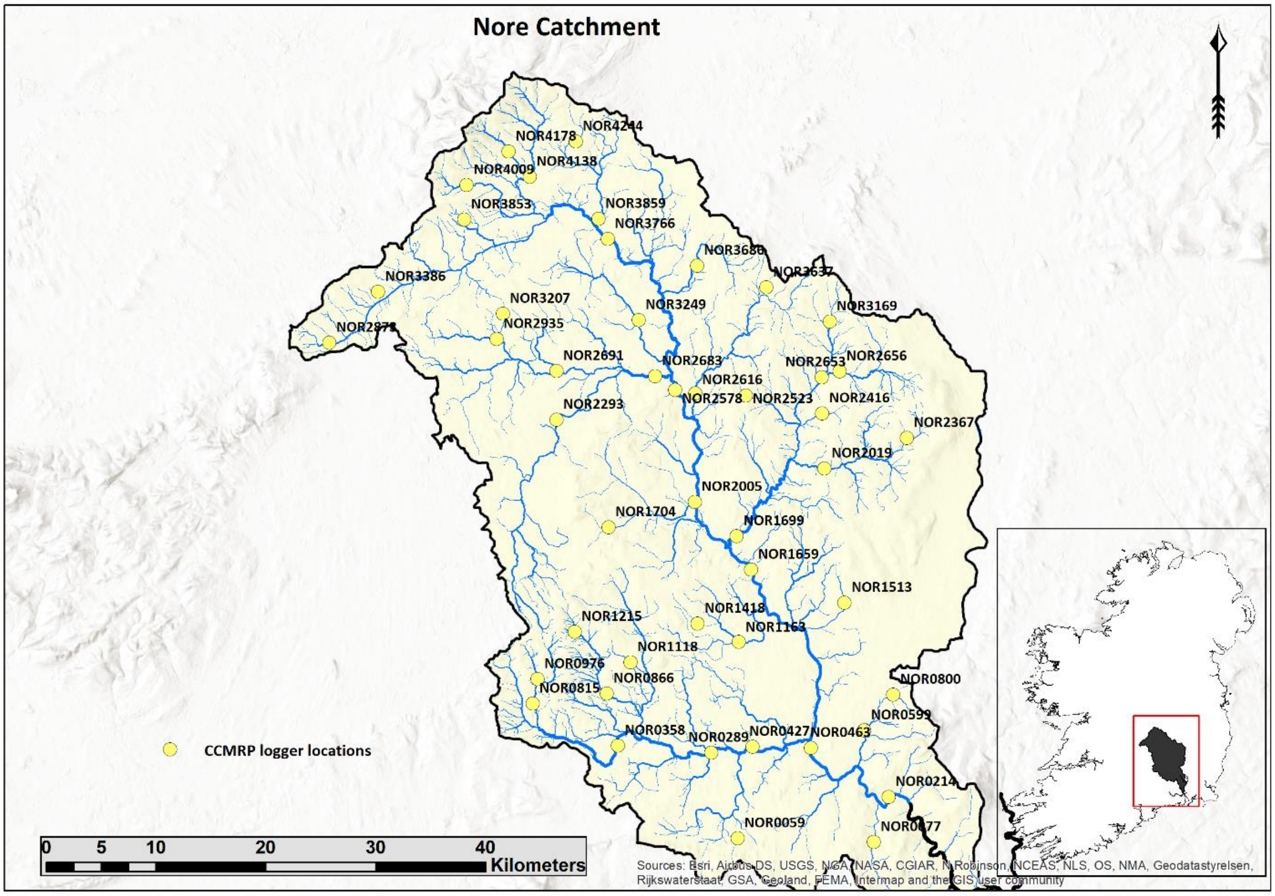

Fig. A6 Nore catchment showing locations of CCMRP monitoring sites

2.3.4.7 Vartry catchment

The Vartry River catchment is located within the Eastern River Basin District and covers an area of approximately 104km^2. The Vartry River was impounded in the 1860s as part of the Vartry Water Supply Scheme (lower reservoir and dam) and an additional reservoir was constructed in 1923 (upper reservoir). The scheme incorporates a water treatment plant, two reservoirs (Fig. A7), a pipeline and a dam located south of Roundwood, Co. Wicklow.

The annual average rainfall in the contributing catchment is 1030 mm; 19% of the soils in the contributing catchment are classified as being poorly drained and 1% of the subsoils in the catchment are classified as being organic/peat in nature (EPA GeoPortal https://gis.epa.ie/EPAMaps/). The Vartry catchment has a FARL (Flow Attenuation from reservoirs and lakes) value of 0.83, meaning significant lake/reservoir influence flow in the river (Fig. A7). The higher areas of the Wicklow Mountains are underlain by granite bedrock while metamorphic slates and quartzites underly the eastern coastal part of the catchment.

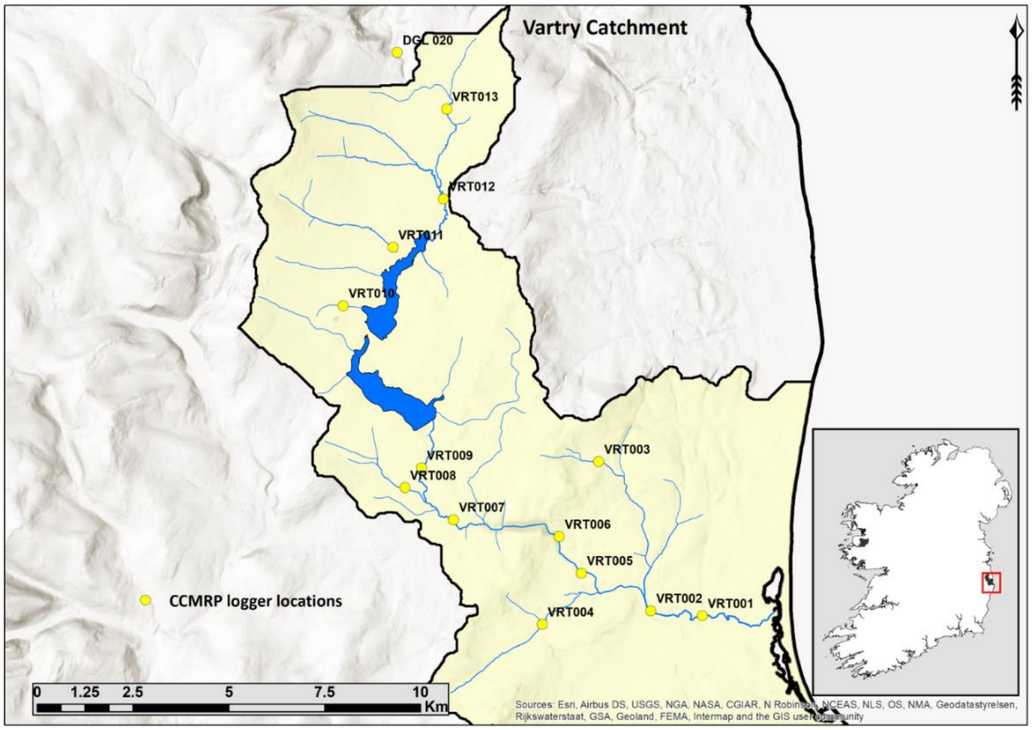

Fig. A7 Vartry catchment showing locations of CCMRP monitoring sites

2.3.4.8 Dargle Catchment

The Dargle River catchment is located within the Eastern River Basin District and covers an area of approximately 128 km^2. The Dargle River rises in the Wicklow mountains and flows in a north-easterly direction through a series of rapids and waterfalls before entering the sea at Bray, Co. Wicklow. Significant urban activity is present towards the mouth at Bray.

The annual average rainfall in the contributing catchment is 993 mm; 32 % of the soils in the contributing catchment are classified as being poorly drained and 17 % of the subsoils in the catchment are classified as being organic/peat in nature. The Dargle catchment has a FARL (Flow Attenuation from Reservoirs and Lakes) value of 0.99, meaning lakes have no influence on flow in the river. This catchment's geology is mixed between granite, slate, shale and schist, with the land used mainly for agriculture.

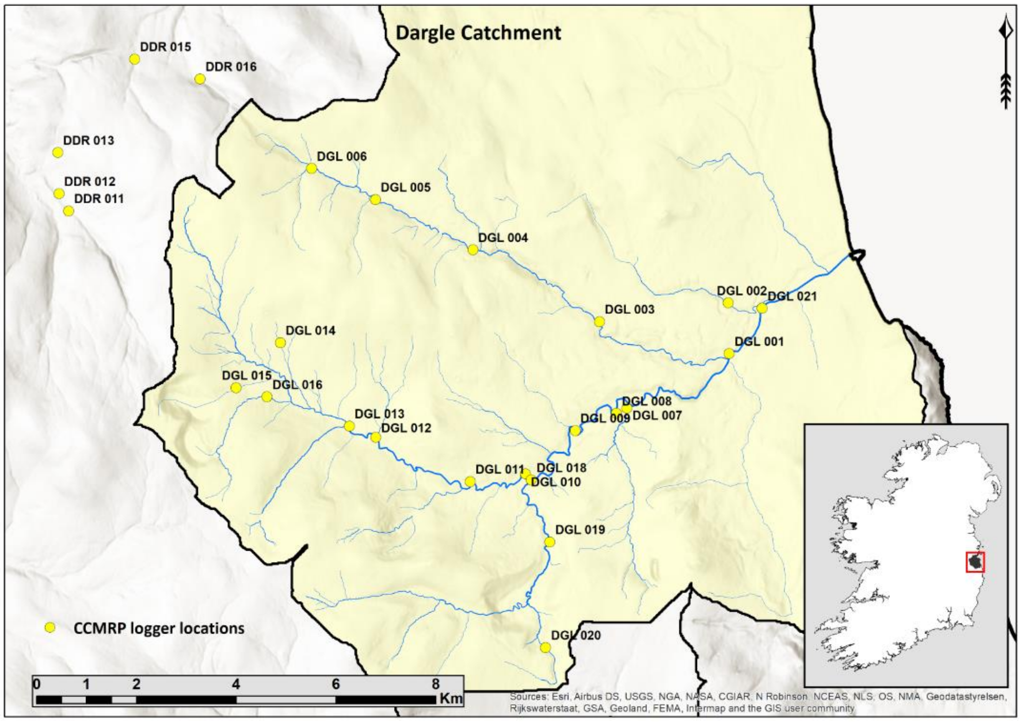

Fig. A8 Dargle catchment showing locations of CCMRP monitoring sites

2.3.4.9 Dodder Catchment

The River Dodder catchment is located within in the Eastern River Basin District and covers an area of approximately 113km^2. The river flows in a north easterly direction through south Co. Dublin, reaching the River Liffey at Grand Canal Dock in Dublin city. There are two reservoirs and a dam located within the upper catchment (Glenasmole and Bohernabreena) (Fig. A9).

The annual average rainfall in the contributing catchment is 1190 mm; 23% of the soils in the contributing catchment are classified as being poorly drained and 15% of the subsoils in the catchment are classified as being organic/peat in nature (EPA GeoPortal https://gis.epa.ie/EPAMaps/). The Dargle catchment has a FARL (Flow Attenuation from reservoirs and lakes) value ranging from 0.90 – 0.96, meaning lakes/reservoir upstream have an influence on flow in the river. The geology of this catchment is mixed between granite, limestone and slate. This catchment consists of scrubland in the upper catchment, with agriculture lower down towards the two reservoirs.

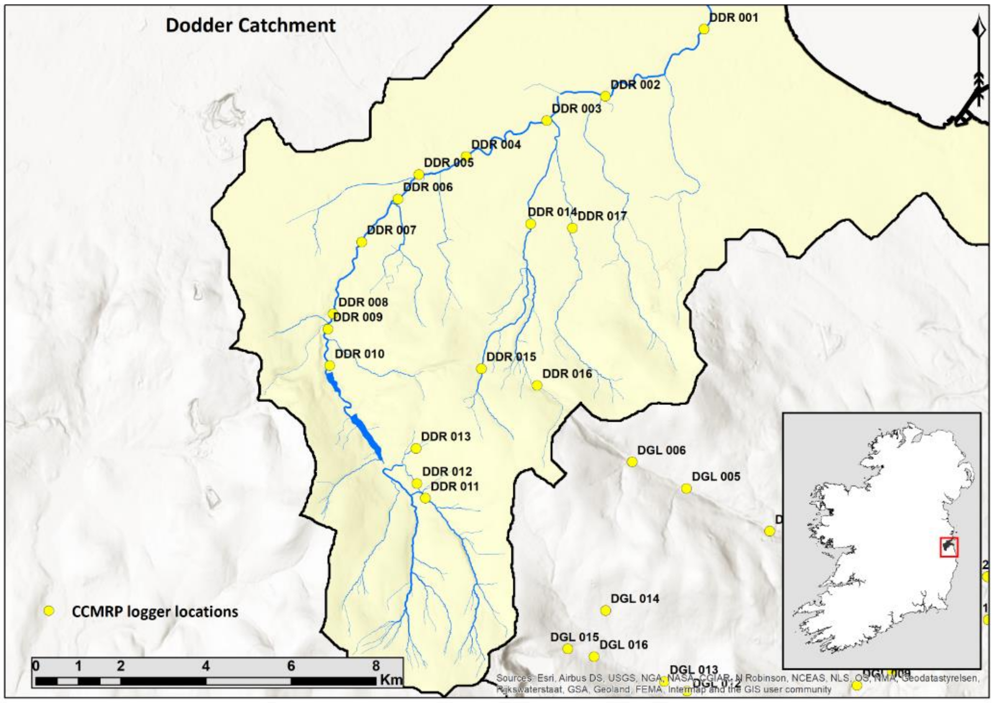

Fig. A9 Dodder catchment showing locations of CCMRP monitoring sites

Inland Fisheries Ireland
3044 Lake Drive,
Citywest Business Campus,
Dublin 24,
Ireland.
D24 Y265

www.fisheriesireland.ie
info@fisheriesireland.ie

+353 1 8842 600