

# Summary Report into the July 2025 Lough Sheelin Fish Kill (Captain's Bay and Lower Mount Nugent River)

IFI/2025/1-4786



Iascach Iníre Éireann  
Inland Fisheries Ireland

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## Introduction

A report of dead fish in Captain's Bay, Lough Sheelin (An overview Ordnance Survey map and an aerial photography map of the area are shown in Figures 1. and 2.) was received by Inland Fisheries Ireland (IFI) on the evening of 16<sup>th</sup> July 2025. IFI Officers attended the scene within minutes, on arrival they encountered a small number of struggling brown trout, which they immediately attempted to revive and c. 6 revived brown trout were released c.200m outside of Captain's Bay. Twenty three brown trout which could not be revived were recovered from the Captain's Bay area on 16<sup>th</sup> July, and further dead fish were found within the lower reaches of the Mount Nugent River on the 17<sup>th</sup> July and subsequent days. An investigation and recovery operation commenced between the 16<sup>th</sup> and 22<sup>nd</sup> July, a total of 834 dead fish were recovered. A walkover of the Mount Nugent River commenced on the 16<sup>th</sup> July, with water quality investigations and checks for potential pollution sources undertaken throughout the Mount Nugent Catchment.

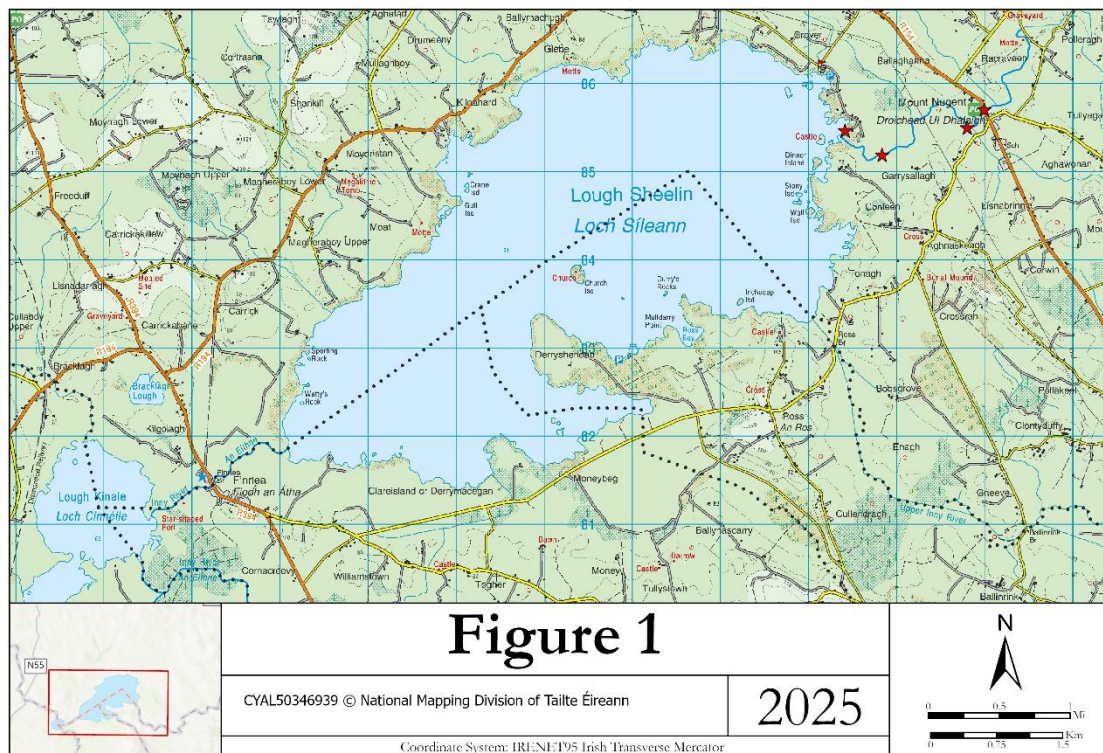
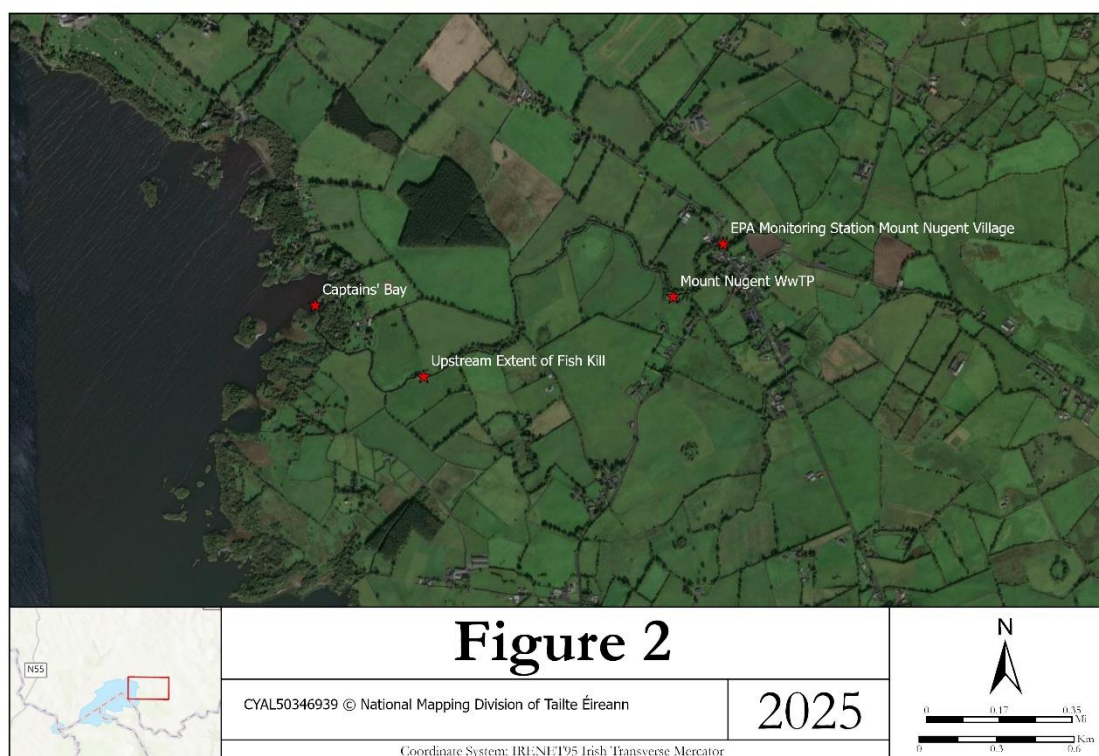


Figure 1. Ordnance Survey Discovery Map showing Captain's Bay, the Mount Nugent River, Mount Nugent WWTP and Mount Nugent Village.



*Figure 2. Aerial photography map showing Captain's Bay, the Mount Nugent River, Mount Nugent WWTP and Mount Nugent Village.*

## **IFI investigations**

In total, 23 dead trout were collected from Captain's Bay in Lough Sheelin (all on 16<sup>th</sup> July). By the end of 17<sup>th</sup> July, the cumulative total of mortalities was 68 fish, 23 fish from Captain's Bay and 45 fish from the lower Mount Nugent River. A total of 811 fish, mainly large wild brown trout (but also including 2 pike measuring 57 and 60 cm, 2 roach, 1 perch and 2 stone loach, all under 15 cm) were collected from the lower 580 metres of the Mount Nugent River between 17<sup>th</sup> and 22<sup>nd</sup> July. The vast majority of these were large female adult trout (81 trout were measured, minimum size was 16.7 cm, maximum fish 66.5 cm and a mean size 52.0 cm, a length frequency distribution and age estimation graph is presented in Figure 5.). A large number of the fish in the Mount Nugent River had died and sunk to the bottom during the original kill, only rising to the surface as they decomposed and filled with gas, with the first indication of the presence of these fish being late on Friday evening and continuing to rise until Tuesday. All dead fish which were seen were recovered by IFI. There were no further sightings of distressed fish after the initial sightings in Captain's bay on the evening of 16<sup>th</sup> July.



*Figure 3. Some of the large wild brown trout recovered from Captain's bay on the 16<sup>th</sup> July 2025*

Whilst the fish recovered on Wednesday the 16<sup>th</sup> of July were relatively fresh, rigor mortis had set in and the eyes had started to cloud on those fish recovered on Thursday 17<sup>th</sup> of July. Rigor mortis can take a few hours to set in, but the speed of onset varies with temperature (higher temperatures speed up rigor mortis) and may set in quicker if the fish are stressed before death. The dead fish found from Friday 18<sup>th</sup> of July onwards were quite decayed, it is believed these fish died during the initial fish kill, but had sunk to the river bed after dying and were not visible in previous checks of the river section until late on the evening of Friday 18<sup>th</sup> July and subsequent days. Decomposition of the fish caused gases to be released and the fish floated to the surface.

Once the initial report was received on 16<sup>th</sup> July, the Mount Nugent River and its tributaries were thoroughly checked, with pollution inspections carried out at a number of sites in the Mount Nugent, Schoolhouse and Pound Rivers. At all sites, the water in the river appeared clean and clear, there was no smell, no visual evidence of any point source pollution, no dead fish and no discharges were observed. A number of domestic, agricultural, licenced premises and potential pollution sources were also checked with no evidence of pollution sources or discharges found.

The Mount Nugent wastewater treatment plant (WWTP) was checked; there was no discharge through the storm overflow (which is to the Schoolhouse Stream) and no evidence of a recent discharge. Test strips were used downstream of the confluence where the Schoolhouse Stream enters the Mount Nugent River, at the outfall of the wastewater treatment plant and at Mount Nugent village on the evening of the 16<sup>th</sup> July. The test strips in the Schoolhouse stream and Mount Nugent WWTP outfall registered zero for ammonia and nitrite, with a nitrate value of 2 parts per million (ppm). Levels at the village registered zero for ammonia, zero for nitrite and 2 ppm for nitrate, this value is typical of the baseline levels in the Mount Nugent River (from IFI routine test strip monitoring). The Mount Nugent wastewater treatment plant is licenced and monitored by the Environmental Protection Agency (EPA). The outfall from the treatment plant is a further c. 1.5 km upstream of the upstream extent of the fish kill. It was noted that woody debris and other materials (including a football) were held in place by overhanging vegetation and tree branches in this section – and thus it is likely that any dead fish would have also been held up in this vegetation, but none were found. Test strips in Captain's bay on the evening of 16<sup>th</sup> July were in the normal range for the lake with a value of 0 ppm for ammonia and nitrite and 1 ppm for nitrate.

On the 17<sup>th</sup> of July, the Mount Nugent River was travelled by boat and both banks were checked for potential pollution sources as far as the navigable reaches, with the remaining fields walked along the river banks. No evidence of discharges was detected. Land use along this stretch of the river was noted with no recent land spreading activity evident or land-based activities of concern noted. Test strips were used in the Lower Mount Nugent River and registered zero for ammonia and nitrite, with a nitrate value of 2 ppm.

Lake water temperatures on 17<sup>th</sup> July were 21.3 °C and 21.6 °C in the inlet of Captains Bay and Crover Boat launch respectively. It should be borne in mind that the data logger in Captains Bay (0.5 m below the surface) is c. 500 m away from the sheltered shallow inlet section of the bay, (where the dead fish were found) and is likely more exposed and in a deeper section of water giving rise to reduced temperatures and more favourable dissolved oxygen levels than the shallow inlet where the dead fish were found. Note there was a difference of c. +1 degree between temperatures taken with a hand held logger at depths of c. 30 cm in the inlet of Captain's Bay on the 17<sup>th</sup> July and those taken by the data logger in Captains' Bay.

Water temperatures in Mount Nugent village were 17.5 °C on the evening of the 16<sup>th</sup> July, however the acoustic receiver measured a temperature range of between 16.8-16.9 °C on Wednesday (16<sup>th</sup> July), with a range of 16.5-17.2 °C on Thursday 17<sup>th</sup> July.

Over the course of the following week further checks were carried out within the catchment. Lake temperatures returned to below 20 °C. Other watercourses were found to have lower water temperatures than the Mount Nugent, such as in the R. Inny where temperatures were 2-3 °C lower than the Mount Nugent on the same day - this is to be expected as the River Inny is spring fed, and this results in lower water temperatures.

## Timeline of events



Figure 4. Timeline of events

## Fish data

A representative sample of fish were retained and the following information was collected from the fish; lengths, weight, sex, maturity, scale samples and genetic tissue.

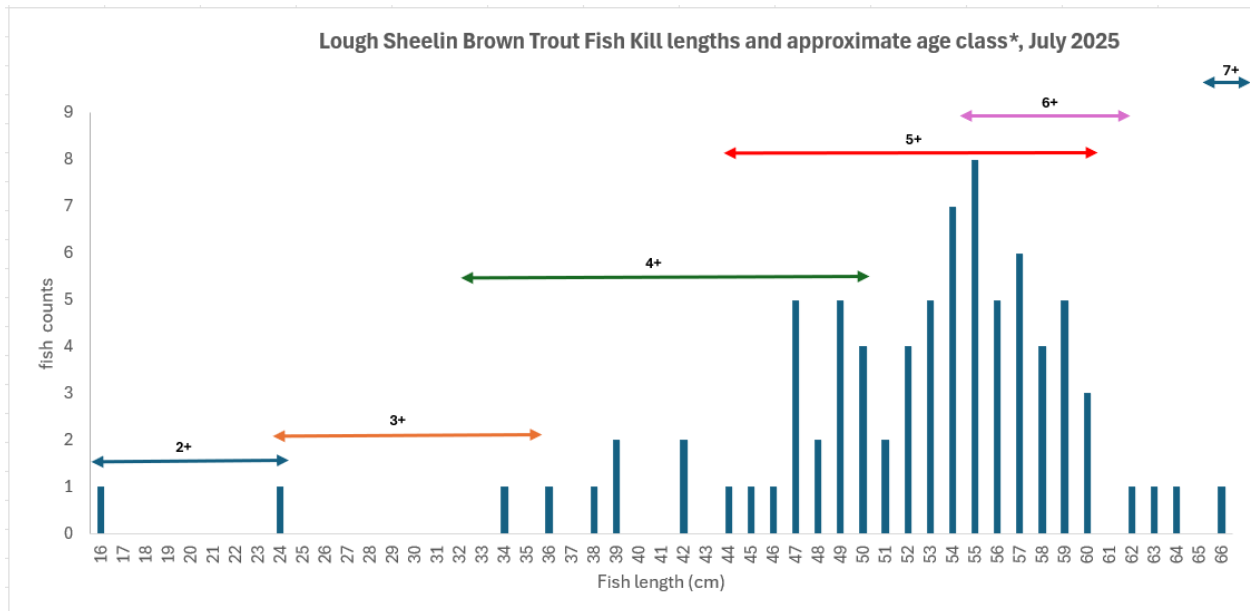


Figure 5. Length Frequency distribution of 81 fish recovered from the Lough Sheelin fish kill, with age estimation applied using data from previous surveys. Provided by Karen Delanty, IFI Research.

\* Age class based on data from IFI Lough Sheelin surveys (2000 - 2021)

The upper size ranges of the fish, particularly those between 4+ and 7+ indicate lake fish rather than river fish, and it is likely that they would have been resident in the lake and moved into the river at this time, rather than resident in the river. The density of large fish recovered within the lower reaches of the Mount Nugent was very high.

Seventy nine percent of a sample of 62 trout (which were in condition to be sexed) were female.

A detailed brown trout genetic stock identification of the Lough Sheelin population was carried out in 2011-2012 (Delanty *et al.*, 2021 - [Sheelin Report](#)). As part of that study the juvenile baseline population structure of the Lough Sheelin trout stock was determined. The data from the study was available to the July fish kill investigation. Juvenile baseline genetics allows for the genetic stock identification of adult fish, i.e. adult brown trout can be assigned to their baseline population and therefore their spawning river.

A total of 81 brown trout tissue samples were collected for genetic analysis from the fish kill mortalities. These samples were sent to Queens University Belfast for analysis (partners of

the original Lough Sheelin trout genetic study). DNA was extracted from all 81 samples, however only 59 samples yielded high quality data useable for analysis. The results from these samples is provided in Table 1. below.

Table 1. Genetic Stock Identification of Adult samples, Lough Sheelin, July 2025

<b>Best Assignment</b>		
<b>Baseline Source - Reporting Group</b>	<b>Number samples</b>	<b>%</b>
Mount Nugent / Crover	55	93.2
Upper Inny	3	5.1
Not Assigned	1	1.7
<b>Total</b>	<b>59</b>	<b>100</b>

The results obtained are in line with the earlier genetic study in which the Mount Nugent / Crover reporting group (very little difference in genetic structure between the Mount Nugent and Crover juveniles and so are presented as a reporting group) was identified as the most important contributor to the adult lake stock (60.3%) and then the Upper Inny (13.8%). Given the location of the fish kill samples used in the current genetic analysis it is not surprising that a higher percentage of adult fish were identified as Mount Nugent / Crover fish but also interesting to note some Upper Inny fish present there also.

## **Lough Sheelin Environmental and Fish Monitoring**

This report should be read in conjunction with Appendix 1. “Preliminary Data Synthesis Report: Lough Sheelin Environmental and Fish Monitoring”, (Walsh et al, 2025) which gives details of the data collected by IFI’s remote sensors in Lough Sheelin and the Mount Nugent River and provides an explanation and interpretation of this data.

Inland Fisheries Ireland has a data buoy, remote sensors, acoustic listening stations (with temperature loggers) and a weather station situated in Lough Sheelin and its catchment.

A data buoy is located at the deepest point of the lake, which measures water temperature at depths of 0.5, 2.5, 4.5, 6.5, 8.5, 10.5 and 12.5 metres from the surface, conductivity (uS/cm), dissolved oxygen (mg/L), temperature, and Chlorophyll-a fluorescence (ug/L) is measured at 0.5 m below the water surface every 10 minutes. Data loggers measure dissolved oxygen (D.O.) and temperature adjacent to the data buoy every 10 minutes at three depths: surface

(0.5 m), middle (6.5 m), and bottom (12.5 m) and at 0.5m below the surface in four shallow bays around the lake: North (1. Captain's Bay), South (2. Sailors Garden), East (3. Curry Point - Inchacup), and West (4. Chambers' Bay).

An IFI environmental monitoring station is located in Mount Nugent Village close to the Environmental Protection Agency (EPA) hydrometric station (EPA, 2021) with established ratings curves, which is over 2 km upstream of where the dead fish were found (Fig. 1). A dissolved oxygen data logger records D.O. and temperature every 10 minutes and a water quality monitoring device records water temperature (°C), D.O. (mg/L), pH, turbidity (NTU), and conductivity (uS).

Meteorological data (including air temperature and rainfall) are recorded at 15-minute intervals from an automated weather station at the Inland Fisheries Ireland base at Lough Sheelin. Further information on these loggers can be found in Appendix 1. (Walsh et al., 2025).

A fish tracking project was initiated on Lough Sheelin and its tributaries in April 2023 to investigate the impacts and extent of climate change, environmental change and extreme weather events on fish populations. It is of note that the fish tracking acoustic receiver is located c. 500 m upstream of the lake on the Mount Nugent and also monitors temperature, this is very close to the upstream limit of the fish kill.

Further details on the aforementioned projects can be found in Preliminary Data Synthesis Report: Lough Sheelin Environmental and Fish Monitoring.

## **IFI electrofishing operations**

Stock management electrofishing operations for pike were underway on the 14<sup>th</sup> and 15<sup>th</sup> of July 2025 and from 9am-11am on the 16<sup>th</sup> July in Sailor's Garden, Lough Sheelin. Boom boat testing (with 1 boom deployed) was carried out on Monday 14<sup>th</sup> July on Sheelin for less than 1 minute (immediately outside the harbour wall in Kilnahard).

IFI Research electrofishing operations were undertaken at a total of five sites / zones using boom boat electrofishing (2 sites in Chambers' bay and 1 site at Orangefields, Watty Rock and North of Chambers' bay) to target cyprinid fish in marginal, shallow areas, particularly tench (*Tinca tinca*). Electrofishing was carried out in an intermittent fashion, targeting areas where tench might be encountered. The electrofishing gear was activated for a maximum period of 10 seconds if no target species were seen.

These electrofishing operations were located on the West side of the lake over 3.5 km away from Captains Bay and the Lower Mount Nugent River, which are located to the Eastern side of Lough Sheelin. The electrified field generated during these operations is very limited and extends only metres from the boat.

## **Weather and Climate information**

Met Éireann noted that the persistent warmth seen in June, July and August 2025 was driven by a combination of factors, with climate change being an underlying driver. Met Éireann also noted that warmer nights during summer 2025 were a critical factor in pushing the overall mean summer temperature higher (Met.ie, 2025).

July 2025 was the warmest month of 2025 so far and the hottest July since 2021 (which had a mean temperature of 16.83 °C). July 2025 was the 9<sup>th</sup> warmest July and 12<sup>th</sup> warmest of any month in 126 years of records (*using the Island of Ireland dataset\**), with an average temperature of 16.59 °C, which is 1.74 °C above the 1961-1990 long-term average (LTA) for July and 1.21 °C above the more recent 1991-2020 LTA (met.ie). Continuing the recent warmer-than-normal monthly trend, this was the 5<sup>th</sup> consecutive month with temperatures in the respective top 9 averages on record in 126 years of records (met.ie).

Ireland has been impacted by hot and dry weather spells, with unprecedented low flows this summer and since last September. Ballyhaise annual rainfall records were examined from 2022-2025 and compared with Long Term Averages, see Table 2. Low cumulative rainfall as seen at the Ballyhaise station, for the Summer as back as far as September 2024, represented a 29% reduction on the same 11 months in the previous year. A cumulative total of 712.9 mm of rainfall from September 2024-end July 2025, compared with September 2023 to July 2024 of 1002.3 mm. The year to July 2025 cumulative rainfall including Jul is 815.9 mm when compared with the long-term average of 1021.9 mm.

Table 2. Total rainfall in millimetres for BALLYHAISE (Source Met.ie)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2025	61.2	75.9	20.4	93.9	52.1	115.2	40.7	59.7	109.5	n/a			628.6
2024	62.0	86.8	136.8	98.0	32.4	40.9	61.2	103.0	47.3	62.7	68.5	75.0	874.6
2023	92.7	26.5	130.3	83.6	52.0	94.7	154.7	134.2	127.9	129.2	89.7	137.4	1252.9
2022	43.7	122.9	32.7	62.6	76.0	76.2	39.5	52.0	135.8	205.2	118.1	84.2	1048.9
LTA	98.3	80.1	77.3	70.0	65.5	72.2	83.7	92.6	77.7	97.8	100.5	106.2	1021.9

The EPA’s hydrograph (Figure 6.) and hydrological bulletin for July 2025 shows Lough Sheelin lake levels were below normal, ).

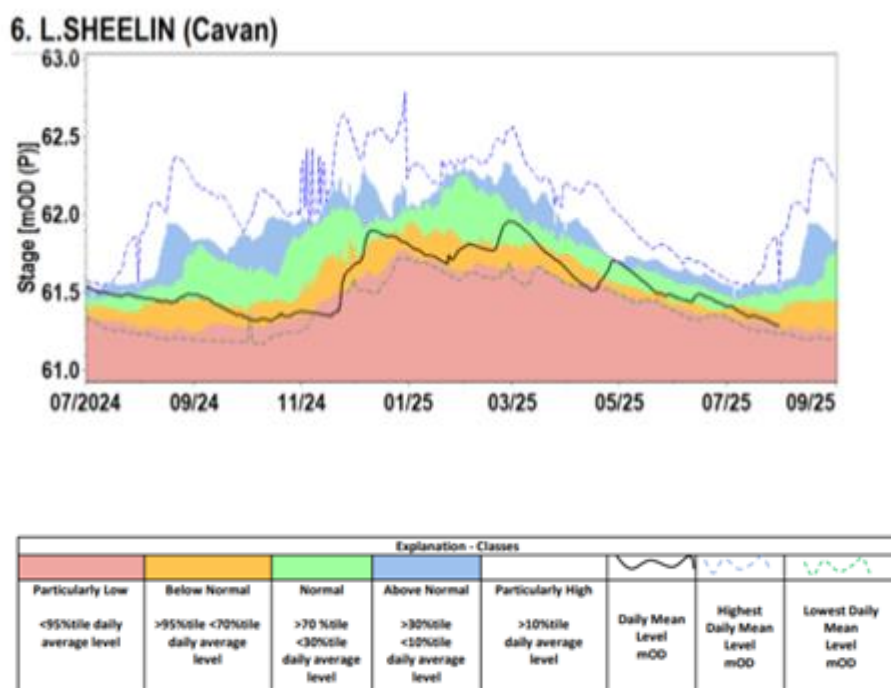


Figure 6. Lake Level Hydrograph for Lough Sheelin (EPA.ie)

Of particular note were the excessive air temperatures experienced the weekend prior to the fish kill with recorded temperatures reaching 27 °C. On the 12<sup>th</sup> July a record air temperature for Ireland for the year to date of 31.1 °C was set in Mount Dillon, Co. Roscommon (62 km away), this was Mount Dillon’s 2nd highest maximum temperature on record, and the highest

temperature recorded in Ireland since Friday 12th August 2022. July's rainfall as measured at Ballyhaise, Co. Cavan was 49% of 1991-2020 Long-Term Average (LTA) rainfall values and was the month's lowest monthly rainfall total of 40.7 mm for the country.

## **Discussion**

Water temperatures in excess of 21 °C were experienced and measured by the data logger in Captain's Bay (which is tending towards lethal for trout). The heavily weeded bay, and lower section of the Mount Nugent would lead to substantial diurnal oxygen variation believed to have played a key role in the death of the larger trout. Larger fish experience more physiological stress due to increased energy and metabolic requirements, have a higher oxygen demand and are more susceptible to reductions in dissolved oxygen levels.

It is common for dissolved oxygen reductions to occur in a time lag behind increased temperatures. The prolonged period of low flows, dry weather and high temperatures prior to the fish kill would place fish under significantly increased physiological stress.

Water levels were very low in the Mount Nugent River from early July. Water temperatures in the lower Mount Nugent river exceeded 20°C from shortly after midday on the 12<sup>th</sup> July and exceeding 21 °C from 6.20 pm that day until 9.40 pm on Mon 14<sup>th</sup> July. Temperatures began to slowly drop below 20 °C after this date. This monitoring station is upstream of where the majority of dead fish were recovered. It is worth noting that lake water temperatures did not drop as quickly. Water temperatures in Captain's Bay were in excess of 20°C for much of the time period from the evening of 9<sup>th</sup> July-20<sup>th</sup> July, with temperatures on the 10<sup>th</sup> July reaching and exceeding 23°C , exceeding 22°C on the 12<sup>th</sup> July and exceeding 21°C on the 11<sup>th</sup>, 13<sup>th</sup> and 16<sup>th</sup> July.

Increased temperatures result in lower dissolved oxygen levels within the water. This starts to become critically important for trout at water temperatures in excess of 20 °C. The levels of aquatic vegetation in the river can also impact on dissolved oxygen levels, reducing them further at night-time when respiration occurs consuming oxygen, but photosynthesis does not. Fish, and in particular wild brown trout, are susceptible to high temperatures. Temperature affects their physiology because they are ectotherms, relying on their environment to maintain a healthy body temperature.

Key physiological processes which impact stress and survival are influenced by temperature and oxygen consumption. Fish consume more oxygen at higher water temperatures.

For brown trout, growth and feeding limitations occur 18-19°C, metabolic stress is induced >20°C, and lethal water temperatures are 22-25°C with mortalities occurring at 26°C (Elliott & Elliott, 2010). Elliot (1994) states that death is a function of exposure time to thermal stress, it is believed that sustained values exceeding 20 °C induce significant physiological stress and increase mortality risk (Matson and Kelly, 2024). Figure 7. shows the thermal requirements of Brown Trout (Elliot, 1981).

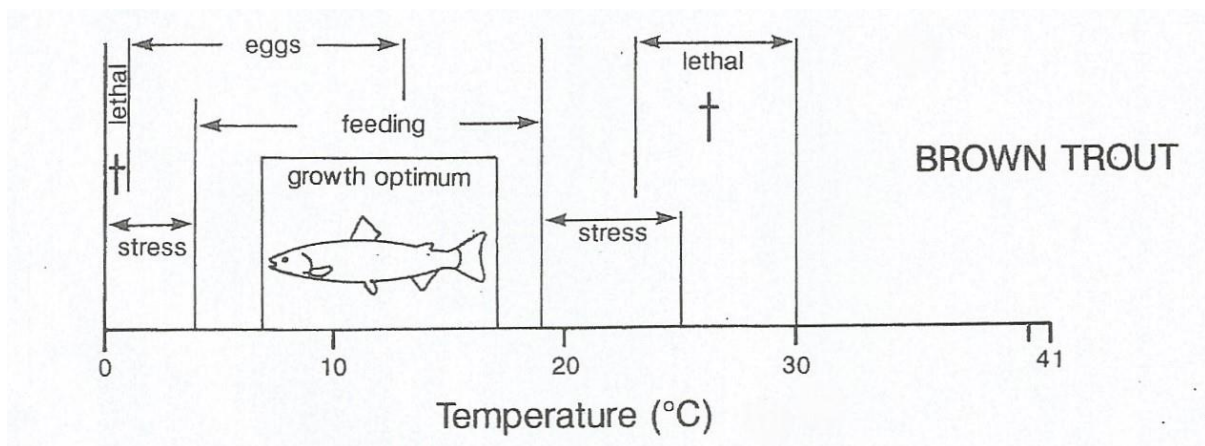
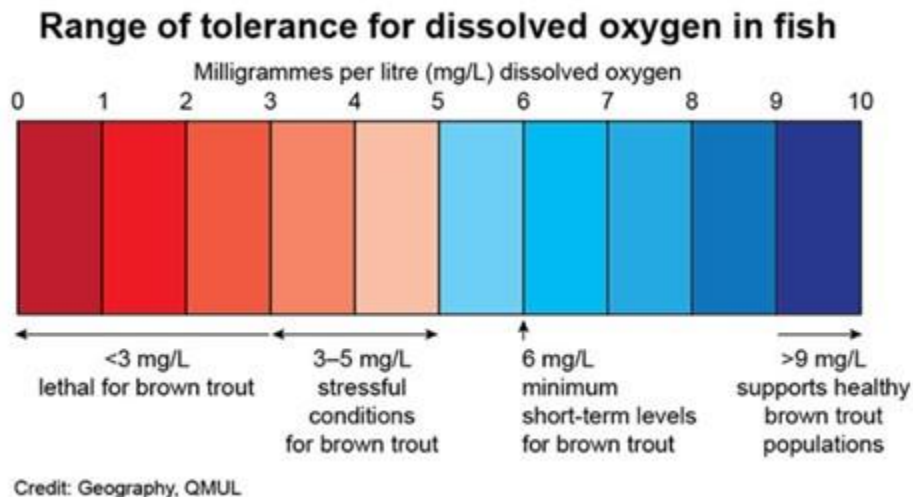


Figure 7. Thermal Requirements of Brown Trout (Elliot, 1984).

Increased temperatures also affect the solubility of oxygen. For example, water at 5 °C can hold a maximum of 12mg/l (100% saturation) of oxygen, whereas water at 20 °C can hold a maximum of only 9.1mg/l (100% saturation). Consequently, less oxygen is available to organisms at higher water temperatures (Environmental Agency, 2000b). Dissolved oxygen thresholds are critical for salmonids, for brown trout, a dissolved oxygen level of less than 7 mg/l induces mild stress, whilst less than 5 mg/l moderate stress, and less than 3 mg/l causes severe or lethal stress (Kelly & Kelly, 2024). Alabaster and Lloyd give 6-9 mg/l dissolved oxygen as the requirements for brown trout (Alabaster and Lloyd, 1982).



*Figure 8. The sensitivity of brown trout to different concentrations of dissolved oxygen in water*

In eutrophic systems, daily algal cycles (photosynthesis and respiration) further amplify D.O. fluctuations, leading to supersaturation during daylight, followed by sharp nocturnal declines, heightening deoxygenation risk during warm, low-flow periods when oxygen demand is high (Kelly and Kelly, 2024).

Increasing water temperatures may affect a range of other environmental conditions which have the potential to cause harm and have an impact on fish at temperatures that fall well short of the lethal levels defined.

Moreover, dissolved oxygen may become a major issue in warm water because:

- the solubility of oxygen in water falls as temperatures rise, so air saturation levels are lower;
- oxygen-consuming processes, such as decay of vegetation, are accelerated at higher temperatures; and
- the ability of most species to withstand depleted levels of oxygen is reduced at elevated temperatures (Solomon and Lightfoot, 2008).

Many of the brown trout mortalities and both pike had a large body size and were females with maturing eggs which will lead them to be more susceptible to physiological stress.

The dissolved oxygen logger in Captain's Bay showed a decline in dissolved oxygen levels on the 16<sup>th</sup> July, with a drop in DO levels to as low as 2.9 mg/l for a period of up to 2 hours from 10 am that day. At the same time water temperature Captain's bay was above 20 °C and reached a temperature above 21 °C during this period.

The data buoy logger records a drop in dissolved oxygen in the middle layer of the lake on 14<sup>th</sup> and 16<sup>th</sup> July, likely associated with diurnal biological activity. However, on the 16<sup>th</sup> of July, D.O. in the middle layer of the lake dropped below 6mg/l intermittently for a period of over 6 hours from 5 am onwards, dropping below 3mg/L, reaching a minimum of 2.1mg/L at 10:00, recovering to above 7mg/L within two hours, suggesting a short-lived but potentially stressful or lethal low-oxygen event. The trout would tend to occupy the middle layer in such high temperatures as the surface temperature was higher and the lower layer tends to be deoxygenated.

The dissolved oxygen levels in the Mount Nugent River (at the village, upstream of the fish kill) were demonstrating quite significant diurnal variation in oxygen levels since 9<sup>th</sup> July with the general trend moving downwards with each oscillation, it dipped below 5 mg/l on 14<sup>th</sup> July, between 5 am and 9.15 am and experienced a decline below 5 mg/l between 21.45pm on 15<sup>th</sup> July and 7 am on the 16<sup>th</sup> July, with a low of 2.9mg/L at 01:00 on the 16<sup>th</sup> July. It is likely that these conditions were replicated or possibly worse downstream in the lower Mount Nugent due to the extensive aquatic plant growth in that section.

## Summary

The sheer density of fish (based on the mortalities of over 800 large trout over c. 580 m of river) would be likely to cause survival problems for the fish in such reduced dissolved oxygen levels.

The size and species range of the dead fish recovered suggests a partial fish kill which primarily impacted large trout. Only seven fish of other species were recovered. The upstream limit of the fish kill was in the Mount Nugent River c. 580 metres upstream of the lake. Two female large pike were recovered at 57 and 60 cm in length. Previous acoustic tagging studies suggest that movements of fish towards inflowing streams is apparent when the lake temperatures become isothermal (i.e. its temperature profile does not vary with water depth in the deeper parts of the lake) and that the distance of the fish from the inflows reduces during heat waves. (Barry, *pers comm*). This is supported by the entry of three of the tagged trout to the Mount Nugent between 3<sup>rd</sup> and 14<sup>th</sup> July.

Research studies have shown that when the lake changes from being stratified to a mixed state that fish start to move around the lake and seek refuge, moving to shallower waters (Barry *pers comm*). The lake changed from the 14-16<sup>th</sup> July from being stratified to mixed with winds on the 14<sup>th</sup> believed to have stimulated this change while the rainfall event on the

14/15<sup>th</sup> July may have further driven this turnover. Local weather stations recorded rainfall events on the 14<sup>th</sup> and 15<sup>th</sup> July, IFI's weather station at Kilnahard, North Western Lough Sheelin measured 21.8 mm on 15<sup>th</sup> July, while the Met Eireann Ballyjamesduff station, which is in the Upper Mount Nugent Catchment measured 15.2 mm and 5.3 mm on 14<sup>th</sup> and 15<sup>th</sup> July respectively.

The size and age class of the large brown trout suggests that they are lake fish, rather than resident Mount Nugent fish, which had moved up into the lower reaches of the Mount Nugent River, likely seeking thermal refuge. It is not known when these fish moved from the lake or Captain's Bay into the Mount Nugent but tagged fish appeared in the Mount Nugent from the 3<sup>rd</sup> of July.

With the exception of those fish which had sunk and floated back to the surface whilst decaying, the fish were in good condition with no marks or fungus evident. They did however have open flared gills suggesting that they suffered oxygen deprivation before death. Live fish were noted in Captains Bay and Mount Nugent village on 17<sup>th</sup> July during walkovers and inspections by boat. Live trout were also seen rising by IFI Officers in the Mount Nugent River downstream of the wastewater treatment plant on 19<sup>th</sup> July. An IFI research survey for the Water Framework Directive on 19<sup>th</sup> August 2025 in Mount Nugent village captured 223 largely juvenile fish of mixed size range and species, including 116 trout.

A fish kill caused by a pollutant or point source would typically kill a larger range and mix of fish species and a larger range of trout sizes as the survey indicated are present in the river.

The lower reaches of the Mount Nugent are characterised by weeded berms and silty bed. Captains Bay is a weeded inlet dominated by water lily (see Figures 9. to 12.).

The surface temperature on the lake was in excess of 21 °C on 16<sup>th</sup> July, following a prolonged period of lake temperatures in exceeding 20 °C in Captains Bay.



*Figure 9. Captains Bay inlet, shallow and dominated by water lily.*



*Figure 10. Lower Mount Nugent River vegetative growth encroaches on the channel.*



*Figure 11. Lower Mount Nugent River*

## **Conclusion**

Following an extensive investigation and review of available data, IFI is of the opinion that this fish kill was caused by prolonged high water temperatures and low levels of dissolved oxygen in both the lake and river. These were exacerbated by a number of factors specified below:

834 dead fish were recovered during the fish kill investigation. Given the thorough on site investigations, it is believed only a small percentage of dead fish may not have been recovered.

The presence of excessive weed, silt and grasses in the lower Mount Nugent adding to the dissolved oxygen pressures, particularly at night time, when respiration occurs, but photosynthesis does not.



Figure 12. Lower Mount Nugent River, considerable in channel weed growth.

The Lough Sheelin catchment has a long history of water quality issues and nutrient loadings to the lake and rivers from surrounding lands and soils, nutrient enrichment was a contributing factor in combination with the other issues already described (high water temperatures and low dissolved oxygen). Eutrophication is a state or a response to increased nutrient levels (i.e. the enrichment of water) causing accelerated or unwanted growth of microscopic algae or plant life (Kerins et al, 2007), the trophic status of Lough Sheelin and the contribution of nutrients from the Mount Nugent stream from a range of sources are an additional pressure. It must be emphasised that the investigation yielded no evidence of direct pollution discharges occurring within the impacted area or immediately upstream.

Kelly and Kelly (2024) found that fish kills resulting from high temperatures and drought whilst rare, often coincide with a complete absence of thermal refugia as the temperature data suggests. They also suggest that mortalities attributable to high temperature probably happened when other pressures also existed, such as nutrient enrichment (eutrophication) and it was potentially the increase in water temperature and low water levels that compounded the effect of the underlying water quality problem (Kelly and Kelly, 2024).

Lake levels were below normal and rainfall for the month (at Ballyhaise) was 49% of long term average for July and the lowest of the range within the Country's gauges, resulting in low river flows.

The high density of large fish in such a short stretch of river, the body size of these fish and the fact many were female with maturing eggs added additional physiological stress to the fish.

The absence of a thermocline within the lake and the associated fish movements of lake fish into the riverine environment in search of thermal refuge.

In the days preceding the fish kill both temperature and dissolved oxygen (in both the lake and the river) were within or above the critical range.

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## **Appendix 1.**

Preliminary Data Synthesis Report: Lough Sheelin Environmental and Fish Monitoring. National Research Survey Programme, Walsh, A., Barry, J., Treanor, N., Kelly, S. and Kelly, F.L. (2025).

# Preliminary Data Synthesis Report: Lough Sheelin Environmental and Fish Monitoring

July 2025

IFI/2025/1-4784



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# **Preliminary Data Synthesis Report: Lough Sheelin Environmental and Fish Monitoring - July 2025**



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

CITATION: Walsh, A., Barry, J., Treanor, N., Kelly, S. and Kelly, F.L. (2025). Preliminary Data Synthesis Report: Lough Sheelin Environmental and Fish Monitoring. National Research Survey Programme, Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24.

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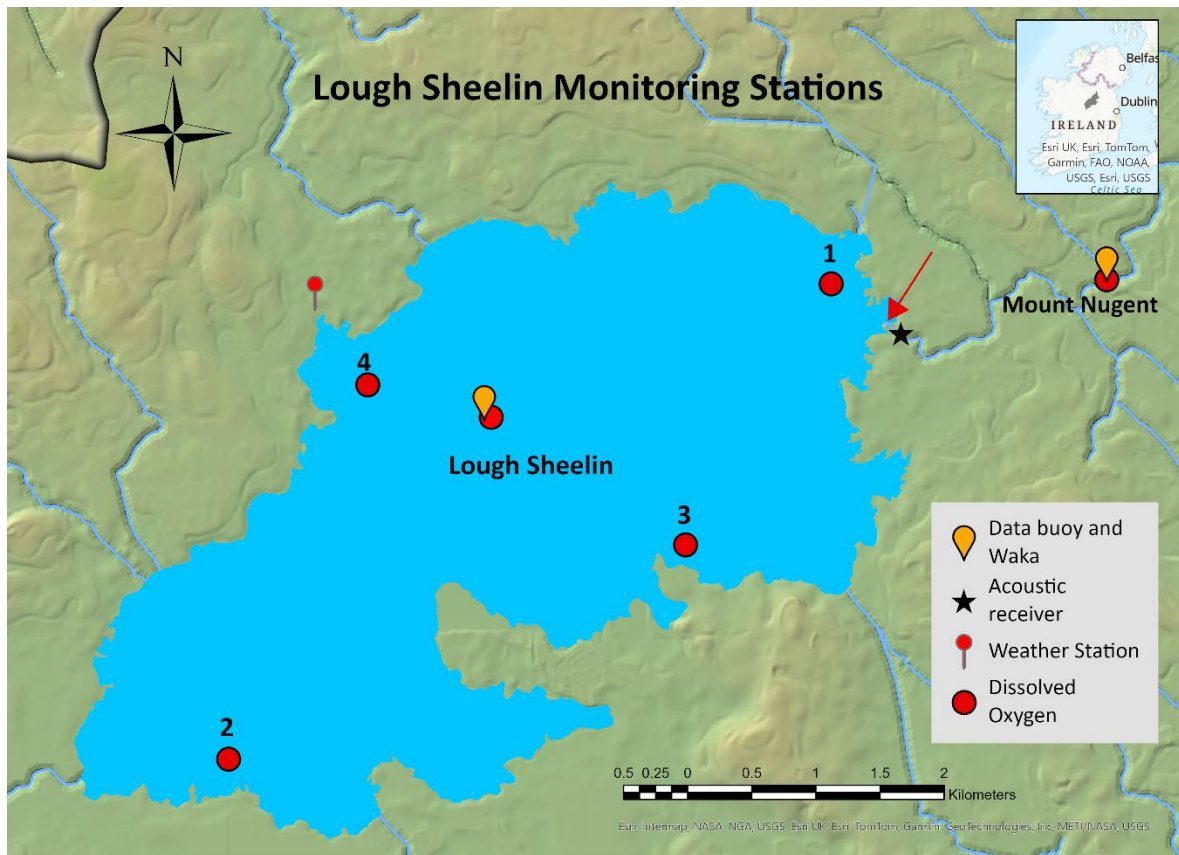
# 1. Background

IFI received a report of a fish kill in Captain's Bay, Lough Sheelin, Co. Cavan on the 16th of July (Fig. 1). IFI recovered 834 dead fish, mainly large wild brown trout (*Salmo trutta*), from Captain's Bay and the lower reaches of the Mounnugent River (just upstream of the lake), following the incident. IFI research was requested to compile data from high-frequency data loggers deployed in the catchment for the Climate Change Mitigation Research Programme and the OPW-funded Research Programme by IFI SHRBD for July 2025 to inform the ongoing fish kill investigation. This report synthesises the meteorological, environmental and fish tracking data collected from Lough Sheelin and the Mounnugent River in July 2025, with a focus on 14th to 18th July.

## 1.1 Introduction

As part of Inland Fisheries Ireland's Climate Change research programme, the Upper Inny and Lough Sheelin catchment was designated as a sentinel site in 2021 to investigate lake – catchment interactions under changing climatic and environmental conditions. The two main inflowing tributaries (Upper Inny and Mounnugent) and the Inny outflow (Finea) of Lough Sheelin were selected as dissolved oxygen (D.O.) and temperature monitoring sites to help assess the influence of tributaries and outflow conditions on overall lake dynamics. Such monitoring is fundamental for understanding how external inputs and water exchanges shape the lake's oxygen and temperature dynamics (oxythermal structure) and overall ecological resilience. In 2023, as part of the above projects, the Lough Sheelin Fish Tracking Project was initiated to build on this work, investigating fish behavioural responses to environmental and climate change within the lake and its tributaries during extreme events.

For brown trout, growth and feeding limitations occur at 18-19°C, metabolic stress is induced >20°C, and lethal water temperatures are 22-25°C with mortalities occurring at 26°C (Elliott & Elliott, 2010). As oxygen solubility declines with temperature, dissolved oxygen thresholds are also critical for cold-water fish. For brown trout, D.O. <7 mg L<sup>-1</sup> induces mild stress, <5 mg L<sup>-1</sup> moderate stress, and <3 mg L<sup>-1</sup> severe or lethal stress (Kelly & Kelly, 2024). In eutrophic systems, daily algal cycles (photosynthesis and respiration) further amplify D.O. fluctuations, leading to supersaturation during daylight, followed by sharp nocturnal declines, heightening deoxygenation risk during warm, low-flow periods when oxygen demand is high (Kerins et al., 2007).



**Fig. 1: Map of Lough Sheelin showing dissolved oxygen monitoring sites (red dots), the Mountnugent multiparameter IoT water quality device and data buoy (including multiparameter water quality meter)(orange balloon symbols), the Mountnugent acoustic receiver (black star), location of fish kill July 2025 (red arrow), and the IFI weather station (red pin).**

## 2. Methodology

### 2.1 Study area

Lough Sheelin is a high alkalinity lake located in the Drumlin belt of the central-northern part of Ireland and situated on the upper reaches of the Inny River, a tributary of the River Shannon. The largest proportion of the catchment lies within Co. Cavan with the remainder divided between Co. Meath and Co. Westmeath. Low permeability gley soils, vulnerable to waterlogging and nutrient loss, predominate in the northern and western parts of the catchment. Deep, well-drained brown podzolics, grey-brown podzolics and brown earths are predominant in the eastern sub-catchments, while the soils closer to the lake shore around the Inny outlet are composed of blanket and basin peats.

The lake's trophic status has been well documented (e.g. Flanagan and Toner, 1975; Champ, 1991, 1993, 1998, 2003; Duggan and Champ, 1992; Kerins *et al.*, 2007). The annual mean total phosphate value for Lough Sheelin over a 45-year period (1976 to 2022) was 0.29µg/l indicating the lake has been

generally mesotrophic during the monitoring period. There were signs in the 80's (1982 to 1984 and 1987 to 1991 and late 90s (1993 to 2000) that the water quality in the lake was improving (possibly because of a slurry export scheme (1981-1984) and other mitigation measures); however between 2000 and 2022 (excluding 2017, 2018 and 2019) TP remained at  $\geq 0.024$  ug/l, indicating moderate status and no improvement in water quality. Overall, from 1976 to 2022, 60% of monitoring years equalled or exceeded the environmental standard for good water quality (0.025 ug/l P) and since 2001 the EQS for good status based on TP has been exceeded 16 times (73%) (de Eyto *et al.*, 2024).

Additionally, in the most recent EPA Catchment Assessment (2024), water quality in the Upper Inny sub-catchment remains under pressure, with nutrient inputs, particularly phosphorus, continuing to drive eutrophication risk in Lough Sheelin.

## 2.2 Lough Sheelin Meteorological Data

Meteorological data (including air temperature and rainfall) are recorded at 15-minute intervals from an automated weather station (Davis Vantage Pro 2) at the Inland Fisheries Ireland base at Lough Sheelin (Plate 1). As the weather station is in a sheltered area, wind data was obtained from the Ballyhaise Met Éireann station (Met Éireann, 2025).



**Plate 1: Weather station installed at Inland Fisheries Ireland Lough Sheelin base, transmitting meteorological data in near real-time.**

## 2.3 Lough Sheelin Environmental Monitoring

A data buoy is located at the deepest point of the lake (Fig. 1 and Plate 2). This consists of a monitoring platform housing an internal datalogger and telemetry system that records and uploads measured data in near real-time. The system comprises a thermistor array with seven water temperature ( $T_w$ ) loggers recording water temperature every 10 minutes at depths of 0.5, 2.5, 4.5, 6.5, 8.5, 10.5 and 12.5 metres (NexSens TS210). The buoy is fitted with a multiparameter water quality meter recording water temperature ( $^{\circ}\text{C}$ ), conductivity ( $\mu\text{S}/\text{cm}$ ), dissolved oxygen ( $\text{mg}/\text{L}$ ) and chlorophyll- $a$  fluorescence ( $\mu\text{g}/\text{L}$ ) at 0.5 m below the water surface every 10 minutes. Data is logged internally within the datalogger and transmitted via the same telemetry system as the water temperature data to a web portal, allowing visualisation of water quality parameter data (Plate 2). Calibrated (offline) D.O. loggers (HOBO U26-001) are deployed adjacent to the buoy, recording both D.O. and temperature every 10 minutes at three depths: surface (0.5 m), middle (6.5 m), and bottom (12.5 m). Identical D.O. logger setups are also deployed 0.5m below the surface in four shallow bays around the lake (HOBO U26-001 loggers): North (1. Captain's Bay), South (2. Sailors Garden), East (3. Curry Point - Inchacup,,) and West (4. Chamber's Bay). This integrated monitoring network provides a high-resolution, spatial dataset on thermal and oxygen dynamics in Lough Sheelin and selected tributaries (Fig. 1).



**Plate 2: Data buoy platform installed on Lough Sheelin. Stored inside is a multi-depth thermistor chain surface to bottom (0.5, 2.5, 4.5, 6.5, 8.5, 10.5 and 12.5), and multi-parameter sonde at the surface (0.5m) recording temperature, dissolved oxygen, conductivity, and chlorophyll-a. Data transmits in near real time every 10 minutes to an online dashboard.**

## 2.4 Mounnugent River– Environmental Monitoring

The Mounnugent River (MN) flows into the northeastern end of Lough Sheelin and is the primary inflow to the lake, with a catchment area of 95 km<sup>2</sup> and a mean discharge rate of 1.7 m<sup>3</sup> s<sup>-1</sup>. The MN provides the largest spawning area in the Lough Sheelin sub-catchment and contributes approximately 60% to the overall lake brown trout adult stock in the lake (Delanty *et al.*, 2020). Agriculture is the predominant land use category (>90%) in the Mounnugent sub-catchment. The Mounnugent catchment is the largest inflow tributary and has the highest source of phosphorus to Lough Sheelin and has been assigned a “Poor” water quality status (EPA, 2021).

The IFI environmental monitoring station on the Mounnugent is located close to an Environmental Protection Agency (EPA) hydrometric station with established ratings curves and upstream of where dead fish were found (Fig. 1) (EPA, 2021). A calibrated U26-001 HOBO dissolved oxygen data logger with an anti-fouling guard in protective housing was deployed in 2021 at the site, recording D.O. and temperature every 10 minutes. A multi-parameter IoT water quality monitoring device (Plate 3) recording water temperature (°C), D.O. (mg/L), turbidity (NTU), and conductivity (uS), was deployed in summer 2024. During the summer period, the sensors on this device were cleaned every two weeks and swapped for a calibrated device every eight weeks. Stream flow data was obtained from the EPA online portal from the Mounnugent Bridge - Station number 26056 ([EPA - WISKI Web Public](#)). As part of the Fish Tracking project, water temperature from an acoustic receiver near the outflow of MN was also incorporated into the review of environmental parameters in July 2025.



**Plate 3: Multi-parameter IoT device floating in the Mount Nugent. Sensors include temperature, dissolved oxygen, pH, turbidity, and conductivity. Data transmits to an online dashboard in near real time, every 15 minutes.**

## 2.5 Fish tracking project

A fish tracking project was initiated on Lough Sheelin and its tributaries in April 2023 to investigate the impacts and extent of climate change, environmental change and extreme weather events on fish populations. In 2023, 12 acoustic receivers were deployed throughout the lake, along with two additional units in inflowing tributaries and one in the outflowing river. In 2024, seven additional acoustic receivers were added to improve spatial coverage (Fig. 2).

To date, 88 fish have been sampled, comprising 74 brown trout (*Salmo trutta*) collected by rod-and-line angling, and 14 coarse fish (4 pike *Esox lucius* and 10 tench *Tinca tinca*) obtained via boom-boat electrofishing. Tagged fish have been implanted with acoustic transmitters since May 2023 on Lough Sheelin (Barry *et al.*, 2024). All tagging procedures were conducted in accordance with ethical guidelines and were approved by the Health Products Regulatory Authority of Ireland (Project number: AE19118/P011).



**Fig. 2: Active Lough Sheelin acoustic receiver array in 2025.**

## 3. Results

### 3.1 Lough Sheelin Meteorological data

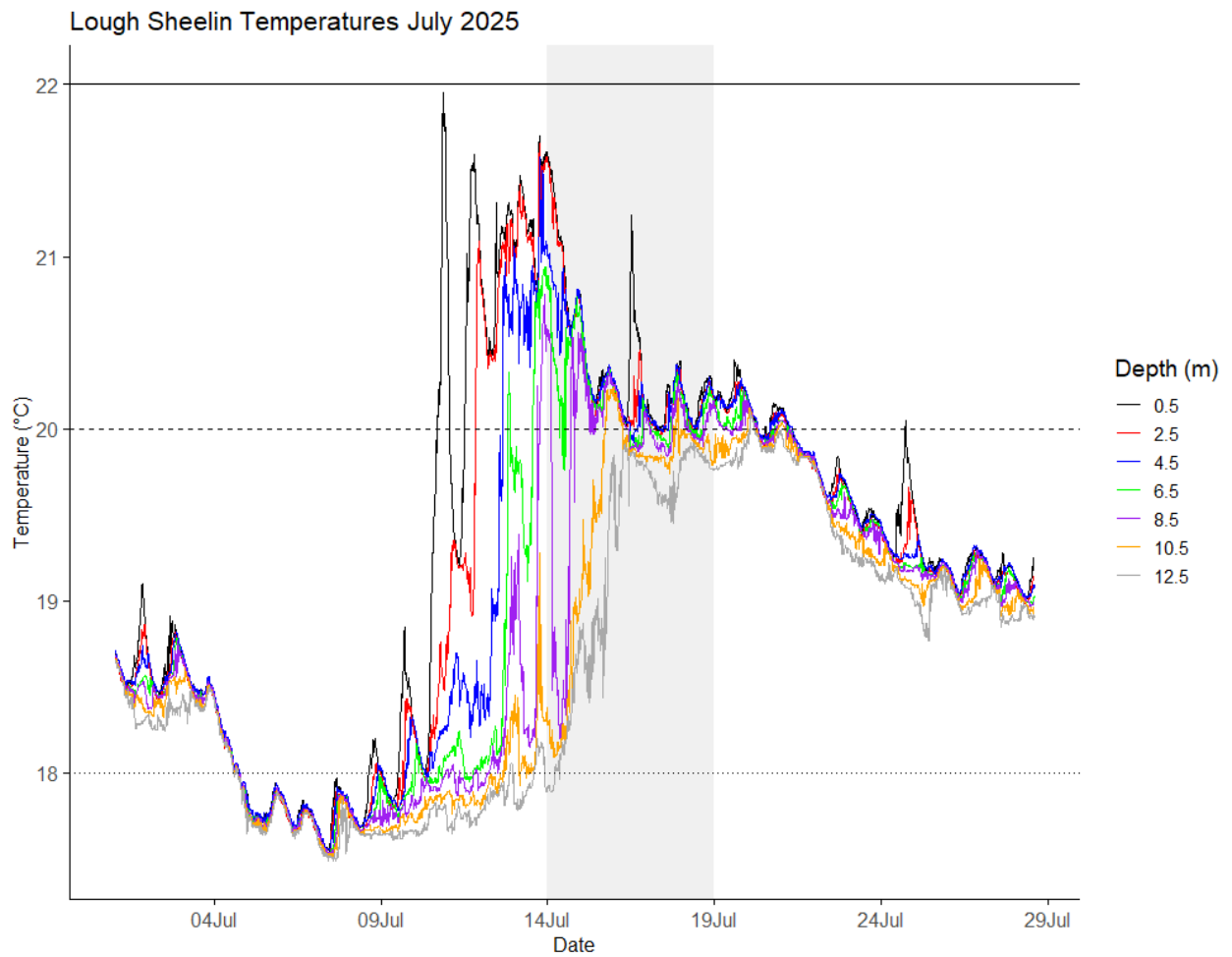
The lowest air temperature was 7.7°C recorded at 03:00 on the 3<sup>rd</sup> of July, after which conditions gradually warmed. The warmest day of the month was the 12<sup>th</sup> of July, air temperature exceeded 27°C for more than six consecutive hours (12:00-19:00), with a maximum temperature of 29.3°C at 15:00. A subsequent cool period occurred on the 16<sup>th</sup>, when air temperature dropped to 8.6°C in the early morning. Solar radiation follows a diurnal pattern, with values typically peaking around midday. The maximum solar radiation was 831.25 (W/m<sup>2</sup>) at 12:00 on the 10<sup>th</sup> of July. Hot and sunny conditions dominated in early July, whereas both air temperature and solar radiation were suppressed during mid-July, reflecting a spell of cloudier and unsettled weather.

A rainfall event occurred on the 15<sup>th</sup> of July, with 21.8 mm recorded at the IFI Lough Sheelin weather station. This coincided with marked hydrological and D.O. changes in the river and lake (Fig. 5 and Fig. 8). Wind data from the Ballyhaise station show variable wind speeds throughout July, with frequent gusts above 8 m/s in the first half of the month and a general decline towards late July. Wind direction was predominantly from the west and southwest, often exceeding 6 m/s, which likely enhanced surface mixing during and after rainfall.

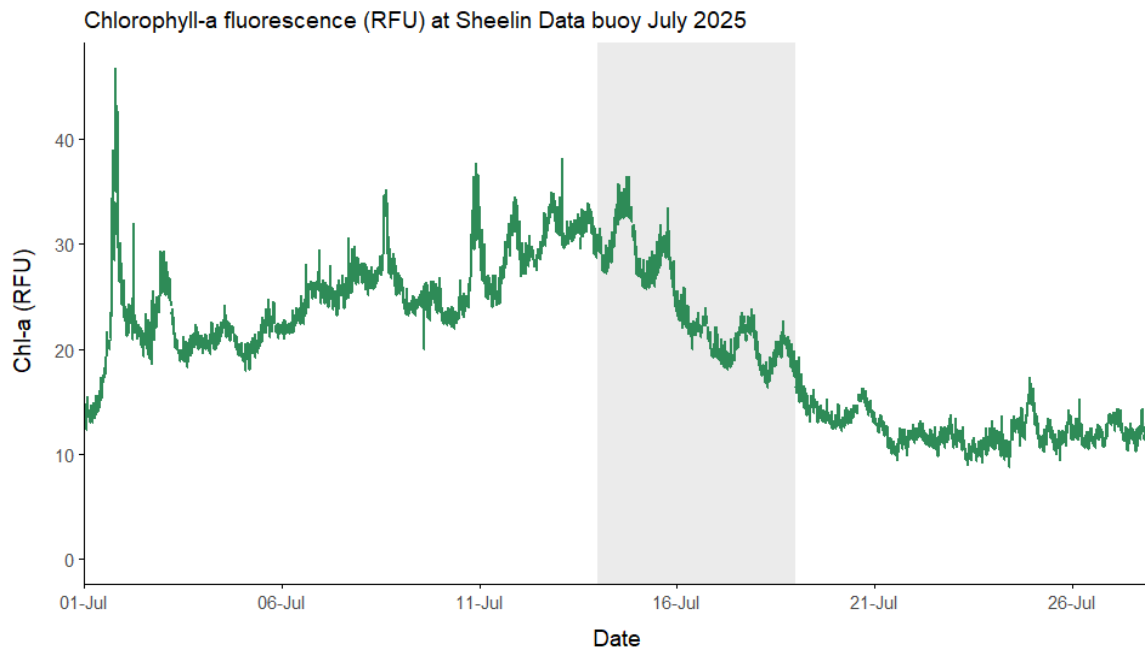
### 3.2 Lough Sheelin Environmental Monitoring

#### *Middle Lake*

In early July 2025, water temperatures throughout the Lough Sheelin water column were relatively uniform, indicating an isothermal lake. From the 12–16<sup>th</sup> of July, thermal stratification developed, with surface water temperatures exceeding 21°C while bottom temperatures remained near 18°C. A full water column overturn began on the 14<sup>th</sup> of July, and by the 16<sup>th</sup> the lake was again relatively uniform at 20°. Minor fluctuations observed later in the month reflect daily heating and cooling cycles, but no further sustained stratification occurred (Fig. 3). Surface (black and red lines) temperatures showed a steady increase to a mid-month water temperature peak (21.95°C), while the middle and bottom layers warmed more gradually (Fig.3).



Chlorophyll-a fluorescence (RFU) at the Sheelin data buoy (Fig. 4) showed an initial peak at the start of the month, followed by relatively stable conditions. This was interrupted by pronounced increases >35 RFU, on the 10<sup>th</sup>, 13<sup>th</sup> and 14<sup>th</sup> of July coinciding with surface warming, elevated air temperature, and increased solar radiation. After the 15<sup>th</sup>, chlorophyll-a levels declined gradually and stabilised to 12-20 RFU, tracking the change in weather conditions and breakdown of stratification.

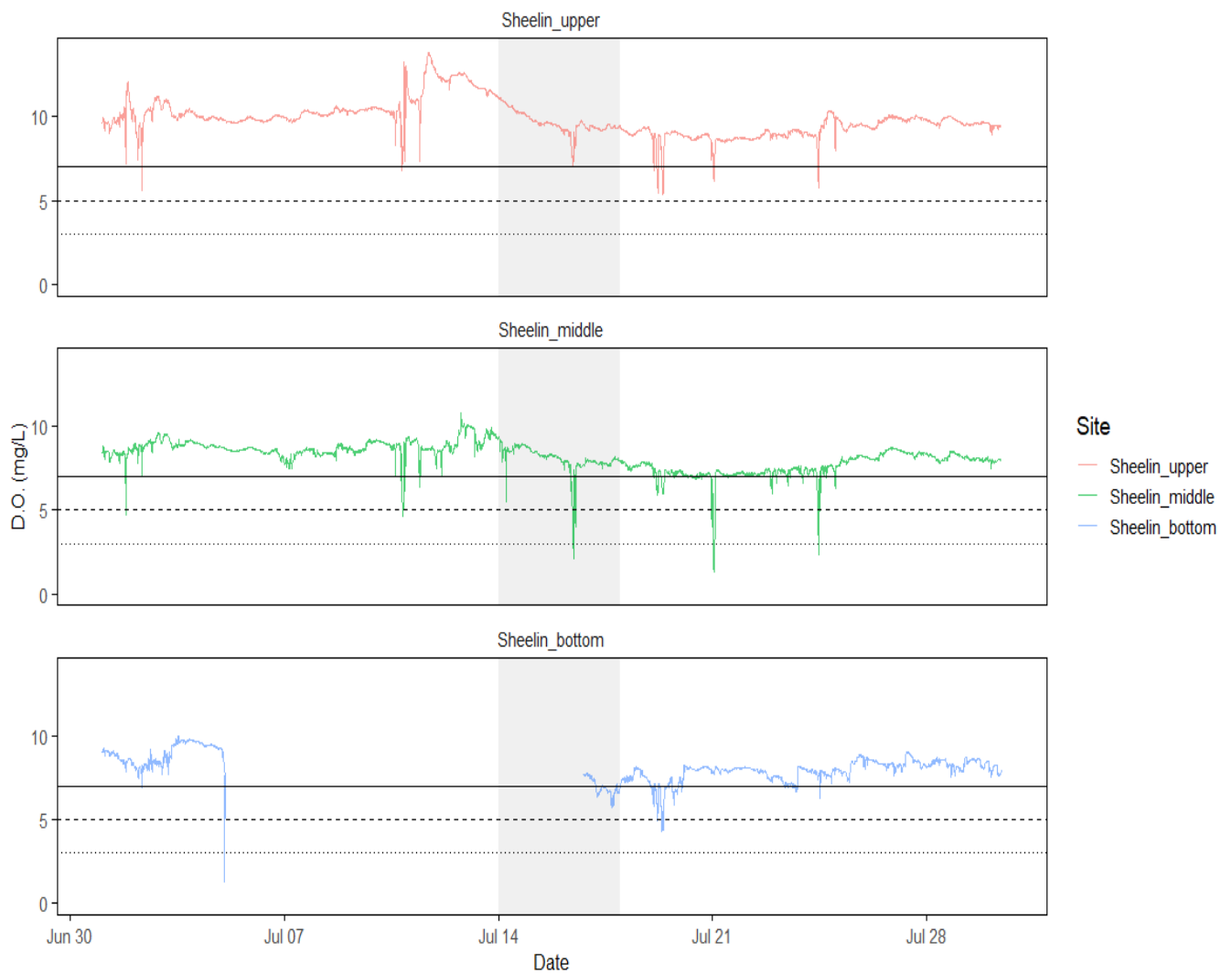


**Fig.4: Lough Sheelin data buoy Chlorophyll-a fluorescence (RFU) for July 2025 (sensor is located 0.5m from the lake surface and records every 10 minutes). The grey shaded area highlights the period 14/07-18/07.**

D.O. remained relatively high and stable in the surface and middle layers, with some regular short-term declines, likely associated with diurnal biological activity. However, on the 16<sup>th</sup> of July, D.O. in the middle layer dropped below 3mg/L, reaching a minimum of 2.1mg/L at 10:00, recovering to above 7mg/L within two hours, suggesting a short-lived but potentially stressful low-oxygen event (Fig. 5).

The bottom D.O. logger (Fig. 5. Lower panel - blue) recorded sustained 0mg/L readings from the 4–15<sup>th</sup> of July. These values are probably due to the sensor settling into sediment during low lake levels rather than remaining suspended in the water column, affecting the accuracy of the bottom measurements and have therefore been removed from Fig. 5.

## Dissolved Oxygen at Sheelin Databuoy July 2025



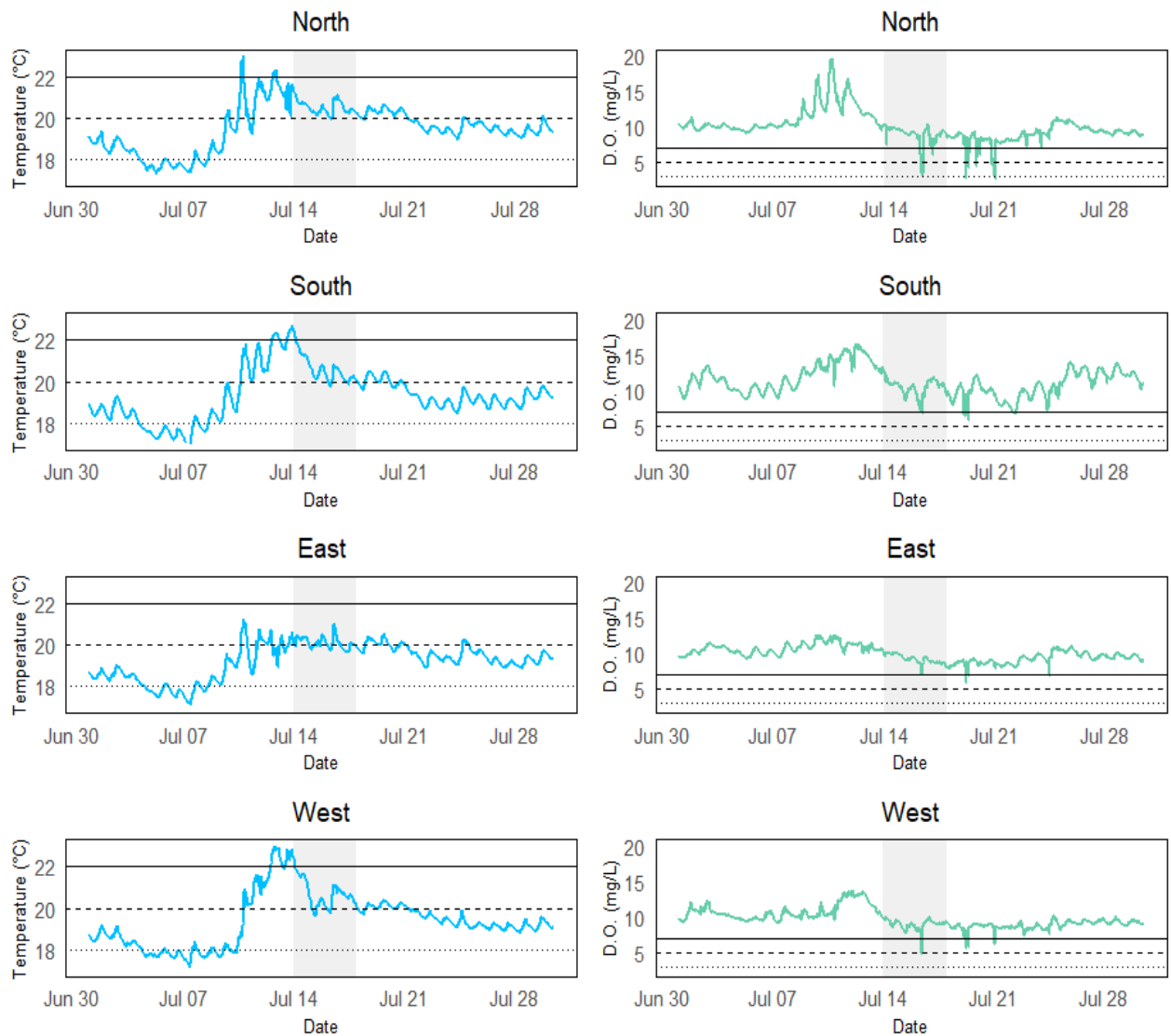
**Fig.5: Lough Sheelin dissolved oxygen (mg/L), recorded at 0.5m (Sheelin\_upper, blue), 6.5m (Sheelin\_middle, green), and 12.5m (Sheelin\_bottom, red) from the lake surface for July 2025. The horizontal lines denote 7mg/L, 5mg/L, and 3mg/L. The grey shaded area highlights the period 14/07-18/07.**

### *Lough Sheelin Bays*

Temperature and D.O. dynamics in the bays mirrored middle-lake patterns, but with greater spatial variability. All bays warmed steadily during early July, peaking between the 11–15<sup>th</sup> of July. The north, west, and south bays briefly exceeded 22°C, particularly on the 13<sup>th</sup> and 14<sup>th</sup> while the east bay remained cooler and did not surpass 22°C. After July 16<sup>th</sup>, water temperatures declined slightly across all bays and stabilised around 20°C, consistent with the breakdown of stratification (Fig. 6).

D.O. was generally high but showed short-term variability, especially from the 14–18<sup>th</sup> of July. The north bay exhibited much larger D.O. fluctuations, with occasional drops below 5mg/L. The south bay showed a stronger diurnal signal, with peaks to 15mg/L, but also occasional drops to below 7mg/L during early mornings. The east and west bays maintained more stable D.O. levels, generally above 7mg/L, however, all sites experienced a drop in D.O. on the 16<sup>th</sup> and 19<sup>th</sup> of July (Fig. 6).

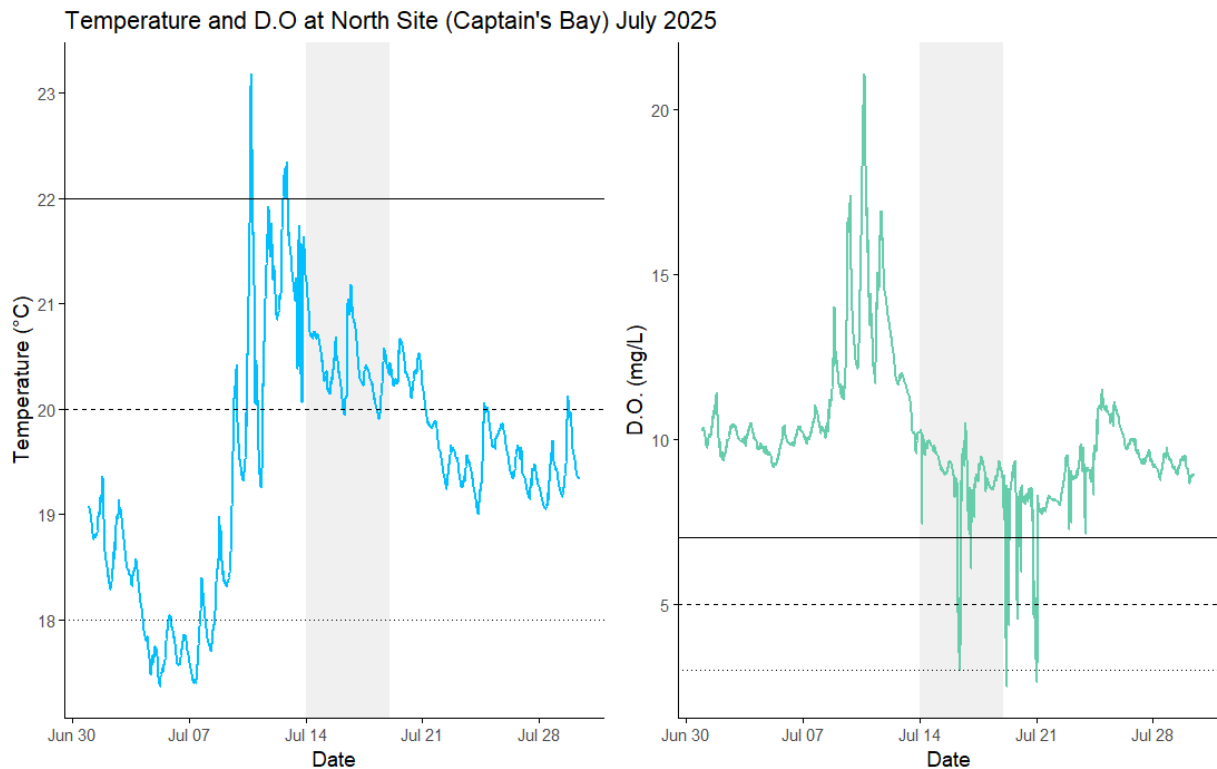
### Temperature and D.O. at Sheelin Bays July 2025



**Fig.6: Dissolved oxygen (mg/L) and water temperature (°C) at Sheelin bays (north, south, east, west) during July 2025. Grey shaded area marks the period 14/07–18/07. The horizontal lines mark 18, 20, and 22°C (water temperature), and 7, 5, and 3mg/L (D.O.).**

In the North Bay (1. Captain’s Bay), the maximum D.O. of 21mg/L on the 10<sup>th</sup> of July coincided with the maximum solar radiation for the month. D.O. dropped to 2.9mg/L at 10:00 on the 16<sup>th</sup> of July, recovering to 7mg/L by 12:00, while water temperatures remained above 20°C (Fig. 7). Early morning declines continued at this site reaching 2.4mg/L on the 19<sup>th</sup> and 2.6mg/L on the 20<sup>th</sup>, until water

temperatures cooled to below 20°C. This pattern closely matched the mid-layer decline in the middle lake (Fig. 6).

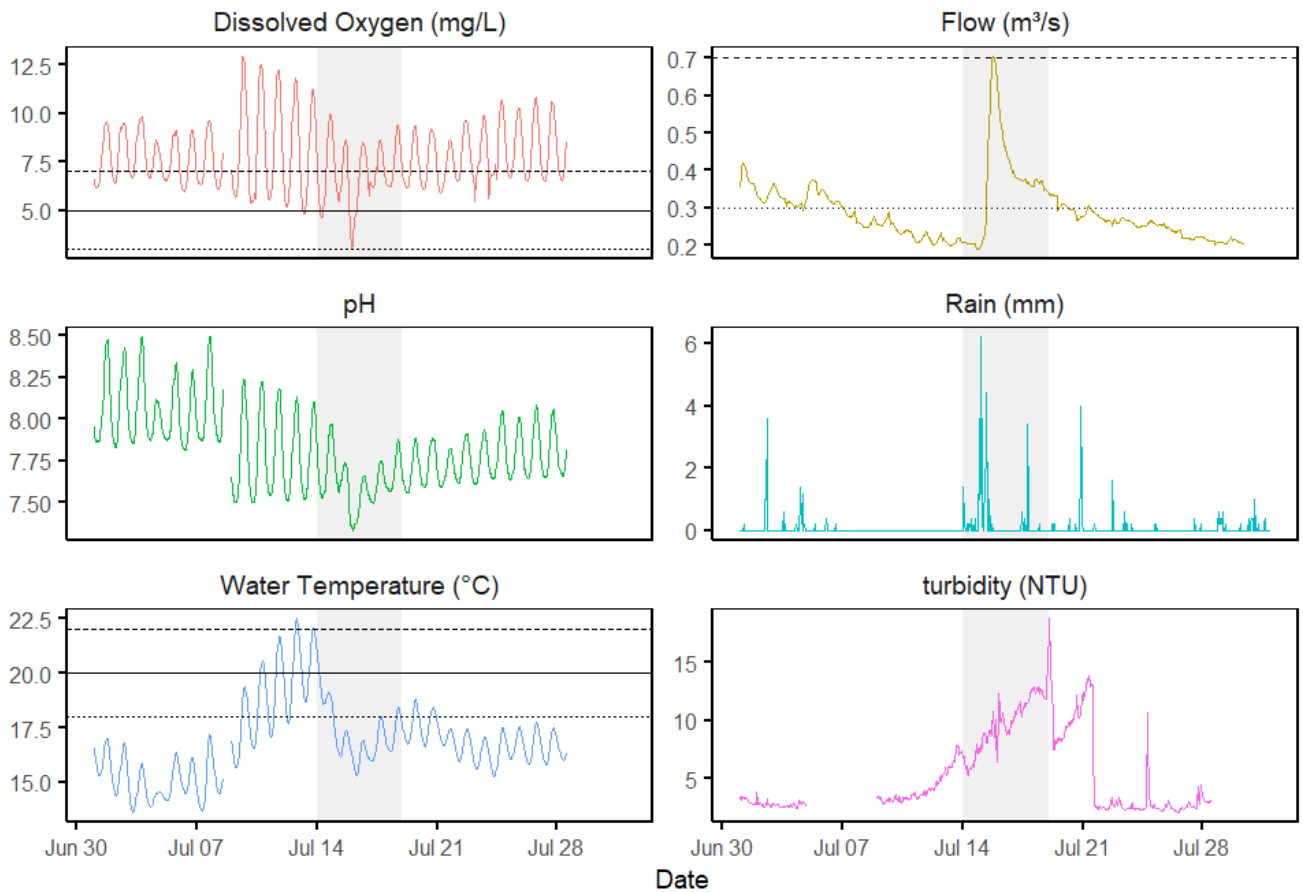


**Fig.7: Water temperature (°C, blue) and dissolved oxygen (mg/L, green) at the north bay in Lough Sheelin, July 2025. Grey shaded area marks the period 14/07–18/07. The horizontal lines mark 18, 20, and 22°C (water temperature) and 7, 5, and 3mg/l (D.O.).**

### 3.3 Mountnugent River Environmental Monitoring

The Mountnugent River, which flows into Captain’s Bay, experienced pronounced fluctuations in environmental conditions in July (Fig. 8). Water temperatures peaked at 22°C on the 14<sup>th</sup> of July, then dropped below 18°C between the 15–18<sup>th</sup> of July. Over 25mm of rain on the 15<sup>th</sup> July increased flow from <math><0.18\text{m}^3/\text{s}</math> to >math>>0.7\text{m}^3/\text{s}</math> and coincided with a drop in pH, increase in turbidity, and a sharp D.O. decline to 2.9mg/L at 01:00 on the 16<sup>th</sup> July (Fig. 8).

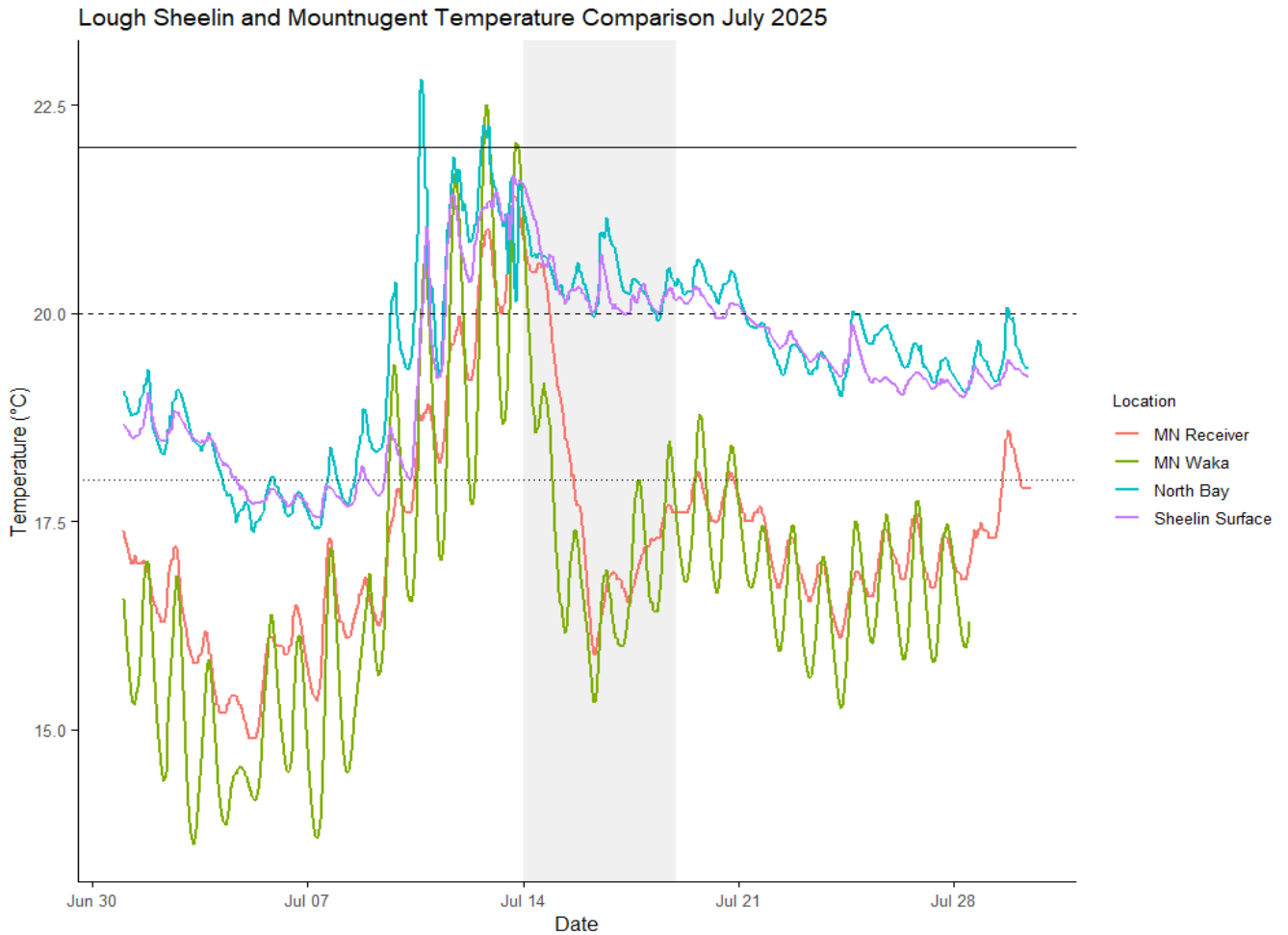
## Mountnugent Monitoring July 2025



**Fig.8: Mountnugent River monitoring during July 2025, showing dissolved oxygen (mg/L), flow (m<sup>3</sup>/s), pH, rainfall (mm), and water temperature (°C). The grey shaded area highlights between the 14/07–18/07. The horizontal lines mark 3, 5, and 7mg/L (D.O.), 18, 20, and 22°C (water temperature), and 0.3 and 0.7 m<sup>3</sup>/s (Q95 and Q50 estimated percentile flow). Hourly averages were calculated for each variable to ensure consistency across the dataset. \*Flow data was derived from the EPA online data portal ([EPA - WISKI Web Public](#)).**

### 3.4 Lake vs River water temperatures

Comparison of river and lake surface water temperatures (Fig. 9) showed that in early July, river water temperatures were consistently cooler than the lake. By mid-month, both river and lake surface water temperatures warmed to >21°C, with the north bay recording the highest temperature of 23.1°C on the 10<sup>th</sup> of July. Following rainfall and an increase in flow, water temperature declined at the Mountnugent monitoring sites, while the lake remained over 20°C (Fig.9).



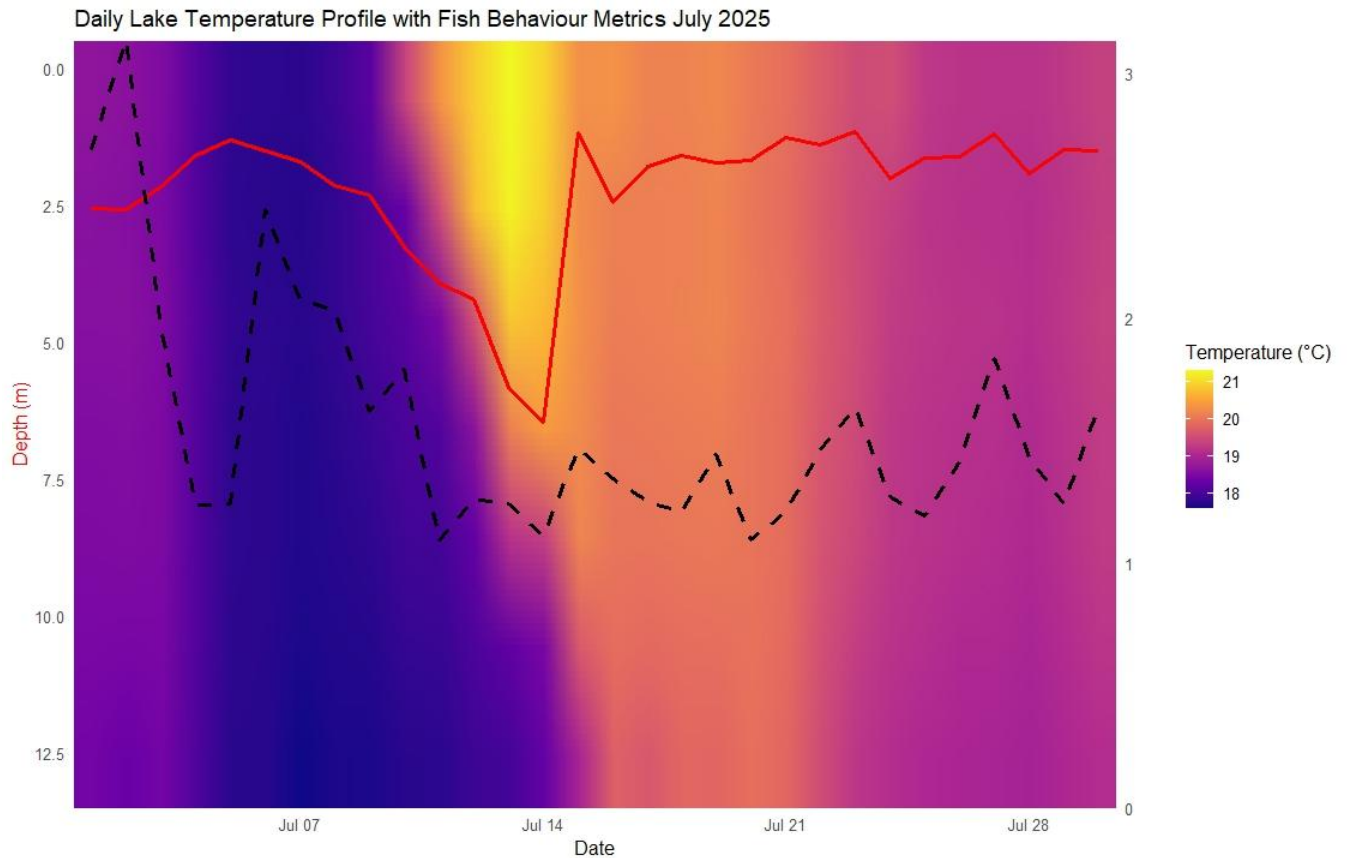
**Fig.9: Water temperature comparison between the Mountnugent River (Upper [MN Waka, Green], and Lower [MN Receiver, Red]) and Lough Sheelin (North Bay [Blue] and Sheelin Surface at Databuoy [Purple]) for July 2025. The grey shaded area highlights the period 14/07–18/07. Horizontal lines mark 18, 20, and 22°C.**

### 3.5 Fish tracking project -Fish behaviour

Six tagged brown trout were detected within the acoustic telemetry array during July 2025. Fish movement was summarised using a daily temperature–depth heatmap (0–12.5m; data buoy thermistor) overlaid with mean depth and activity of tagged fish active in the array (mean number of stations detected per day as proxy for activity) (Fig.10). Prior to the mid-July thermal peak (13–14<sup>th</sup> July), trout predominantly occupied depths of approximately 2–3m across the lake. As surface waters warmed and the oxy-thermal habitat compressed, fish shifted to deeper depths (~6–7m). Fish returned to shallower layers (~2–3m) on the 15<sup>th</sup> of July (Fig. 10).

Daily activity, expressed as the mean number of stations visited, declined during the mid-July thermal event (from >2 to <2), suggesting reduced movement and/or spatial constriction of home ranges under

thermal stress. Individual movement trajectories revealed heterogeneous responses, with three of the six trout entering the lower Mountnugent tributary on 3<sup>rd</sup>, 13<sup>th</sup>, and 14<sup>th</sup> July (see Appendix for example track; Fish 2555). One fish exhibited extended residence within Captain’s Bay during the 14<sup>th</sup>-18<sup>th</sup> July.



**Fig. 10: Daily lake water temperature profile for July 2025 (heatmap; warmer colours = warmer water, 0–12.5m \*data buoy). Overlaid are mean fish depth (m) (red line, left axis) and mean activity – number of stations detected on (black dashed line).**

## 4. Summary

In July 2025, Lough Sheelin exhibited marked changes in its oxythermal environment, which were recorded by high-frequency monitoring. A brief mid-July stratification event altered the thermal and dissolved oxygen structure in the lake, leading to stressful conditions for fish (Elliot 2000; Elliot and Elliot 2010). This event was preceded by a period of hot, sunny weather, during which elevated air temperature and solar radiation coincided with peak D.O. concentrations in the North Bay (1. Captain's Bay; Fig.1). A spike in chlorophyll-a also aligned with the strongest surface warming in the middle of the lake (Data buoy; Fig.1) and the onset of stratification, conditions that likely promoted algal growth. The sequence of high temperatures and algal growth may have promoted the observed high daytime oxygen supersaturation through enhanced photosynthetic activity. This elevated productivity may have contributed to a sharp but brief decline in D.O. in the middle layer on the 16<sup>th</sup> of July, as heightened algal respiration and decomposition can create short-lived oxygen stress during stratified periods. However, a period of cooler, windier weather and 21.8mm of rain on the 15<sup>th</sup> of July affected the lake and river environment by breaking stratification and creating mixed, isothermal conditions throughout the water column, and increasing discharge from inflowing tributaries. The mixing potentially redistributed low-oxygen waters from the lake bottom, thereby increasing respiration-driven oxygen demand (Jennings *et al.*, 2012).

After the rainfall event, decreases in both temperature and pH were observed, followed by the lowest D.O. concentration (2.9mg/L) recorded in July at the Mounnugent River monitoring site (upstream of the area where dead fish were found). This subsequently corresponded to low D.O. levels being observed in Captain's Bay (inflow area of Mounnugent river; Fig.1). D.O. concentrations below 3mg/L were recorded in the river and lake environment. Even for short durations, D.O. at these levels are known to cause physiological stress for brown trout (Elliott & Elliott 2010). It is important to note that in productive systems, early morning declines in D.O. are commonly observed due to diurnal photosynthesis–respiration cycles, particularly under high nutrient conditions (Mulholland *et al.*, 2005), and this pattern was evident in the present data (Figure 8; Mounnugent river, top left). Such dynamics can reduce the availability of suitable habitat for fish during warm summer periods, when both temperature and oxygen may become limiting. The cascade of processes outlined could have contributed to acute deoxygenation events in the Mounnugent inflow to Lough Sheelin.

Only six trout were active in the array during July 2025, comprising three individuals tagged in 2025 and three from the 2024 tagging cohort, whose tag batteries were nearing depletion by late August 2025. While this small sample size represents a caveat and limits the broader inference of population-

level responses, it nevertheless provides a valuable opportunity to observe fine-scale behavioural patterns of individual fish during the period of interest. Thermal stress and stratification during mid-July 2025 induced pronounced behavioural shifts in tagged trout, notably vertical relocation from shallow (~1–2.5m) to deeper (~4-6.5 m) waters as surface layers warmed. Such movement aligns with the common behaviour of cold-water fish tracking more favourable oxygen-temperature conditions under habitat compression. Similar adaptive shifts in depth to maintain optimal environmental conditions have been documented in temperate lakes experiencing thermal habitat loss (Kraemer *et al.*, 2021). The observed decline in activity suggests a contraction of space use and perhaps energy-saving strategies during periods of thermal and hypoxic stress. When temperatures or hypoxia exceed tolerable thresholds, brown trout often suppress activity, likely as a compensatory adaptation to reduced oxygen requirements and to avoid critical metabolic stress. Activity declines are typically observed when water temperatures rise above ~18–20°C or when dissolved oxygen falls below ~5–6 mg/L (optimum >7 mg/L) (Elliott, 2000; Ojanguren & Brana, 2003, Elliott & Elliott, 2010).

Individual variability ranging from tributary entry (n = 3) to local holding and mid-lake refuge use (n = 3) reveals a high degree of behavioural plasticity that may be critical for survival during heatwave events provided suitable refuge habitat remains available. Similar patterns have been reported in other salmonids, such as steelhead trout (*Oncorhynchus mykiss*), which often exploit tributary confluence zones as thermal refuges, highlighting the importance of these buffered environments (Wang *et al.*, 2019). However, in this instance, trout that entered the tributary likely experienced dissolved oxygen levels close to lethal limits, indicating that behavioural adaptations to thermal stress (tributary entry) can become ineffective once environmental thresholds are surpassed. The vertical relocation to deeper waters and reduced activity observed in tagged trout during peak thermal stress emphasise how acutely sensitive salmonids are to short-term habitat compression, a response likely to become increasingly common under intensifying extreme weather and climate-driven heat events.

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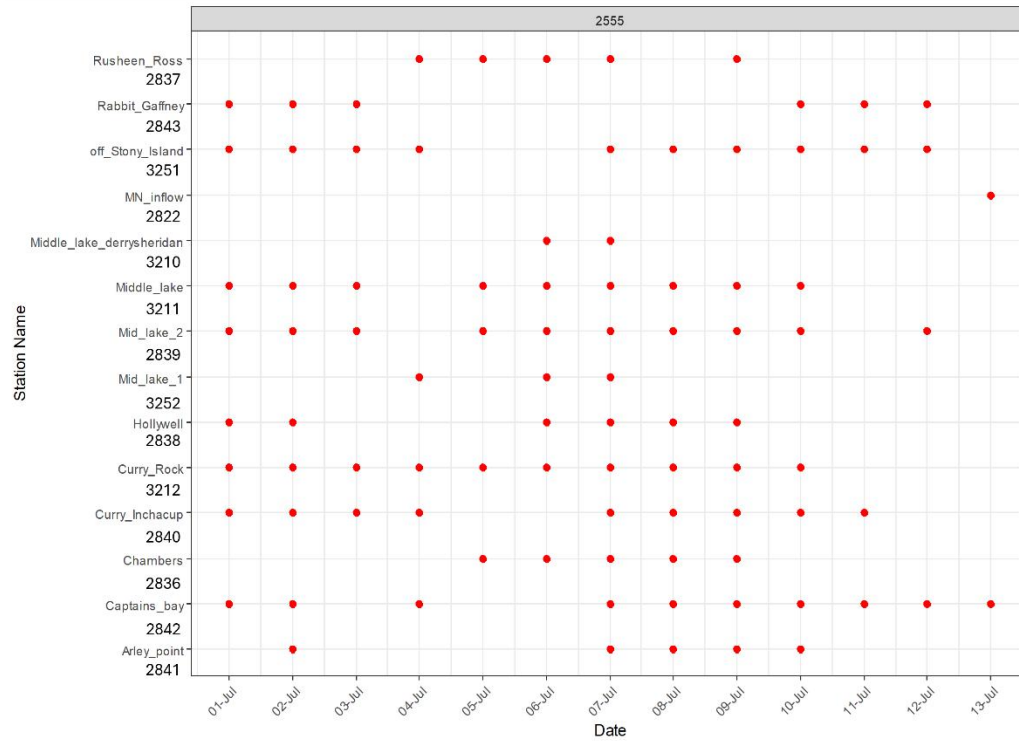
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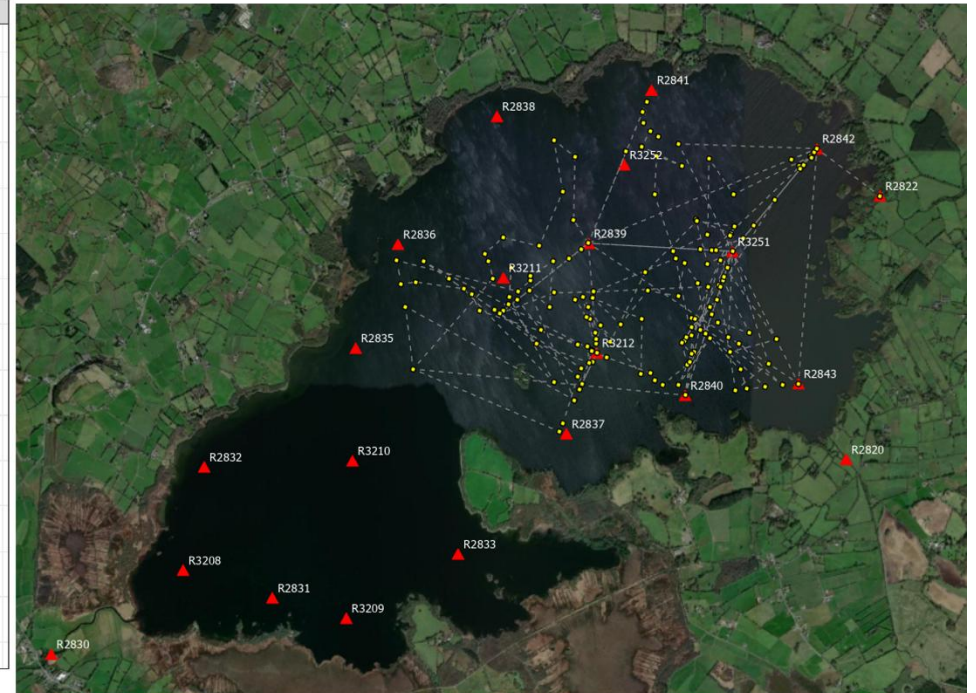


## Appendix

a)



b)



**Fig. A1 Example track of tagged fish. Tag 2555 – 52cm (1st- 13<sup>rd</sup> July). a) Abacus plot of daily presence at each receiver station, with stations identified by local name. b) Interpolated track based on hourly Centre of Activity Locations between 1-13th July; fish entered Mount Nugent inflow at 04:00am on 13<sup>th</sup> July and was not redetected on the lake array\* (\*as of August 10<sup>th</sup> download 2025).**