Lough Ree Power

Thermal Discharge Synthesis Report

Document No.: QS-000152-01-R401-000

Jointly Prepared by ESB International
and
Aquatic Services Unit

Date: February 2018

ESB International, One Dublin Airport Central, Dublin Airport, Cloghran, Co. Dublin, Ireland.
Phone +353 (0)1 703 8000
www.esbinternational.ie
Aquatic Services Unit (UCC), Environmental Research Institute (UCC), Lee Road, Cork.
Phone +353 (0)21 4901934
www.ucc.ie/en/asu/

File Reference:	QS-000152	
Client / Recipient:	ESB Generation and Wholesale Markets	
Project Title:	Lough Ree Power Thermal Discharges	
Report Title:	Lough Ree Power Thermal Discharge Synthesis Report	
Report No.:	QS-000152-01-R401-000	
Revision No.:		
Prepared by:	Gerard Morgan (ASU) and Dr Adrian Buckley (ESBI)	Date: February 2018
Title:	Manager ASU Environmental Consultant	
Verified by:	James Fitzpatrick	Date: February 2018
Title:	Senior Consultant	
Approved by:	Dr Paddy Kavanagh	Date: February 2018
Title:	Senior Consultant	

Template Used: T-020-007-ESBI Report Template

Change History of Report

Date	New Revision	Author	Summary of Change

Table of Contents

1 Introduction 6
1.1 Lough Ree Power 6
1.2 Scope of Report 7
1.3 Thermal Plumes 7
2 Environmental Setting 9
2.1 Cooling water discharge 9
2.2 Hydrology 12
2.3 Water Framework Directive 16
2.4 Draft River Basin Management Plan for Ireland 2018 - 2021 17
3 Thermal Plumes Studies 18
4 Continuous Temperature Monitoring 22
4.1 Introduction 22
4.2 Thermal Plume 23
4.3 General Ambient Temperature Trends 25
4.4 Temperature Averages 26
5 Fisheries 29
5.1 Fyke Net Surveys 29
5.1.1 Species Present and Overall & Relative Abundances 31
5.1.2 Possible Temperature Related Affects in the Data 34
5.1.3 Overall Conclusions – Fyke Net Survey 35
5.2 Comparison of IFI data (2010 and 2016) with Fyke Net Surveys (2016/2017) 36
5.3 Literature Review of Potential Fisheries Impacts 39
6 Diatoms 41
6.1 General Trends 41
6.2 Another possible diatom indicator species 43
6.3 Summary 44
7 Macrophytes 47
8 Macroinvertebrates 49

9 Assessment of acceptability of thermal plume mixing zone at LRP 51
10 Conclusions 53
10.1 Thermal plume surveys 53
10.2 Fish 54
10.3 Diatoms 55
10.4 Macrophytes 55
10.5 Macroinvertebrates 55
11 Overall conclusion 57
12 Recommendations 59
13 References 60

Appendix A: Graphical Information Referenced in Main Report
Appendix B: ASU Literature Review of Potential Fisheries Impacts - Documentation

Table of Tables

Table 2-1: Selected River Shannon Hydrometric Gauges 13
Table 3-1 Flow and Load Conditions during thermal plume surveys at LRP 18
Table 3-2 LRP Non-Conformances associated with results of survey of August 2014. 21
Table 4-1: Continuous Monitoring Points at LRP 22
Table 4-2 LRP Non-Conformances associated with results of continuous temperature monitoring. 28
Table 5-1 Fyke net survey dates and maximum temperatures in the Shannon river at LRP during the surveys. 31
Table 5-2 Total of each species caught during each survey in the Shannon river at LRP in decreasing order 32
Table 5-3 Fish numbers caught at each site in the Shannon River at LRP in the 5 surveys 32
Table 6-1 Diatom determined ecological status at LRP sites 2014-2016 44

Table of Figures

Figure 1-1: General Location of Lough Ree Power at Lanesborough 6
Figure 2-1 River Shannon at Lanesborough. 9
Figure 2-2 River Shannon cross-sections at Lanesborough. (IHD) 10
Figure 2-3 River Shannon cross-sections in bay downstream of Lanesborough. (IHD) 11

Figure 2-4 Location of cross-sections at Lanesborough (IHD) 12

Figure 2-5: Locations of Lough Ree Power, Hodson's Bay Gauge and Athlone Weir 14

Figure 2-6: Flow Duration Curve - River Shannon at Athlone 1951-2017 15

Figure 2-7: WFD river water body status at LRP 16

Figure 3-1. River Shannon at Lanesborough.. 19

Figure 4-1: Continuous Monitoring Points at LRP.. 22

Figure 5-1 Aerial photos showing fyke net fishing locations in the Shannon River at LRP... 30

Figure 5-2 Average depth-averaged temperature at or nearby the 5 paired fyke net sampling stations at LRP for each of the 5 fishing surveys. (Data extracted from IHD temperature monitoring reports) 30

Figure 5-3 Total number of fish of each species collected at all left (warm water) and right (cooler water) sites in each of the 5 survey periods at LRP 35

Figure 5-4 Proportional composition of fish species taken in an electrofishing survey undertaken by IFI on the Shannon in May 2010 upstream (Site A U/S) and downstream/at (Site B d/s) Lanesborough... 37

Figure 5-5 Proportional composition of fish species taken in a boom boat electrofishing survey undertaken by IFI on the Shannon in July 2016 upstream (Site 7) and at (Site 8) Lanesborough Right and Left Sides of the channel.. 38

Figure 6-1 Aerial view of LRP stretch showing 2015 & 2016 biological survey locations 42

Figure 6-2 LRP 2016 Relative abundance of *A. minutissimum* (thermal discharge = green dashed line) 45

Figure 6-3 LRP 2016 Relative abundance of *A. minutissimum* vs temperature (normalised), (thermal outfall = green dashed line) 45

Figure 6-4 Proportional composition of *C. p. euglypta* and *A. minutissimum* in diatom samples at LRP sites in 2015 46

Figure 6-5 Proportional composition of *C. p. euglypta* and *A. minutissimum* in diatom samples at LRP sites in 2016 46

Figure A-1. Summary temperature data at LRP in degrees Celsius (°C) from the monthly continuous in-river monitoring from July 2016 to December 2017

Figure A-2. Proportional composition of the total number of fish caught in all 5 surveys at LRP (2016-2017)

Figure A-3: Pie charts showing the proportional composition of each species taken in each of 5 fyke net surveys at LRP (August & October 2016 and February, November and December 2017)

1 Introduction

1.1 Lough Ree Power

Lough Ree Power Generating Station (LRP) is located adjacent to the River Shannon at Lanesborough County Longford as illustrated in Figure 1-1 below. The station is a peat fired base load station i.e. continuous operation, subject to availability. The installed capacity is 100 MWe and the station was commissioned in 2004. The milled peat-fired boiler generates steam which is used to drive turbines which produce electricity. The steam is then cooled to hot water and recirculated to the boiler. The steam is cooled by water abstracted from and returned to the River Shannon.

The principal aqueous discharge from the power station is cooling water discharge. The station discharges approximately 135 MWth to the River Shannon when on full load. This consists of a flow through the condenser of 4 m^3/s with a temperature rise of approximately 9.5 °C. The flow through the condenser will vary slightly depending on the level of the River Shannon with a corresponding variation in the rise in temperature.

There has been continuous production of electricity on an adjacent site at Lanesborough since 1958 when a 20 MWe unit was commissioned. The station was extended in 1966 and again in 1983. The installed capacity in 1983 was 85 MW and this discharged a thermal load to the River Shannon of approximately 185 MWth. This consisted of a flow through the condenser of 5.5 m^3/s with an approximately 8 °C temperature rise and all units on full load. Lanesborough Generating Station was decommissioned in 2003 and its associated Integrated Pollution Control Licence (P0629) was surrendered in 2010.

Figure 1-1: General Location of Lough Ree Power at Lanesborough

Lough Ree Power Generating Station operates within the framework of Environmental Protection Agency (EPA) Industrial Emissions Licence (IEL) (No. P0610-02). Condition 5.5 of the Licence concerns the thermal discharge from the station and states that:

Discharges from the installation shall not artificially increase the ambient temperature of the receiving water by more than 1.5 °C outside the mixing zone. In relation to temperature, the mixing zone shall not exceed 25% of the cross sectional area of the river at any point.

A Licence Review was completed in September 2013. Condition 5.5 was amended to include the requirement that the mixing zone should not exceed 25% of the cross sectional area of the river. Prior to this, no defined footprint of the mixing zone was specified and the requirement in the licence (P0610-01) under Condition 6.9 was that:

No effluent shall be discharged which results in a temperature increase at the edge of the mixing zone of greater than 1.5^{o}C in the receiving system.

In addition, Condition 5.1 of the Licence states that:

No specified emission from the installation shall exceed the emission limit values set out in Schedule B: Emission limits, of this licence. There shall be no other emissions of environmental significance.

1.2 Scope of Report

ESB Generation and Wholesale Markets commissioned ESB International (ESBI) and Aquatic Services Unit from UCC to undertake a series of surveys and studies of the effects of the thermal discharges from Lough Ree Power Generating Station on its receiving water. These surveys and studies include:

- Five boat based thermal plume surveys at Lough Ree Power (undertaken by Irish Hydrodata) between August 2014 and July 2016.
- Programme of continuous temperature monitoring undertaken by Irish Hydrodata at a number of fixed points in the Shannon at Lanesborough from August 2016.
- Three biological surveys undertaken by Aquatic Services Unit in 2014, 2015 and 2016 which covered diatoms, macrophytes and macroinvertebrates
- Five fyke net surveys at Lanesborough (and at Shannonbridge) undertaken by Denis Doherty (ESB Fisheries) and his team in August 2016, October 2016, February 2017, November 2017 and December 2017.
- Literature Review of Potential Fisheries Impacts. Aquatic Services Unit July 2016

This synthesis report draws together and summarises the results of these surveys and studies. It also considers compliance with the Industrial Emissions Licence associated with the station (No. P0610-02).

1.3 Thermal Plumes

Thermal plumes have a complex physical structure. They are less dense than the receiving waters into which they flow because of their higher temperature. This causes the cooling water to flow over the surface of the ambient water and the increase in temperature to be confined to the surface. The depth of the thermal plume is not constant. The maximum depth of the thermal plume occurs at the discharge point and decreases with distance away from the discharge point. The gradient between the thermal plume and receiving waters is sharp in the vertical direction and sudden variations in temperature of 6 °C can occur over a distance of 1-2 m below the surface. The gradients are considerably less in the horizontal direction.

The main factors which affect the thermal plume are:

- The quantity of heat discharged into the receiving waters.
- The maximum thermal load discharged occurs when the station is on full load.
- River flow.
- Meteorological conditions.
- Bathymetry and
- Vegetation

2 Environmental Setting

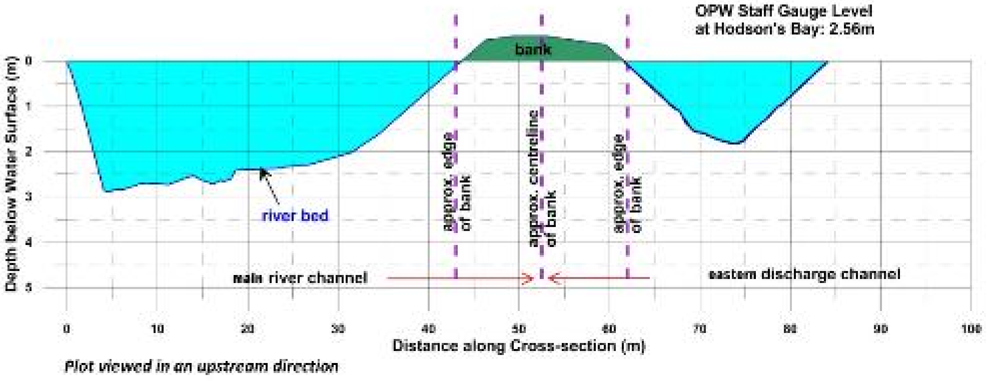
2.1 Cooling water discharge

The thermal cooling water discharge from Lough Ree Power occurs just upstream of the bridge in Lanesborough, and on the left bank of the river Shannon. The abstraction point is sited approximately 140 m upstream of the discharge location. The cooling water consists of a flow through the condenser of 4 m^3/s which is subject to a temperature rise of approximately 9.5 °C. The flow through the condenser does not vary but load will vary with a corresponding variation in the rise in temperature.

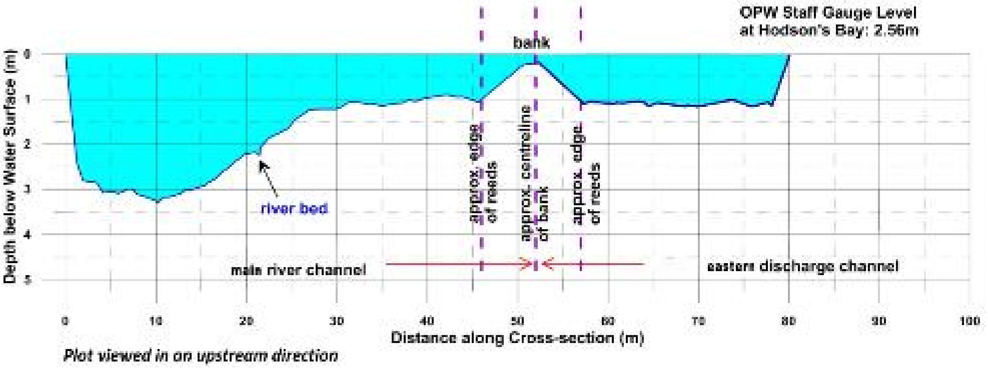
The river Shannon at Lanesborough has two distinct channels from just upstream of the Lough Ree Power cooling water outfall. At the eastern side, there is a narrow shallow channel approximately 30 metres wide which is separated from the main channel by a series of reed bed islands. The channel is bounded by a headland upstream of the cooling water discharge point which separates it from the main river at that point. The eastern channel extends downstream for approximately 450 m. At this point, prior to entering the main body of Lough Ree, the Shannon passes through a small bay for approximately 900m. The reed bed is permeable and some water does flow through it although volumes are small. There are breaks along the length of the reed bed and this allows for much more interchange of water between the two channels. See Figure 2-1.

Figure 2-1 River Shannon at Lanesborough

Figure 2-2 below illustrates typical cross-sections of the River Shannon and eastern discharge channel downstream of the outfall as surveyed by Irish Hydrodata in 2016. In places, this cross-sectional area of this eastern channel is approximately 25% of the total combined cross-sectional area. During periods of very low flow, it is likely that the source of the bulk of the flow in this channel is derived from the cooling water discharge.



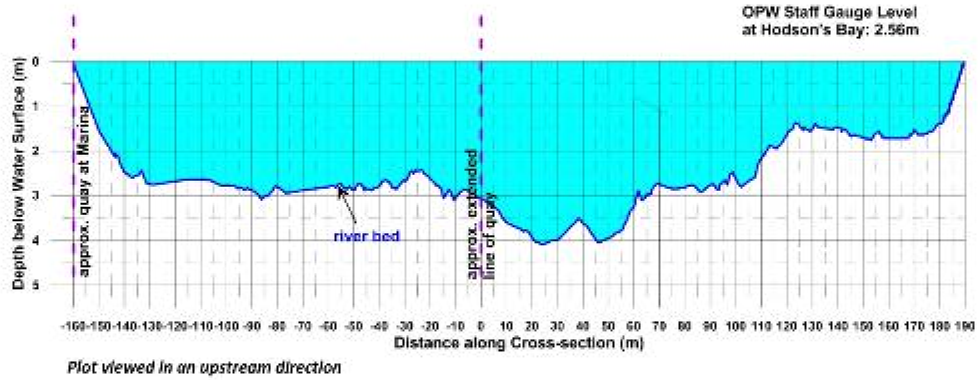
Cross-section at 75m d/s of outfall



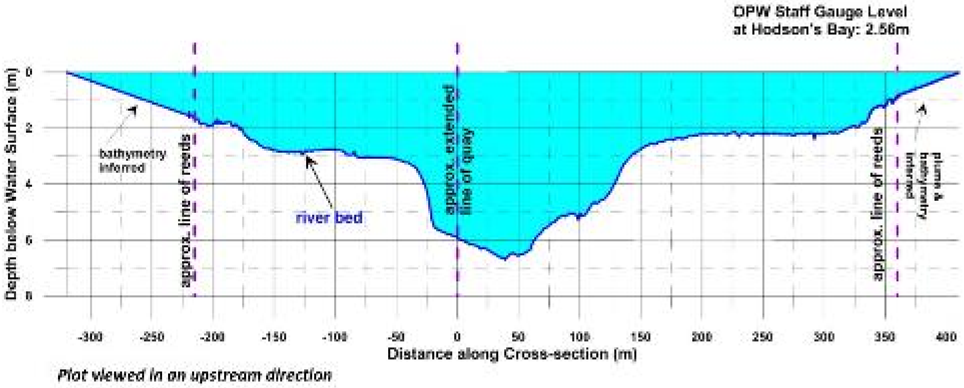
Cross-section at 225m d/s of outfall

Figure 2-2 River Shannon cross-sections at Lanesborough. (IHD)

Figure 2-3 below illustrates typical cross-sections of the River Shannon as it passes through the bay downstream of Lanesborough before it enters Lough Ree as surveyed by Irish Hydrodata in 2016. The cross-section locations are mapped in Figure 2-4.



Cross-section at 475m d/s of outfall



Cross-section at 625m d/s of outfall

Figure 2-3 River Shannon cross-sections in bay downstream of Lanesborough. (IHD)

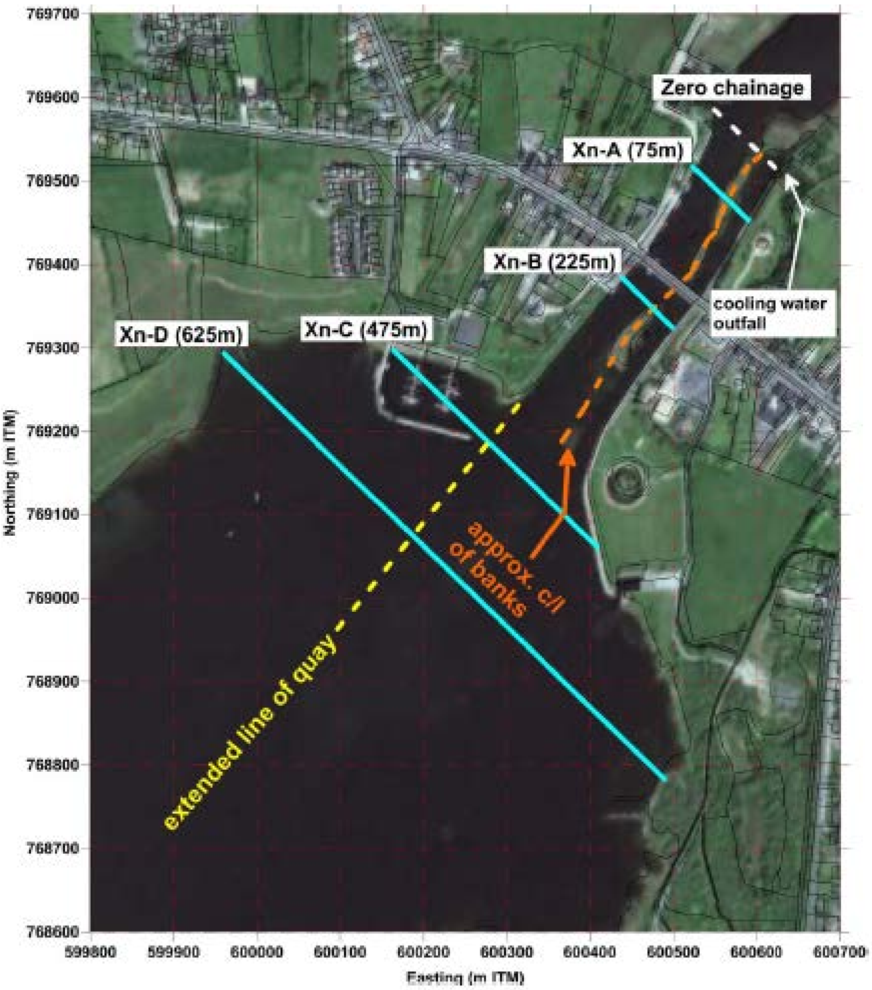


Figure 2-4 Location of cross-sections at Lanesborough (IHD)

2.2 Hydrology

In order to assess the impact of the thermal discharge from Lough Ree Power on the River Shannon, consideration of the flows in the River Shannon is required.

There are a number of hydrometric gauging stations on the River Shannon operated by ESB, OPW and local authorities. These gauges are used to record water levels in the River Shannon. At certain locations, series of flow measurements have been taken and a relationship between water level and flow (known as a rating curve) developed. Table 2-1 below gives details of the relevant gauges for Lough Ree Power Generating Station. The gauge locations are illustrated in Figure 2-5.

Station No	Location	Station Status	Station Type	Catchment Area upstream EPA DTM km²	Easting	Northing
26027	Athlone	Active	Automatic	4,601	204042	241293
26088	Hodson's Bay	Active	Automatic	4,592	200843	246267

Table 2-1: Selected River Shannon Hydrometric Gauges

As noted in Table 2-1, there is a staff gauge located on the Shannon at Lanesborough near the site of Lough Ree Power. A record of water levels is not maintained for this gauge and the site proved to be unsuitable for rating due to the proximity of Lough Ree.

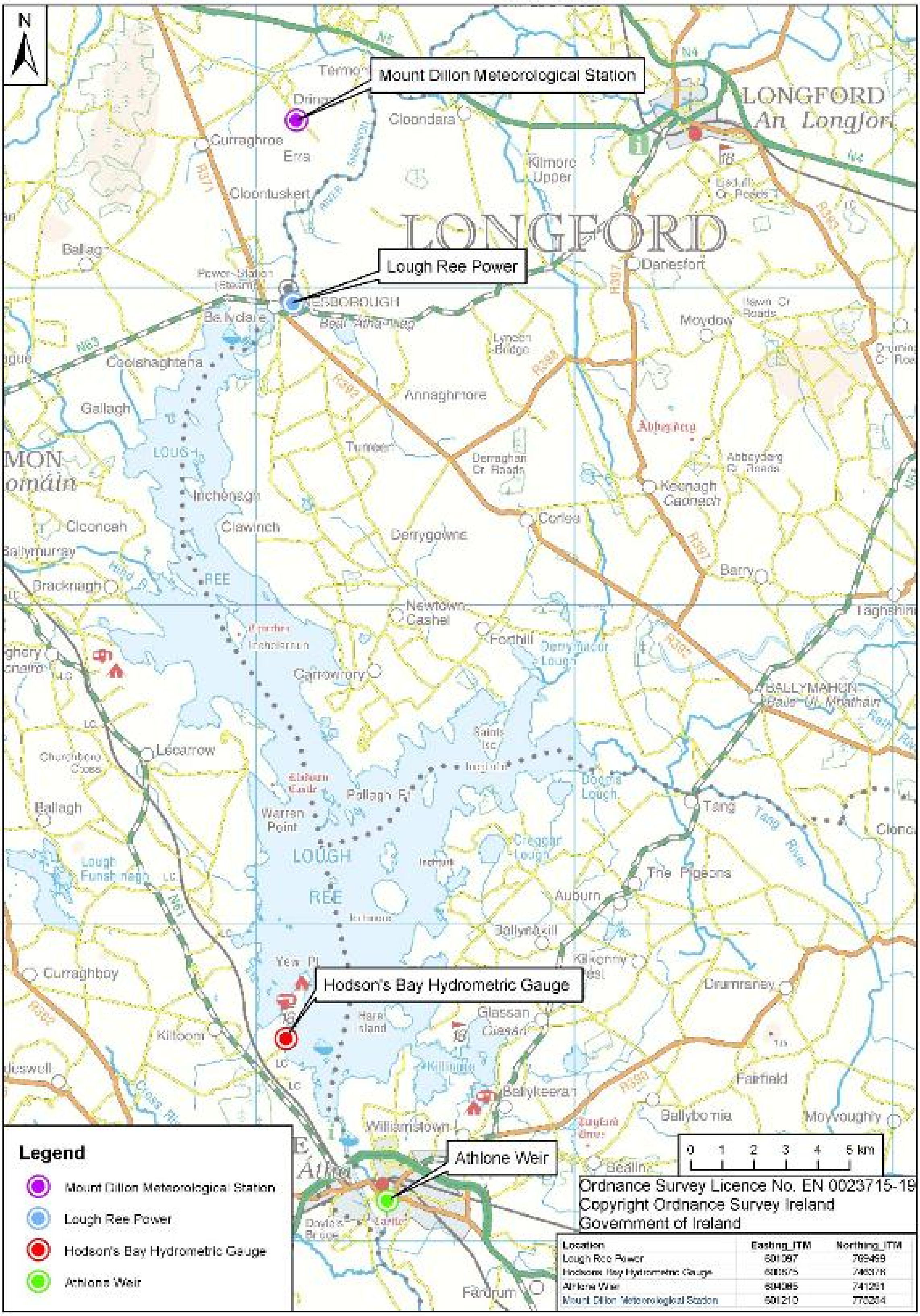
The EPA has advised the use of recorded water levels at the OPW hydrometric gauge (26088) at Hodson's Bay as a reference indicator of flow conditions in the Shannon at Lough Ree Power. The records of water level at Hodson's Bay are available from the OPW website www.waterlevel.ie. The gauge at Hodson's Bay is not rateable.

It should be noted that the operation of the gates at Athlone Weir influences the flow and level regimes in the River Shannon. The water level in Lough Ree is controlled by the weir at Athlone during low flow conditions. The weir at Athlone has 15 gates which can be used to vary the level in Lough Ree and thereby the Hodson's Bay Gauge. The agreed minimum water levels in Lough Ree (measured at the Thatch gauge at Coosane) vary during the year as follows:

- 1st April to 15th of August - 37.49m OD Poolbeg (approx. 2.13m gauge level at Hodson's Bay)
- 16th August to 1st of October 37.19m OD Poolbeg (approx. 1.83m gauge level at Hodson's Bay)
- 1st October to 31st March 36.88m OD Poolbeg (approx. 1.52m gauge level at Hodson's Bay)

The flow at Athlone is controlled to ensure that the minimum water levels in Lough Ree are met. The minimum level required for navigation on the river Shannon upstream of Athlone Weir is 36.88m OD Poolbeg.

Generally, if there is no flooding in the Shannon Callows downstream of Athlone, the water levels in Lough Ree will be drawn down towards the minimum level from October to March to provide for maximum storage for potential winter floods.



Location	Easting_ITM	Northing_ITM
Lough Ree Power	601097	769459
Hodsons Bay Hydrometric Gauge	600575	746376
Athlone Weir	604085	741281
Mount Dillon Meteorological Station	601210	770204

Figure 2-5: Locations of Lough Ree Power, Hodson's Bay Gauge and Athlone Weir

Recorded water level at Athlone can be used to estimate flows over the weir at Athlone. Flows at Athlone can be related to Lanesborough using the relative sizes of catchment areas upstream of both sites as a basis of comparison. However, during low to medium flow conditions, the relationship between flow conditions at Athlone and Lanesborough is unreliable because:

- Lough Ree attenuates, lags and smooths out the natural variation in flow at Lanesborough. For the same water level at Hodson's Bay, there can be significant differences in the flow at Lanesborough.
- The artificial control of the water level at Athlone Weir.

ESB maintains a database of level and flow records from selected gauges on the Shannon (including Athlone) to assist with the operation of Ardnacrusha Hydroelectric Station.

From the ESB database, daily flows at Athlone from 1951 to 2017 were calculated and a flow duration curve produced. The flow duration curve (FDC) (presented in Figure 2-6) shows the proportion of time that specific flow values at Athlone are equalled or exceeded. The long-term average flow in the Shannon at Athlone is approximately 93m³/s.

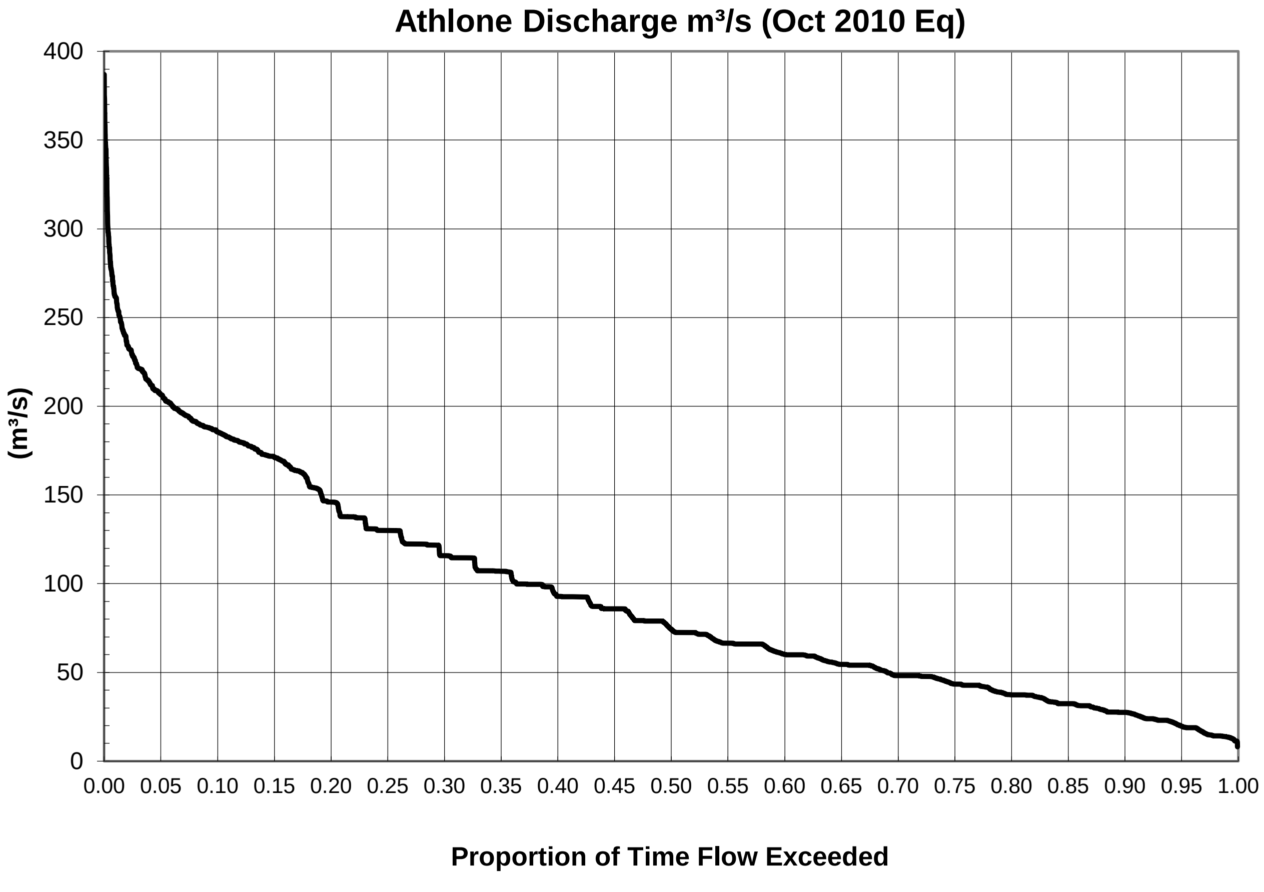


Figure 2-6: Flow Duration Curve - River Shannon at Athlone 1951-2017

2.3 Water Framework Directive

Lough Ree Power Generating Station is located on the Shannon river at Lanesborough in the Shannon catchment water body 26C and just above the uppermost bay of Lough Ree itself. Specifically the power plant and discharge are located in the sub catchment Shannon (Upper)_100 (Code: IE_SH_26S021600) river water body. The thermal cooling water from LRP discharges in an existing channel which forms part of the river within the Shannon (Upper)_010 water body but the thermal plume is known to extend to the bay at the uppermost end of Lough Ree and which is located in the Catchment Water body 26E, see Figure 2-7. It is known from an analysis of water levels in the lake, meteorological conditions and in river and bay temperature monitoring that the Shannon River above Lough Ree is significantly influenced by the water level in Lough Ree and meteorological conditions. Hence, the boundary between river and lake at this location may fluctuate significantly.

The EPA monitors the biological Q value index at the bridge across the Shannon River in Lanesborough, Site Code RS26S021600. This location is less than 230m downstream from the thermal cooling water discharge. This site, is both a Surveillance and Operational monitoring site under the WFD river water monitoring programme. Biological Q values at this location recorded since 2004 are consistently Q3 or Q3-4 with the latest Q value recorded as Q3 in 2014. The WFD status 2010-2015 for the river water body at this location is indicated as “Poor” (EPA Envision database). It is likely that this monitoring location is within the thermal plume mixing zone within the river and the location appropriateness as a WFD Surveillance and Operational monitoring station should be reviewed by the EPA on foot of the in-river survey work carried out by ESB.

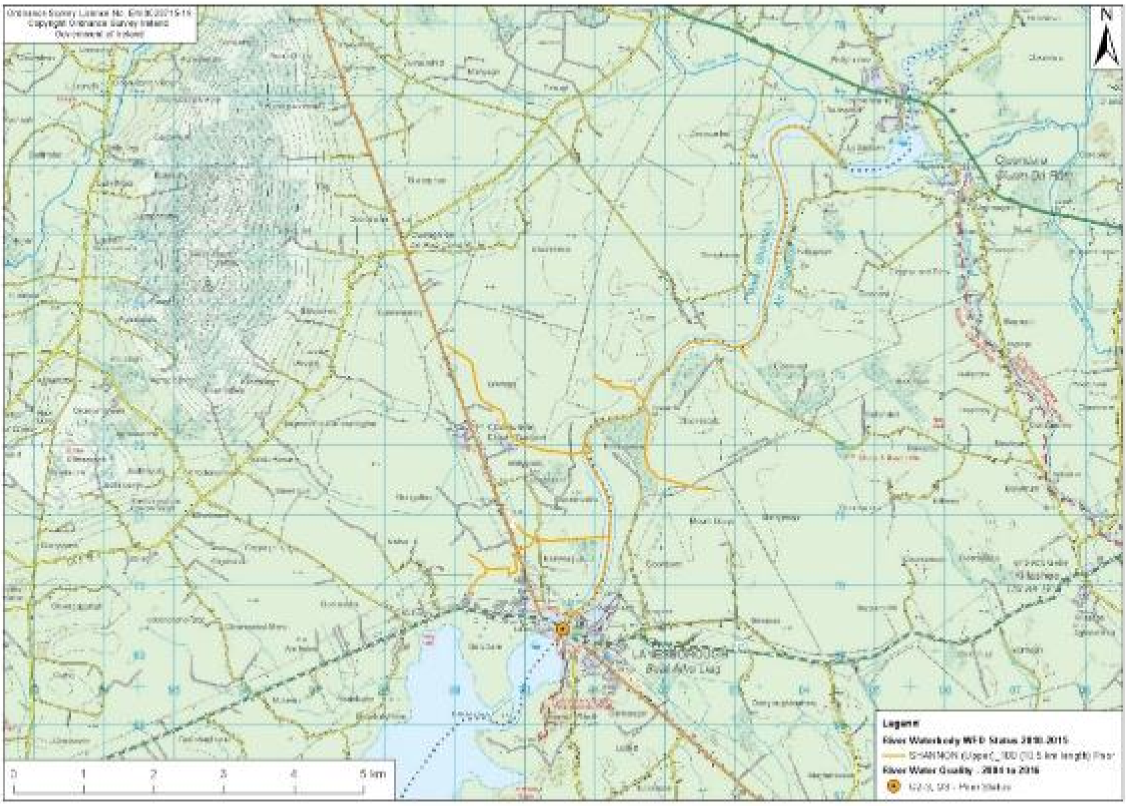


Figure 2-7: WFD river water body status at LRP

2.4 Draft River Basin Management Plan for Ireland 2018 - 2021

Consultation on the draft River Basin Management Plan (RBMP) for Ireland 2018 – 2021 concluded at the end of August 2017. The plan sets out the current status of Irish waters, the key challenges and objectives and the key measures to attain the water status requirements set out in the WFD Directive. The Environmental Objectives for the RBMP remain as follows:

- To prevent deterioration of the status of surface waters
- To protect, enhance and restore surface waters with the aim of achieving good status (ecological and chemical) for all water bodies
- For heavily modified water bodies and artificial water bodies, the aim is to protect and enhance those bodies to achieve good ecological potential and good chemical status
- To progressively reduce pollution from priority substances and cease or phase out emissions, discharges and losses of priority hazardous substances into surface waters

A key prioritisation for the second RBMP Cycle is to:

“Work to improve our knowledge and understanding of hydromorphology and barriers as pressures impacting on water quality, including identifying the scale of these issues, and building the expertise necessary to address them.”

A key measure is the proposal to

“develop and progress a technical solution to enhance fish connectivity in the Lower Shannon focussing around the Ardnacrusha site. Whilst the ultimate outcome here is the development of such a solution – putting in place the necessary structures for delivery of such a project, assigning responsibilities amongst relevant agencies, and developing an appropriate proposal will be key outcomes necessary before implementation of a final agreed project.”

The potential for the thermal discharges from LRP to impact on fish connectivity is therefore a key assessment in terms of understanding whether they act as barriers to achieving fish status required by the WFD and whether any technical solution developed to enhance connectivity at Ardnacrusha would be lessened in effectiveness should this prove both technically feasible and environmentally beneficial.

3 Thermal Plumes Studies

Five boat based surveys of the thermal discharges from Lough Ree Power Generating Station have been undertaken in the River Shannon at Lanesborough since August 2014. The objective of the surveys was to map bathymetry, locate the extent and measure the temperatures of the thermal plume created by the discharge of heated cooling water from the generating station.

The surveys were carried out by Irish Hydrodata (IHD) from a survey launch, to which were attached thermistors at fixed depths below the water surface. The survey method involved steaming the survey boat across the river at varying distances downstream from the discharge location while continuously logging water temperature, position and time data. The surveys were undertaken on

- 1st August 2014
- 4th February 2015
- 20th November 2015
- 1st and 3rd May 2016
- 12th and 13th July 2016

Table 3-1 below presents a summary of hydrological conditions in the Shannon and Lough Ree Power station output during each of these surveys. As noted in Section 2.2 above, river flows at Lanesborough were roughly estimated using data from the hydrometric gauge at Athlone using the relative sizes of catchment areas upstream of both sites as a basis of comparison. In addition, the EPA has advised the use of recorded water levels at the OPW hydrometric gauge (26028) at Hodson's Bay as a reference indicator of flow conditions in the Shannon at LRP. The records of water level at Hodson's Bay used in this report were taken from the OPW website www.waterlevel.ie. (The notes and warnings concerning the source, reliability and use of the data available on this website as set out in http://waterlevel.ie/disclaimer/ are fully acknowledged.)

Wind speed and direction can have a significant influence on the behaviour of a thermal plume. Historic wind records from the Met Éireann station at Mount Dillon, Co. Roscommon, were used to consider conditions at Lanesborough.

Date	Hodson's Bay Level m	Flow at Athlone m^3/s	Estimated Flow at Lanesborough m^3/s	Station Output MW
01/08/2014	2.165	19	11	100
04/02/2015	3.138	188	113	100
20/11/2015	3.037	164	98	100
1st and 3rd May 2016	2.515	55	33	66
12th and 13th July 2016	2.522	55	33	98

Table 3-1 Flow and Load Conditions during thermal plume surveys at LRP

The surveys of February and November 2015 were undertaken during high flow conditions in the Shannon and they showed that the size of the thermal plume was negligible with respect to the river cross-section and the station was fully compliant with Condition 5.5 of its IEL.

The surveys of August 2014, May 2016 and July 2016 were undertaken when river flows were below annual average conditions.

As noted in Section 2.1 above, the river Shannon at Lanesborough has two distinct channels from just upstream of the Lough Ree Power cooling water outfall. At the eastern side, there is a narrow shallow channel approximately 30 metres wide which is separated from the main channel by a series of reed bed islands which extends downstream for approximately 450 m. At this point, prior to entering the main body of Lough Ree, the Shannon passes through a small bay for approximately 900m. See Figure 3-1.

Figure 3-1. River Shannon at Lanesborough

Flows in the River Shannon were low (95 percentile at Athlone) during the 1st August 2014 survey. This survey showed that the thermal plume covered the surveyed width of the River Shannon channel downstream of the eastern outfall channel and the entire depth of water. The bay upstream of the main part of Lough Ree was covered to a depth greater than 2m which was the depth of the lowest thermistor. The level at Hodson's Bay gauge on the 1st of August 2014 was 2.16 m. Condition 5.5 of the IEL was breached.

Water levels were fairly typical of average conditions during the 1st to 3rd of May 2016 survey. This survey showed that the thermal plume was mainly confined to the outlet channel and a small section of the bay upstream of the main part of Lough Ree. It reached a distance of 625 m downstream of the outfall. Just downstream of the N63 road bridge at a distance of 425 m downstream of the outfall, the thermal plume extended into the main channel due to a gap in the reed bed. If the eastern channel is excluded from the calculations of the cross sectional area, Condition 5.5 of the IEL was breached at this one location. If the outfall channel is included in the calculations then Condition 5.5 has been breached in a 200 m long section of the river from just downstream of the N63 road bridge to Lough Ree. During this survey the station was only at 66% of full load. The levels at the Hodson's Bay gauge during the 1st to 3rd of May 2016 were between 2.51 and 2.53 m. The wind direction was mainly from the South West and the wind speed was approximately 18 km/hr, Force 3 on the Beaufort scale.

Waters levels were typical of average conditions during the 12th and 13th of July 2016 survey. This survey showed that the thermal plume was mainly confined to the eastern outlet channel and a small section of Lough Ree. It reached a distance of 800 m downstream of the outfall. Just downstream of the road bridge the thermal plume extended into the main channel due to a breach in the reed bed. During this survey the station load was at 98% of full load. The water level at Hodson's Bay gauge during the 12th and 13th of July 2016 was approximately 2.52 m. The wind direction was mainly from the West North West and the wind speed was approximately 19 km/hr, Force 3 on the Beaufort scale. Condition 5.5 of the IEL was not breached. However at 625 m downstream of the outfall at the mouth of Lough Ree the cross sectional area of the thermal plume was 24% of the cross-section area of the Shannon at this location.

It should be noted that the water level at the Hodson's Bay hydrometric gauge and the calculated flow at Athlone is not a good indicator of the flow in the River Shannon at Lanesborough when the river is not in flood. Levels in Lough Ree can be artificially lowered by opening the gates in the weir at Athlone. In May 2016 the water levels at Hodson Bay were on a downward trajectory indicating that the flow at Athlone was greater than the inflow into Lough Ree. In July 2016 the water levels at Hodson Bay were on an upward trajectory indicating that the flow at Athlone was less than the inflow into Lough Ree.

Non-conformances arising from the results to the survey of August 2014 are set out in Table 3-2.

Non Compliance NC004844 for Electricity Supply Board (Lanesborough) (P0610-02)	
Non Compliance Type:	ELV exceedance
Non Compliance Condition:	5.5
Notification Date:	20/03/2015
Date of Non-Compliance (1st Date if relates to a period):	01/08/2014
Last Date of Non-Compliance in calendar month (if a period)	
Description:	
The results of the August 2014 thermal plume survey on the River Shannon at Lanesborough during conditions of low flow identified several downstream river cross-sections where the mixing zone exceeded 25% of the surveyed cross-section of the river. The thermal plume is in excess of 1.5 degrees Centigrade outside of the mixing zone (i.e. In relation to temperature, the mixing zone shall not exceed 25% of the cross sectional area of the river at any point). This is a non-compliance with Condition 5.5 of IE Licence P0610-02.	

Non Compliance NC004846 for Electricity Supply Board (Lanesborough) (P0610-02)	
Non Compliance Type:	Miscellaneous
Non Compliance Condition:	5.1
Notification Date:	20/03/2015
Date of Non-Compliance (1st Date if relates to a period):	01/08/2014
Last Date of Non-Compliance in calendar month (if a period)	
Description:	
The results of the August 2014 thermal plume survey on the River Shannon at Lanesborough during conditions of low flow identified that temperatures of more than 1.5 degrees Centigrade above the ambient temperature were maintained for 2.2 km downstream of the discharge from PS-SW1. The Agency considers this to be an emission of environmental significance. This is a non-compliance with Condition 5.1 of IE Licence P0610-02.	

Table 3-2 LRP Non-Conformances associated with results of survey of August 2014.

The following Compliance Investigation (CI) is related to the survey of August 2014.

- CI 896, Opened 13/11/2014. Risk–Medium. Status – Active

4 Continuous Temperature Monitoring

4.1 Introduction

Following the thermal plume studies described in Section 3 above, a programme of continuous temperature monitoring was instigated in July 2016 at seven fixed locations in the River Shannon in the vicinity of Lough Ree Power at Lanesborough. At each location, between two and four temperature thermistors with loggers were deployed to measure and record temperatures at 0.3m, 0.8m and where possible, at 1.5m and 3.0m below the water surface. Figure 4-1 below maps the locations of the continuous monitoring points, which are designated as points L1 to L7. The locations are tabulated in Table 4-1.

Figure 4-1: Continuous Monitoring Points at LRP

One location is at the intake (designated as L1) and the remaining six are downstream of the outfall.

ID	Location	Easting (m ITM)	Northing (m ITM)	Logger Depth T1 (m)	Logger Depth T2 (m)	Logger Depth T3 (m)	Logger Depth T4 (m)
L1	Intake	600798	769660	0.3	0.5	1.5	
L2	Outfall discharge	600609	769512	0.3	0.5		
L3	Discharge channel u/s of bridge	600548	769406	0.3	0.5	riverbed	
L4	Bridge pier	600476	769397	0.3	0.5	riverbed	
L5	Discharge channel d/s of bridge	600394	769194	0.3	0.5	1.5	
L6	Ballyleague Marina breakwater	600259	769206	0.3	0.5	1.5	3.0
L7	Bay leading to L. Ree	600255	768833	0.3	0.5	1.5	

Table 4-1: Continuous Monitoring Points at LRP

The programme of continuous monitoring has been ongoing since the 11th of July 2016. Temperature records at 5 minute intervals are available from that date up to December 31st 2017. In addition, the assessment considered station load (MW), flow conditions in the River Shannon, water levels at Hodson's Bay and meteorological conditions. The results of the continuous monitoring are discussed below in Sections 4.2 , 4.3 and 4.4.

4.2 Thermal Plume

From a review of the continuous temperature data for locations L1 to L7, LRP station load, meteorological records and the water levels at Hodson's Bay hydrometric gauge (See Figure 4-3 below), the following conclusions are drawn for the period 11/07/2016 to the end of April 2017:

- Below average rainfall in the period resulted in low water levels and low flows in the river Shannon at Lanesborough. The water level at Hodson's Bay has been below the 50 percentile level of 2.61 m for 77% of the time. Levels above the 50 percentile level occurred between the 31/12/2016 to 22/01/2017 and between 27/02/2017 to 12/04/2017. The maximum level reached between 31/12/2016 and 22/01/2017 was 2.7 m just above the 50 percentile level and occurred on the 09/01/2017. The maximum level reached between 27/02/2017 and 12/04/2017 was 3.169 m (just below the 10 percentile level of 3.175 m) occurred on the 12/03/2017. The percentile levels have been obtained from the OPW web site www.waterlevel.ie
- The thermal plume is mainly confined to the confined eastern channel of the river where the outfall occurs until it reaches the entrance to Lough Ree.
- When Hodson's Bay levels are at or below the 50 percentile value, the thermal plume takes up the entire cross section of the eastern outfall channel and there is very little temperature dissipation at points L2 and L3. Above the 50 percentile level there is significant temperature loss at points L2 and L3.
- There is no evidence of the thermal plume in the main river channel at Location L4 from the 11/07/2016 to the beginning of May 2017 with the exception of a few short periods. The short periods of elevated temperature occurred on 12/08/2016, 16/10/2016, 2/02/2017, 23/02/2017, 24/042017, 25//04/2017 and 26/04/2017. These periods were of short duration no longer than 2 to 3 hours and cannot be explained.
- The thermal plume is not observable at point L5 (which is located at the mouth of the outfall channel as it enters the inlet bay to Lough Ree) when water levels are above the 25 percentile Hodson's Bay level of 2.904 m. The temperature rise is still significant at point L5 when levels are below the 50 percentile level. Similar to location L3, the temperature rise decreases with increasing flow.
- At location L6 at Ballyleague Marina on the west bank of the river Shannon opposite L5, the plume is only observable when the wind is from a southerly direction or during calm conditions. The temperature spikes at Location L4 can also be observed.
- At location L7 which is approximately 400m downstream of the mouth of the outfall channel on the east bank, the thermal plume is only observable when the wind is from a northerly direction.
- Over the monitoring period the thermal plume is not observable at both L6 and L7 at the same time except for a short period of approximately 14 hours on 21/02/2017. This

occurred when flows were low and the wind was from a southerly direction. From the continuous temperature monitoring at the 6 locations downstream, it is not possible to determine if the thermal plume covers more than 25% of the cross sectional area at any location except for a period on the 21/02/2017.

From April 2017 to the 07/09/2017, the following conclusions can be made:

- Very low flows occurred in the river Shannon at Lanesborough until the 20/08/2017. During this period water levels in Lough Ree were being controlled to ensure that the minimum water level would be achieved for the summer period. Therefore the water level at the gauge at Hodson's Bay is not a good indicator of flow at Lanesborough.
- There is evidence of the simultaneous presence of thermal plume at all monitoring locations on a number of occasions.
- From the 20/08/2017, flows increased with a corresponding decrease in the size and extent of the thermal plume. From the 1/09/2017 the thermal plume is not observable at locations L4 or L6.
- When flows were around or below 30 m^3/s at Athlone weir, it appears that the thermal plume extended across both channels of the river at Lanesborough. It also appears the thermal plume covered a significant portion of the inlet bay to Lough Ree just downstream of Lanesborough.

Lough Ree Power was off load from the 07/09/2017 for a major outage and returned to service on the 21/11/2017.

From 21/11/2017 to the end of December 2017 (latest data), the following conclusions can be made:

- The water level at Hodson's Bay has been above the 50 percentile level of 2.614 m for 100% of the time. The maximum level reached was 3.182 m (just above the 10 percentile level of 3.175 m) and this occurred on the 31/12/2017.
- The thermal plume is mainly confined to the eastern outfall channel until it reaches the entrance to Lough Ree.
- There is no evidence of the thermal plume in the main river channel at Location L4 to the end of December 2017.
- The thermal plume is not observable at point L6 at Ballyleague Marina on the west bank of the river Shannon opposite L5 to the end of December 2017.
- At location L7 which is approximately 400m downstream of the mouth of the outfall channel on the east bank, the thermal plume is not observable during this period.

Figure 4-2 presents a summary of recorded water levels at the Hodson's Bay gauge since the start of the monitoring programme taken from www.waterlevel.ie.

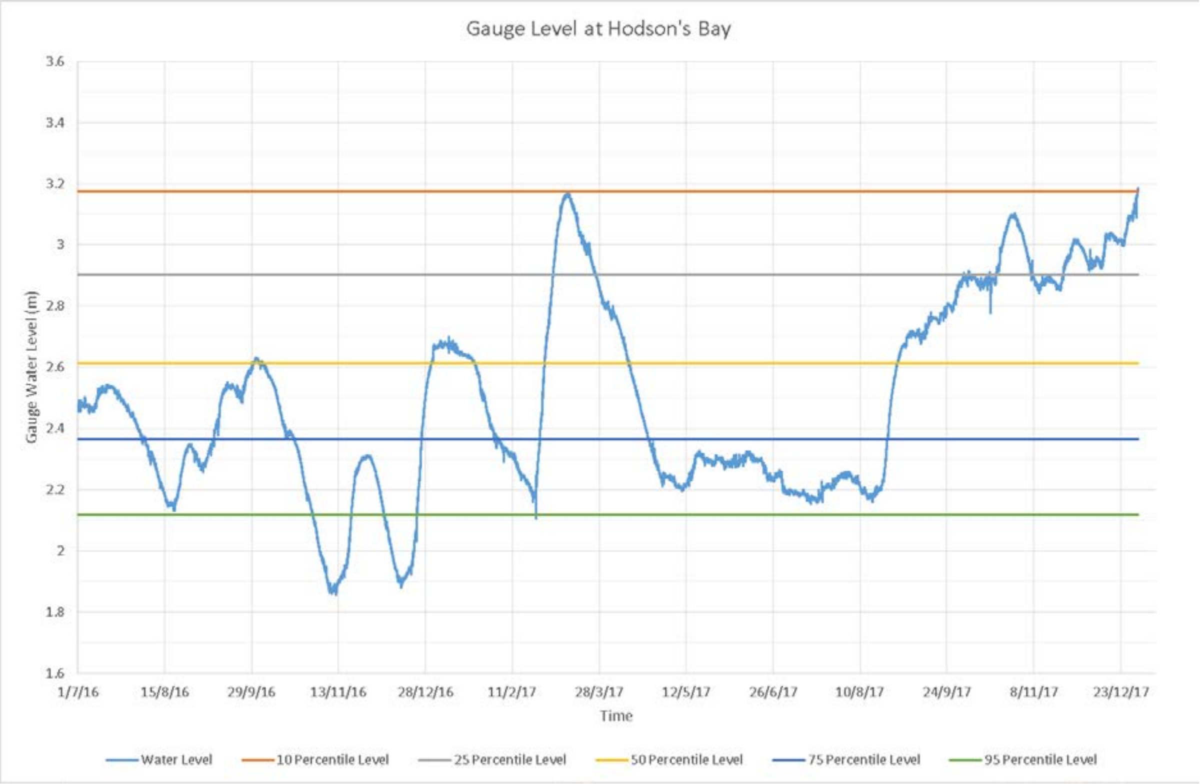


Figure 4-2: Water Level at Hodson's Bay (www.waterlevel.ie.)

4.3 General Ambient Temperature Trends

L1 measures the ambient temperature at Lanesborough. The water temperature is measured at depths of 0.3m, 0.5m and 1.5m from the water surface. The temperature measurements show:

- The temperature is uniform throughout the water column. Temperature measurements taken during the thermal plume surveys of May and July 2016 also show this uniformity.
- The diurnal variation is temperature is generally less than 1 ^{o}C
- There is a distinct seasonal variation in temperature with maximum temperatures occurring in June and July and minimum temperatures in December and January. It appears that the main factors that affect the ambient water temperature is air temperature, sunshine and the length of the day.

Figure 4-3 show the trends in background temperature (i.e. the temperature at 0.3 m depth upstream of the thermal discharge) for each of the 13 reporting periods (from July 2016 to December 2017) at LRP.

At LRP, the highest ambient river temperatures (20-22°C) occurred in the 3 recording periods July-August (mainly July) (2016), late May- late June (mainly June) (2017) and June –August (mainly July) 2017. Temperatures were generally below 10°C in the period November to March in both years, between 10°C and 15°C mainly in September and October in both years and between 15°C and 20°C+ between late April and August.

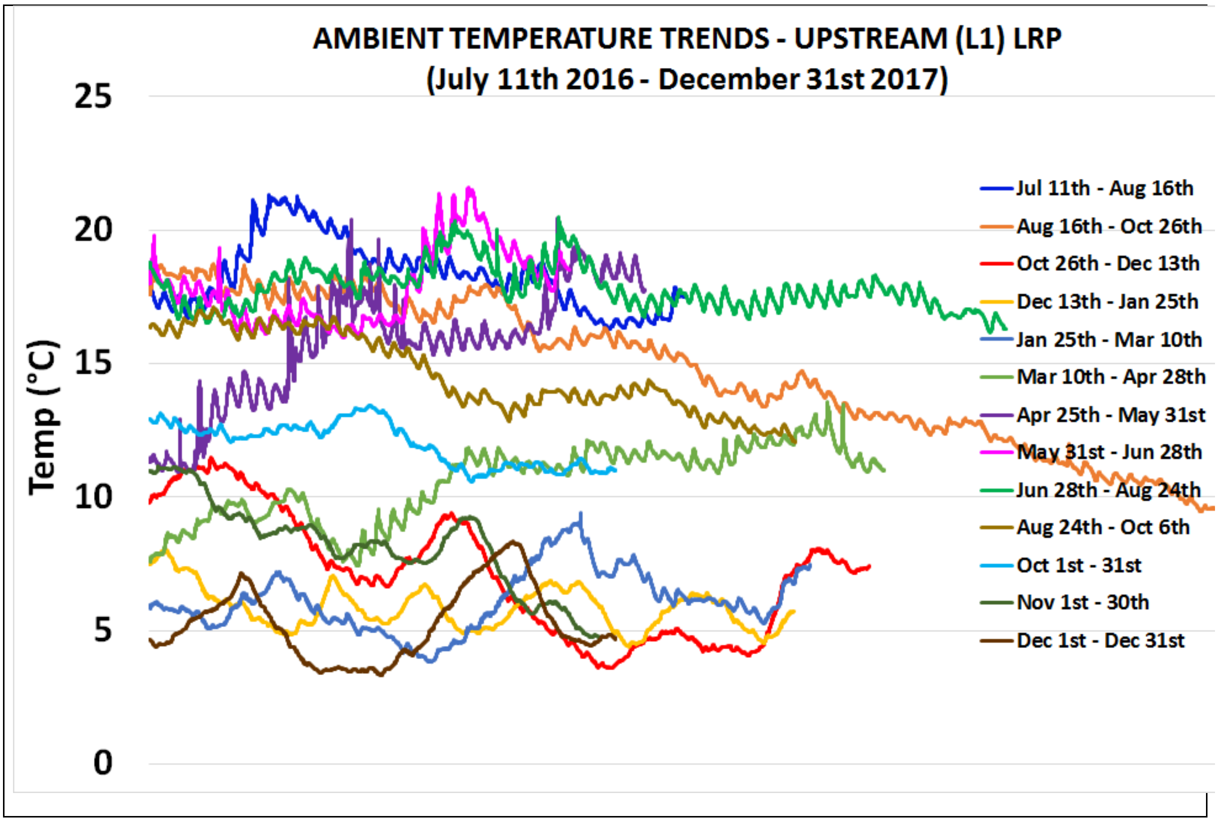


Figure 4-3: Upstream (L1 - ambient) temperatures at 0.3m depth at LRP for 13 reporting periods between July 2016 and December 2017.

4.4 Temperature Averages

The cooling water discharge from Lough Ree Power has a positive buoyancy. The maximum temperature rise will occur at the surface and decrease with depth. Points L2 and L3 are very close to the outfall and at low to medium flows there is very little temperature variation between the surface and bottom thermistors.

Figure A-1 in Appendix A, presents for each of the 13 reporting periods, the average and maximum absolute temperatures at each of the LRP stations at each depth (left side graphs) and the incremental increase in average temperature at each of the stations downstream of the cooling water discharges, also at each depths (right side graphs). The latter were calculated by subtracting the average upstream (ambient) temperature at each depth (0.3m, 0.5m and where relevant 1.5m and 3.0m) from the corresponding average temperature at the downstream stations for each of the eight sample periods in turn.

These data show that, in terms of average absolute temperature, each LRP site essentially followed the same trend in each of the first six reporting periods even though, as expected, temperatures dropped steadily from an upstream ambient of about 18°C throughout the monitoring period from July/August 2016 to a January/ March 2017 average of just 5.8°C. The small vertical bars denote standard deviation and these have a tendency to be widest at Site L5 where there tends to be a greater degree of fluctuation between the 0.3m and 1.5m temperature compared to most sites at any given time.

In terms of average incremental temperature increases, the differences between sites was very pronounced with Sites L2, L3 and L5 on the eastern side of the river displaying by far the highest incremental increases in temperature consistent with the shallow nature of this channel and the direct discharge of the thermal cooling water into it. In the case of Sites L2 and L3, the temperature was generally the same as or close to what would be expected at the point of discharge i.e. 7-8°C above the intake (i.e. upstream) temperature. Sometimes Site L3 was 1 to 1.5°C lower than Site L2, with Site L5 being 1-2 degrees cooler again, at the surface. However, the latter site differed from Sites L2 and L3 in that it showed, on average, a pronounced drop in temperature between the 0.3m and 1.5m depths, with the lower site showing relatively a more pronounced temperature drop. In contrast, there was generally very little difference in average temperatures at each depth at Sites L2 and L3. This shows that conditions at Site L5 were the most variable of all the sites and this may be because it's at the point where the flow from the distinct channel into which the cooling water discharge occurs is beginning to mix properly with the water from the main river flow and also expand out into the bay area at the northern end of Lough Ree.

What is also clear from the data, is that during the first 6 monitoring periods, on average Site L4 on the right bank side of the river (i.e. in the main channel) was essentially unaffected by the thermal discharge showing almost no incremental increase in temperature. Furthermore, downstream at the entrance to the bay area on the same side of the channel at Site L6, the average rise in temperature was less than 1 degree above background for the same period. However, in the next 3 monitoring periods, i.e. April/May, May/June and June/August 2017 2017, there was a noticeable change in this pattern in that Site L4 for the first time registered an average incremental increase in temperature ranging from 2.5-3°C above ambient from 1.5m deep to the surface (0.3m). Also, during these 3 periods the average incremental increase in temperature at Sites L6 and L7 was noticeably higher than in the 6 earlier reporting periods, particularly at Site L6. The reason for these changes, in particular at Sites L4 and L6, is speculated to relate to flow levels in the river, with lower flows resulting in a greater intrusion of heated water from the distinct channel into which the cooling water discharge occurs on the eastern side of the central islands across to the western right bank side of the central islands at such times (pers comm IHD).

In terms of maximum absolute temperatures, the highest recorded were in the first recording period (July/August 2016) when 30°C was recorded at Sites L2 and L3 and came close to that again in May/June 2017 when a maximum of just over 29°C was recorded at the same sites. This would be consistent with the thermal cooling water flow comprising practically all the flow in the confined channel. The corresponding upstream (Site L1) surface maxima were 21.3°C and 21.6°C respectively.

The following non-conformances arising from the results to the programme of continuous monitoring have been logged:

Non Compliance NC009142 for Electricity Supply Board (Lanesborough) (P0610-02)	
Non Compliance Type:	ELV exceedance
Non Compliance Condition:	5.5
Notification Date:	16/08/2017
Date of Non-Compliance (1st Date if relates to a period):	16/08/2017
Last Date of Non-Compliance in calendar month (if a period)	
Description:	
The continuous monitoring temperature data for Period 6: March - April 2017 and Period 7: April - May 2017 on the River Shannon at Lough Ree Power demonstrated that the combined cooling water and screen wash water discharge (Emission point reference number: PS-SW1 (Combined PS-SW1 and PS-SW2)) artificially increased the ambient temperature of the receiving water by more than 1.5 degrees centigrade. The data also demonstrated that the mixing zone for temperature exceeded 25% of the cross-sectional area of the river. Temperature increases were noted on both east and west banks and in Lough Ree.	
Non Compliance NC009535 for Electricity Supply Board (Lanesborough) (P0610-02)	
Non Compliance Type:	ELV exceedance
Non Compliance Condition:	5.5
Notification Date:	17/10/2017
Date of Non-Compliance (1st Date if relates to a period):	17/10/2017
Last Date of Non-Compliance in calendar month (if a period)	
The continuous monitoring temperature data for Period 8: May - June 2017 and Period 9: June - August 2017 on the River Shannon at Lough Ree Power demonstrated that the combined cooling water and screen wash water discharge (Emission point reference number: PS-SW1 (Combined PS-SW1 and PS-SW2)) artificially increased the ambient temperature of the receiving water by more than 1.5 degrees centigrade. The data also demonstrated that the mixing zone for temperature exceeded 25% of the cross-sectional area of the river. Temperature increases were noted on both east and west banks and in Lough Ree.	

Table 4-2 LRP Non-Conformances associated with results of continuous temperature monitoring.

5 Fisheries

In July 2016, ASU undertook a review of the thermal sensitivity and related biology of each of the fish species recorded on the main channel of the Shannon by Inland Fisheries Ireland (IFI) in 2010 from or near the Lough Ree Power (LRP) facility and the theoretical risk that the thermal discharges might pose for them (ASU,2016 a). In addition, in September 2016, ASU produced a second shorter report in response to specific questions posed by IFI in response to the review (ASU, 2016 b). Both of these documents will be referenced as required in the following fisheries-related aspect of the synthesis report. However, the greater emphasis in this section will be on the findings of the 5 separate fyke-net surveys undertaken by Denis Doherty, ESB Fisheries Scientist, between August 2016 and December 2017 at LRP as these are to date the most focused fisheries surveys at these sites (Doherty, 2017). Reference will also be made to the results of a Water Framework Directive (WFD) fish monitoring surveys undertaken by IFI on the Shannon in 2010 and 2016 both upstream and downstream of Lanesborough.

5.1 Fyke Net Surveys

The 5 fyke net survey campaigns were undertaken by Denis Doherty (ESB Fisheries) and his team in August 2016, October 2016, February 2017, November 2017 and December 2017. Each survey consisted of 10 sets of three fyke nets set at 5 paired sites i.e. 5 along the right (west) bank and left (east) bank of the river, the first pair situated upstream of the power station thermal discharge (Doherty, 2017). The locations of each set of nets at are presented in Figure 5-1. The distribution of nets cover the same stretch used for biological sampling (2014-2016).

Table 5-1 lists the dates of the surveys and the maximum temperatures recorded at the same or nearby sites during the week of the surveys at LRP. Figure 5-2 presents the depth averaged average temperatures at each of the fishing sites for each of the three seasonal surveys. These data have been extracted from the IHD continuous temperature monitoring data for LRP for the weeks commencing on the survey dates or dates bracketing the survey dates as indicated in Table 5-1. As the two sets of data do not overlap precisely in terms of locations, the nearest logical site or combination of sites for the temperature monitoring was used to represent temperature data at the nearest left and right bank fishing sites.

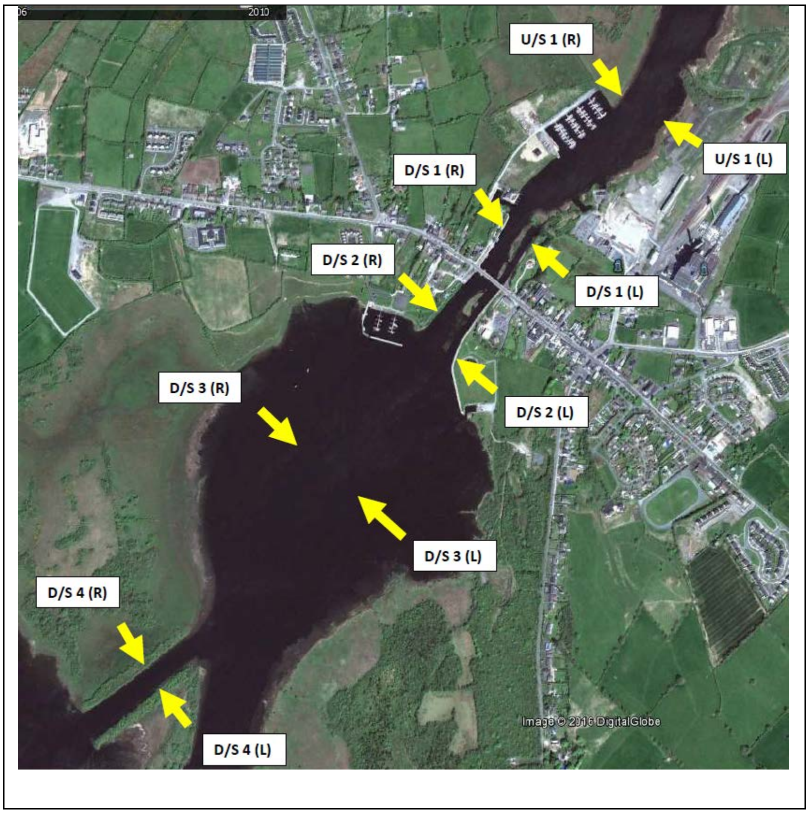


Figure 5-1 Aerial photos showing fyke net fishing locations in the Shannon River at LRP

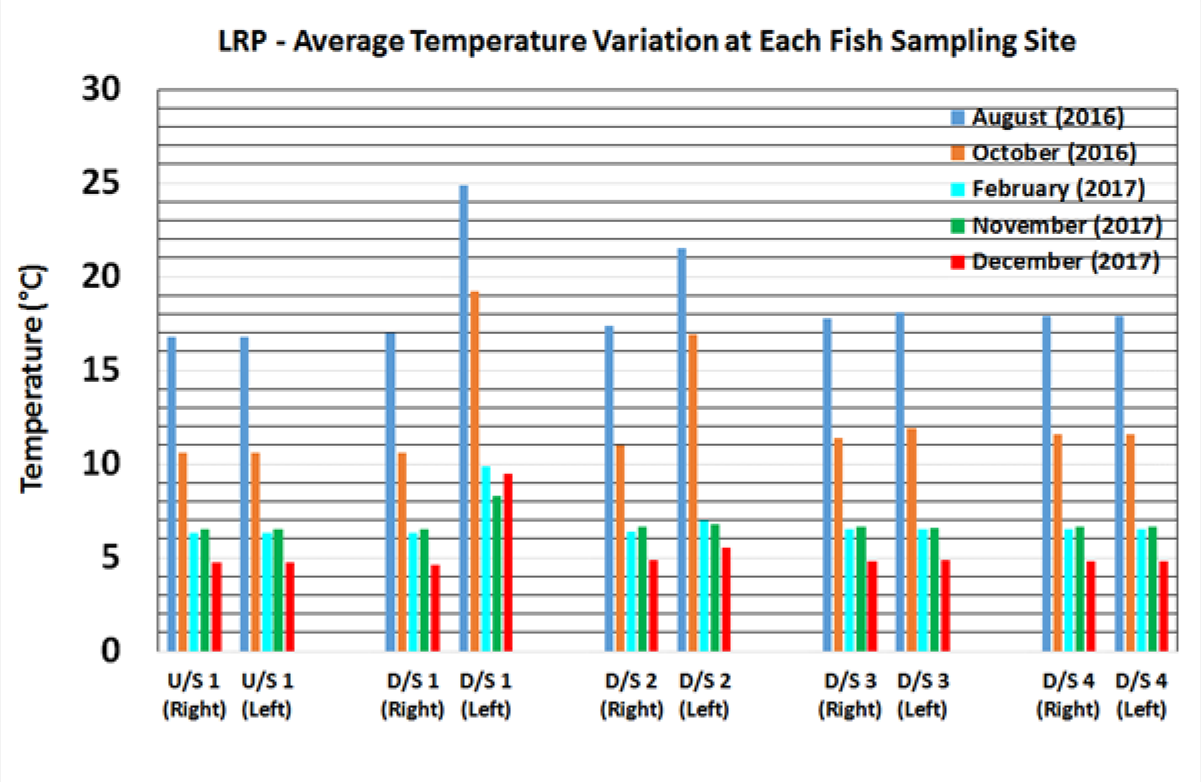


Figure 5-2 Average depth-averaged temperature at or nearby the 5 paired fyke net sampling stations at LRP for each of the 5 fishing surveys. (Data extracted from IHD temperature monitoring reports)

5.1.1 Species Present and Overall & Relative Abundances

Table 5-2 lists the 10 fish species caught at LRP in decreasing order of total abundance over the five survey periods, as well as a breakdown of numbers for each species for each survey. Table 5-3 presents the individual fish numbers taken in each net during each survey. Figure A-2 in Appendix A shows the relative abundance for each species in all surveys, while Figure A-3 in Appendix A shows the same data broken down by each survey (August 2016 to December 2017).

The list in Table 5-2 is dominated in terms of species and numbers by coarse fish and eel whereas brown trout and pollan (salmonids and coregonids) were generally represented by small and very small numbers respectively, with just a single pollan (*Coregonus atumnalis*) recorded, in October 2016.

An obvious feature of the data was the higher number of fish taken in the August 2016 survey compared to subsequent surveys. During the later months, numbers ranged from about just 12.5% to 33% of the August numbers at LRP, with the lowest total (36 fish) recorded in the November 2017 survey. This may be because the much lower temperatures during the surveys reduced the likelihood of capture due to lower fish activity rates. It may also reflect the movement away from the sites of some species, perhaps to lake waters or to deeper areas of the river during winter. In February 2017, eels were almost numerically as high in LRP as in August 2016, although making up a much higher portion of the catch (Table 5-2 and Figure A-3). This is considered by Denis Doherty to be due to the later out-migration of silver eel on the Shannon in 2016, which was corroborated by the records of eel numbers at Killaloe Weir for the 2016/2017 period (Doherty, 2017).

Survey Dates W/C	**U/S Temp (°C)**	**Range of D/S Surface Max Temp (°C)**
	Shannon River at LRP	**Shannon River at LRP**
Aug 8th 2016	17.8	20.5 - 25.7
Oct 17th 2016	11.1	12.4 -17.7
Feb 27th 2017	7.4	7.7 - 13.5
Nov 21st-28th 2017	5.5-8.5	5.6-14.6
Dec 16th – 21st 2017	3.3-6.8	3.2-12.5

Table 5-1 Fyke net survey dates and maximum temperatures in the Shannon river at LRP during the surveys.

LRP	Perch	Eel	Roach	*Hybrids	Tench	Trout	Pike	Bream	Gudgeon	Pollan	Tots
Aug 2016	183	59	37	13	4	-	6	5	-	-	**307**
Oct 2016	26	14	16	6	18	2	4	-	1	1	**88**
Feb 2017	4	46	2	16		4		3			**75**
Nov 2017	10	6	16			3			1		**36**
Dec 2017	2	2	28	4	-	6	3	2	-	-	**47**
Tots	**225**	**127**	**99**	**39**	**22**	**15**	**13**	**10**	**2**	**1**	**553**
%	**40.7**	**23**	**17.9**	**7.1**	**4**	**2.7**	**2.4**	**1.8**	**0.4**	**0.2**	

* roach x bream

Table 5-2 Total of each species caught during each survey in the Shannon river at LRP in decreasing order

August 2016 (8th)										
Site	**Perch**	**Roach**	**Bream**	***Hybrids**	**Eel**	**Tench**	**Pike**	**Gudgeon**	**Pollan**	**Trout**
U/S 1 - R	9	4		1						
U/S 1 - L	24	5			2					
D/S 1 - R	41	4	1	6	32	2	1			
D/S 1 - L	18	8		4	5	1	1			
D/S 2 - R	11	4	1		10	1				
D/S 2 - L	21	2	1	1	2					
D/S 3 - R	9				1					
D/S 3 - L	17	2	1	1	5		1			
D/S 4 - R	18	3	1		1		1			
D/S 4 - L	15	5			1		2			
October 2016 (17th)										
Site	**Perch**	**Roach**	**Bream**	***Hybrids**	**Eel**	**Tench**	**Pike**	**Gudgeon**	**Pollan**	**Trout**
U/S 1 - R	1	2								
U/S 1 - L		2								
D/S 1 - R		1			6				1	2
D/S 1 - L	8	4		3	2	11	1	1		
D/S 2 - R	1			1						
D/S 2 - L	2	1		1	4	5	2			
D/S 3 - R										
D/S 3 - L	4				1	2				
D/S 4 - R	10	4			1		1			
D/S 4 - L		2		1						

Table 5-3 Fish numbers caught at each site in the Shannon River at LRP in the 5 surveys

February 2017 (27th)

Site	Perch	Roach	Bream	*Hybrids	Eel	Tench	Pike	Gudgeon	Pollan	Trout
U/S 1 - R				1	5					
U/S 1 - L				1	6					
D/S 1 - R	2	1	1		6					1
D/S 1 - L				4	7					1
D/S 2 - R	2		1	1	2					
D/S 2 - L				3	10					1
D/S 3 - R		1	1	1	1					
D/S 3 - L				3	7					1
D/S 4 - R				1	1					
D/S 4 - L				1	1					

November 2017 (26th)

Site	Perch	Roach	Bream	*Hybrids	Eel	Tench	Pike	Gudgeon	Pollan	Trout
U/S 1 - R		5								
U/S 1 - L	4	3								1
D/S 1 - R					1					
D/S 1 - L		3								
D/S 2 - R										1
D/S 2 - L		2								
D/S 3 - R	3									
D/S 3 - L		2			1		1			
D/S 4 - R	1				2					
D/S 4 - L	2	1			2					1

December 2017 (19th)

Site	Perch	Roach	Bream	*Hybrids	Eel	Tench	Pike	Gudgeon	Pollan	Trout
U/S 1 - R	1	5		2						1
U/S 1 - L		7	2	1						1
D/S 1 - R		1								2
D/S 1 - L	1	3					1			
D/S 2 - R		2								
D/S 2 - L		2		1						
D/S 3 - R		2					1			
D/S 3 - L		2					1			
D/S 4 - R		1			1					2
D/S 4 - L		3			1					

*Hybrids = Roach x Bream

Table 5-3: Contd.:

5.1.2 Possible Temperature Related Affects in the Data

In order to discern possible temperature-related effects in the data, numbers of each species captured in left bank nets (i.e. on the warmer water side of the channel) and in the right bank nets (i.e. on the cooler water side of the channel) were plotted for each of the 5 survey events at LRP (Table 5-3). While it is important to bear in mind that these are aggregate totals for netting sites along each bank in each case, including the single left and right bank nets upstream of each station, nevertheless a number of trends were apparent. Firstly, in most cases most species were taken in broadly similar numbers at both sides of the channel. Moreover, the apparent preference for one side or the other in any given species could vary from one survey to the next and finding definite patterns was generally not easy. The single pollan taken in the October 2016 survey at LRP was taken on the cooler side of the river, specifically at D/S 1 (R) (Figure 5-3 and Table 5-3). Given that pollan (primarily known as a lake species) is a cold-water species, it isn't surprising that it would be found during one of the cooler survey periods and also in a cooler part of the channel. Trout are another fish that appear to be showing temperature preferences. They were absent from catches during August 2016 even though upstream and right bank temperatures were close to optimum for the species i.e. ~17°C. This agrees with the findings of the 2016 IFI survey on the Shannon undertaken in July (IFI, 2017) which showed that at 23 main channel sites, not a single trout was recorded. Their 2010 survey, undertaken in May also recorded no trout on the main channel. During the other 4 survey months (Oct, Feb, Nov, Dec) trout seemed to have a more or less equal chance of being recorded on the right or left sides of the channel, and therefore didn't display a discernible temperature preference. It is worth noting that brown trout is one of the most temperature sensitive of all salmonids and is much less capable of dealing with elevated temperatures than any of the fish taken in the fyke net surveys, with the possible exception of pollan.

Eel at LRP showed an apparent preference for right bank (i.e. cooler water) nets in August but the opposite trend was evident in February when similar overall numbers were recorded. The fisheries literature review (ASU, 2016) clearly demonstrated that eel are a thermally tolerant species and none of the temperatures recorded at any netting sites at LRP is likely to have presented a thermal challenge to the species in any of the five fyke net surveys.

At LRP, neither perch nor roach appear to be showing a strong left-right preference, with perhaps a marginal left preference in the data overall for roach.

Roach x bream hybrids overall appear to show a slight left bank preference at LRP (Figure 5-3 and Table 5-3).

Of the remaining species tench showed a very strong left-side bias in the October 2016, which might suggest a definite attraction for the warmer waters of the discharge channel. This would concur with Daufresne and Boet (2007) who included tench in the guild of freshwater fish in France with the greatest affinity for high temperatures.

It is worth noting that, in all five surveys, there is a pronounced temperature differential at LRP between all the left and all the right side sites at D/S1 d/s and D/S2 d/s downstream of the thermal discharge as indicated in the summary temperature data shown in Figure 5-2. At site S3 d/s, this differential becomes marginal and at S4 d/s is no longer discernible.

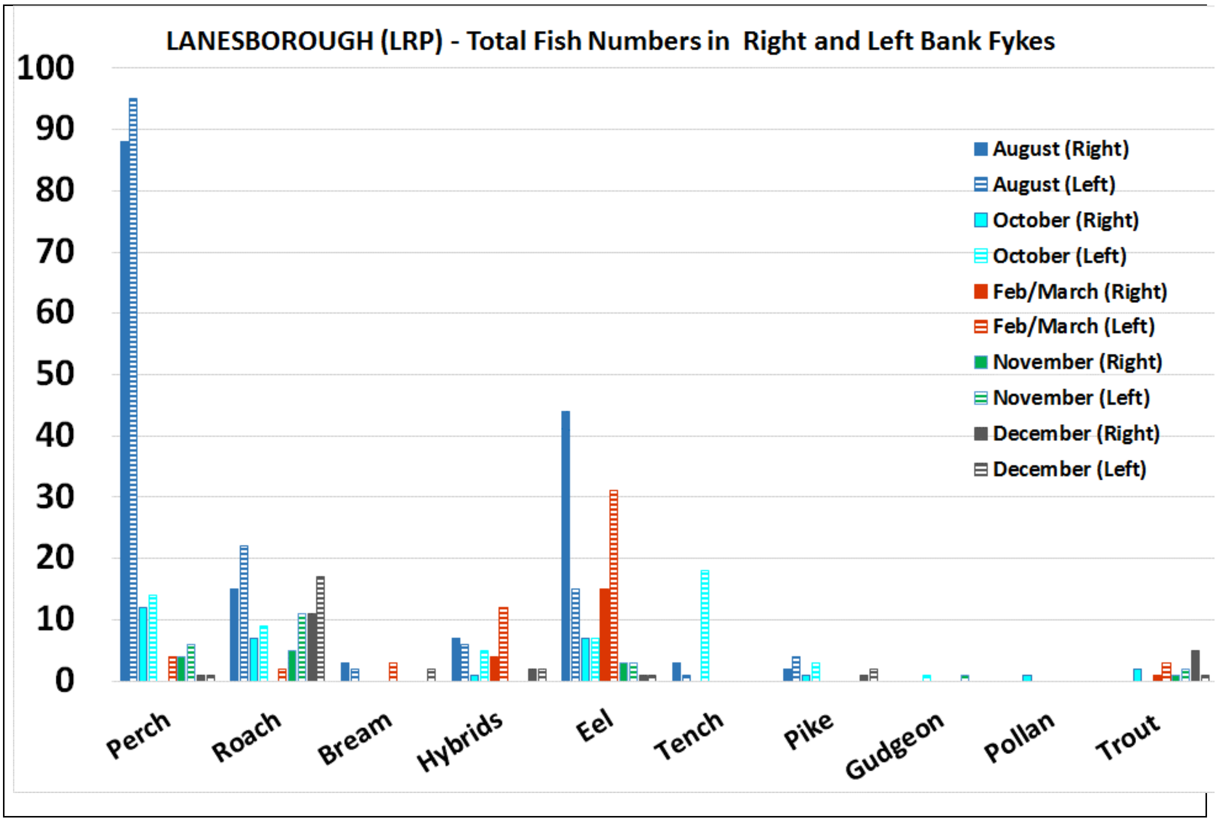


Figure 5-3 Total number of fish of each species collected at all left (warm water) and right (cooler water) sites in each of the 5 survey periods at LRP

5.1.3 Overall Conclusions – Fyke Net Survey

A number of tentative conclusions can be drawn from the five fyke net surveys as follows:

- The overwhelming numerical dominance of cyprinid fish, as well as the greater diversity of this group at LRP, indicates that the main channel of the Shannon at this location can be classified as a cyprinid water.
- All species recorded more than once were encountered in both left and right bank nets at sites downstream of the thermal discharge, which indicates that the presence of warmer water isn't excluding any of these species. The fact that only a single pollan was recorded precludes any statement of temperature preference in this context. However, one would expect that the species would avoid the plume area regardless of the time of year, (ASU, 2016).
- In the case of tench, there is some evidence in the LRP data for October 2016 that this species may be showing an active preference for the warmer water side of the channel.
- Road and roach x bream hybrids may be showing a slight to modest preference for the warmer side of the channel.
- The data also shows a strong seasonal trend with numbers of most species reducing and some not recorded in at least some of the colder months.

5.2 Comparison of IFI data (2010 and 2016) with Fyke Net Surveys (2016/2017)

In summer 2010, IFI undertook electrofishing surveys upstream and downstream of the thermal discharge at LRP and at Clonmacnoise upstream of West Offaly Power (WOP) and in July 2016 they surveyed 23 main-channel sites from Carrick-on-Shannon to Athlone, including sites at Lanesborough. The species and proportional composition of the finding of these surveys are presented in Figure 5-4 and Figure 5-5 as pie-charts. When these are compared to the current fyke net surveys results (Doherty, 2017) a number of observations can be made as follows:

- All the same dominant species were present in both surveys
- Eels were proportionally better represented in the fyke net survey, which would be expected, as fyke nets are specifically designed to capture eels.
- No trout were captured in the IFI surveys which were undertaken during May and July respectively, which concurs to some extent with the August 2016 result in the fyke net survey when trout were absent from LRP.
- Tench were not recorded by the IFI surveys which may suggest that their presence at LRP is seasonally confined or that they are normally only located in any numbers in a very limited area i.e. close to the thermal discharge.
- Relatively more roach than perch were taken in the IFI survey at all sites whereas, in the fyke surveys, perch generally were more common. The reason for this perceived difference isn’t immediately apparent.
- In their WFD Fish survey in the Shannon at Lanesborough (their Site 8), IFI surveyed both the left and right bank sides of the river separately. The only difference between the RHS (western – cool side) and LHS (eastern – warm side) was that there were 36 perch and a single gudgeon on the RHS compared to 5 perch and no gudgeon on the LHS side, while each of the other species were recorded in the same numbers on both sides of the channel (Figure 5-5). We don’t have continuous temperature data for LRP for July 6th 2016 but five days later on July 11th ambient temperatures were just under 18°C and surface temperatures on the LHS side of the channel were 6 to 7°C higher. Data from French rivers, (Daufresne and Boet, 2007) place perch and gudgeon in a slightly less temperature tolerant group than roach and rudd, which may explain the IFI findings. However, given that we are dealing with just one survey the differences may just as easily be random.

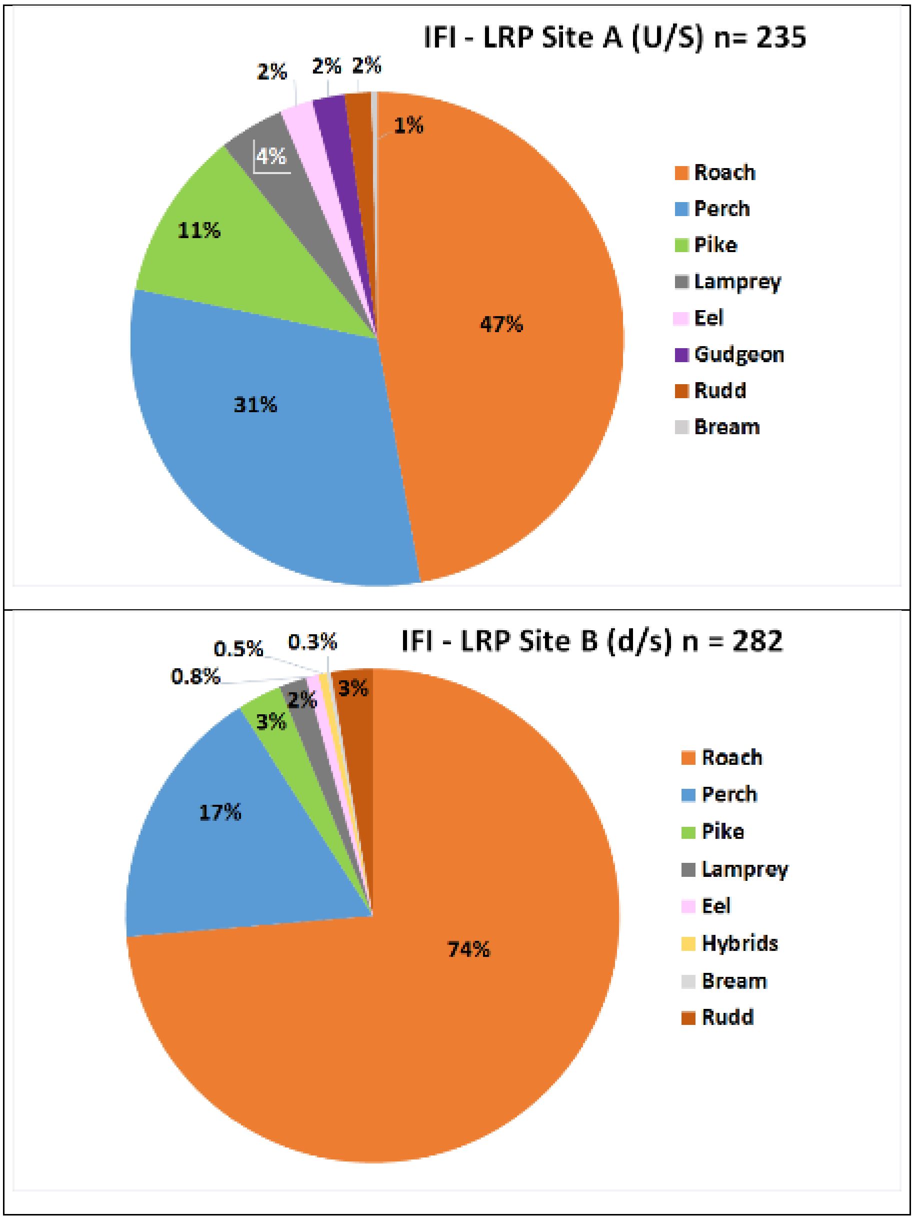
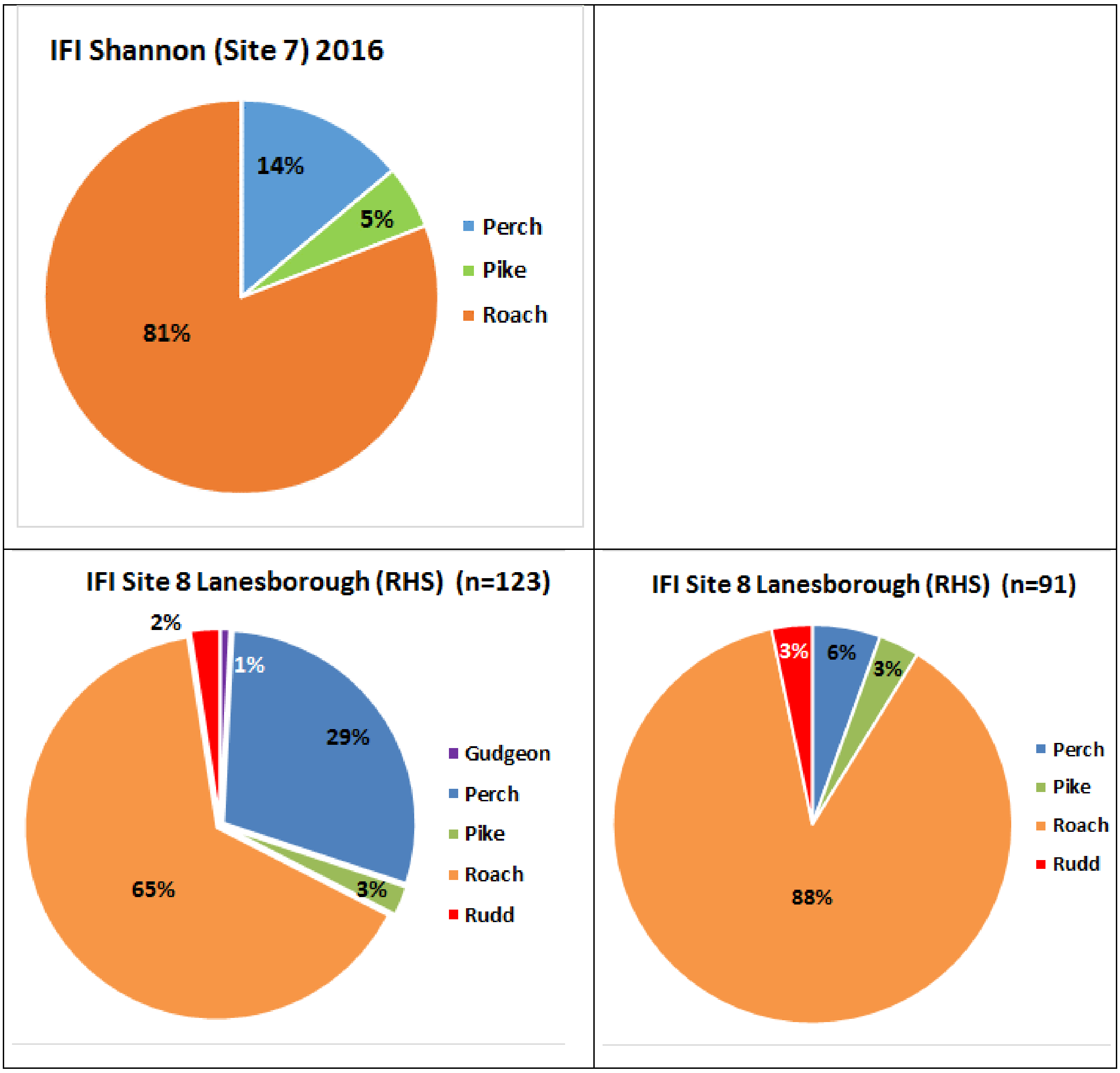


Figure 5-4 Proportional composition of fish species taken in an electrofishing survey undertaken by IFI on the Shannon in May 2010 upstream (Site A U/S) and downstream/at (Site B d/s) Lanesborough.



IFI Shannon (Site 7) 2016

IFI Site 8 Lanesborough (RHS) (n=123)

IFI Site 8 Lanesborough (RHS) (n=91)

Figure 5-5 Proportional composition of fish species taken in a boom boat electrofishing survey undertaken by IFI on the Shannon in July 2016 upstream (Site 7) and at (Site 8) Lanesborough Right and Left Sides of the channel.

5.3 Literature Review of Potential Fisheries Impacts

A literature review of the thermal sensitivities of a relevant range of fish species which occur in or pass through the LRP area was undertaken together with a risk assessment of how the cooling water thermal discharges might impact on the receiving water and fish community. The review report was prepared by Gerard Morgan M.Sc. of the Aquatic Services Unit and submitted to the EPA with additional information being supplied in response to specific questions submitted (ASU, 2016). An addendum to the report has been prepared which specifically addresses the potential thermal plume impact on salmon based on existing data, fish surveys and continuous temperature monitoring data collected to date. The Literature Review, Response to specific queries and Addendum are provided in Appendix B.

The main summary and conclusions of the 2016 Review are as follows:

- The current review and risk assessment would suggest that the thermal discharge at LRP is likely to have only minor impacts on the resident fish community under average conditions of flow and temperature in any given month. In some warmer years during conditions of low flow, particularly in the period June-August, all fish species may exhibit some avoidance behaviour of the upper 300-400m downstream of the station outfall at LRP, especially the discharge channel. Any trout that are present downstream of the discharges are likely to be the most sensitive of the fish present and therefore the most likely to avoid smaller areas downstream of both outfalls. Out-migrating silver eels are very unlikely to be adversely affected by the discharges because of their mainly late autumn to early spring migration window and the propensity for the greatest rates of migrations to be accompanied by increased discharge in the river. In the warmest years where these coincide with low flows, a small portion of the returning adult salmon population may be delayed in their upstream migration downstream of both plants. The vast majority of out-migrating salmon smolts are likely to descend past both plants without interruption. There is a slight possibility that during warmer and lower than usual flow conditions in May or early June a portion of the smolts may be exposed to an increased risk of predation by fish or birds due to a temperature-induced reduction in swimming speed. Neither the potential impacts on adults nor that on smolts is likely to result in a significant negative impacts on the population given that only a very small portion of the population should be affected in any one year and the occurrence, especially in relation to smolts is likely to be rare.

Subsequent to the report preparation, a more specific assessment of the potential impact on migrating salmon (adults and smolts), based on an analysis of the continuous (5-minute) river temperature monitoring from July 2016 to December 2017, combined with more recent adult salmon census data from ESB Fisheries Conservation at Ardnacrusha and Parteen is presented in an addendum to this report in Appendix B. The findings of this assessment supersede those in the original 2016 review in relation to salmon migration. The summary conclusion of that assessment is as follows:

- Over the past 40-50 years there has been a dramatic decline in the numbers of salmon returning to rivers on both sides of the north Atlantic and that is reflected also in the ESB’s records for salmon on the River Shannon. Furthermore, the number reaching the Lough Ree Power station reach at Lanesborough, some 135km upstream of the

Ardnacrusha hydro station, is likely to be only a small proportion of the on-average 2,000 or fewer salmon that return on an annual basis currently, as the majority enter tributaries farther downstream to spawn. Records available for recent years suggest that on average about 35% of all the salmon that escape into the system upstream of the dam do so in the months of June and July and it is likely that only a portion of these salmon are likely to encounter temperatures at LRP that could delay their upstream migration. However, an analysis of the continuous temperature data for this period in 2017, would suggest that only for relatively short periods, in the order of days, during these months would a small portion of fish arriving at LRP be delayed. This assumption is based on a review of the published literature on the species thermal tolerance both in the field and in laboratory studies and the assumption that migrating salmon would choose to follow the coolest track through the temperature-affected reach at LRP. Based on these considerations it has been estimated that fewer than 5% of the annual total number of salmon entering the Shannon upstream of the dam would be likely to suffer delays in migration related to the presence of the thermal discharge at LRP.

- Returning smolts would also be at some risk but one that is less easy to quantify due to the absence of data on the numbers likely to be migrating down through the LRP section of the river. It is believed that in most years by the time temperatures would be high enough to cause the smolts temperature-related difficulty, namely in the form of impaired swimming performance, most of the population would likely have already migrated past this point in the river. Moreover, the significant distance of the site from the sea might also mean that the majority of the smolts would have started to migrate before May. In some warmer years however with lower flows in May, a portion of the smolts migrating could be slowed in their passage through the affected ~2km of the river which might make them more susceptible to predation by pike or perhaps avian predators also. Overall, taking into account the available data on temperature for the site as well as its location, it is considered that the risk to smolts due to LRP is more likely to be more minor than moderate in scale at the population level.

6 Diatoms

Diatoms were collected from macrophytes for analysis at six sites in 2014 and from 10 sites in 2015 and 2016 (see Figure 6-1 for the 2015 and 2016 positions). These collections were analysed for TDI (Trophic Diatom Index) which in turn is used to generate EQR (Ecological Quality Ratio) which determines the WFD (Water Framework Directive) Ecological Status of a given site. Each diatom collection usually contains quite a diverse range of species, several of which tend to be found at the majority of sites. Among these, a smaller number may be well represented at most sites and therefore have the potential to have greater indicator value. *Achnanthidium minutissimum* is such a species and as part of the data analysis, trends in this species were examined at LRP as they seemed to respond closely to the temperature environment at the site. Overall species diversity also appeared to be more or less responsive to the temperature it was also assessed in order to discern a temperature effect.

6.1 General Trends

In terms of TDI and hence EQR and WDF Status, sites upstream of the thermal discharges at both locations tended to have Good or High Status which dropped to Moderate in the stretch immediately below the thermal discharge before recovering to Good or High Status some distance downstream (Table 6-1). The distance required to regain Good status at LRP varied between years; being Site 9 d/s in 2015 and 2016 i.e. 580m d/s the thermal outlet and Site 11 in 2014 (~2km downstream). The reason for the longer recovery interval in 2014 is believed to relate to the lower river levels at that time, which would have resulted in lower amounts of dilution in the river and hence higher average temperatures around the late summer sampling time. Note that the position of Site 11 d/s in the 2015 and 2016 reports was the same position as Site 8d/s in the 2014 survey; it is situated at the top end of Lough Ree. Note that Site 4d/s which is downstream of the thermal discharge is however on the right side of the river i.e. west of the distinct channel into which the cooling water discharge occurs and only had marginally higher temperatures than the upstream sites (sites 1 u/s and 2 u/s) in both 2015 and 2016. This is thought to explain why it has Good Status in both years while Site 3d/s and 5d/s both within distinct channel into which the cooling water discharge occurs and both with higher temperatures, were Moderate Status. An anomaly to these trends is Site 10d/s in 2016 which reverted to Moderate Status even though Site 9 farther upstream and with a higher warmer temperature had already regained Good Status.

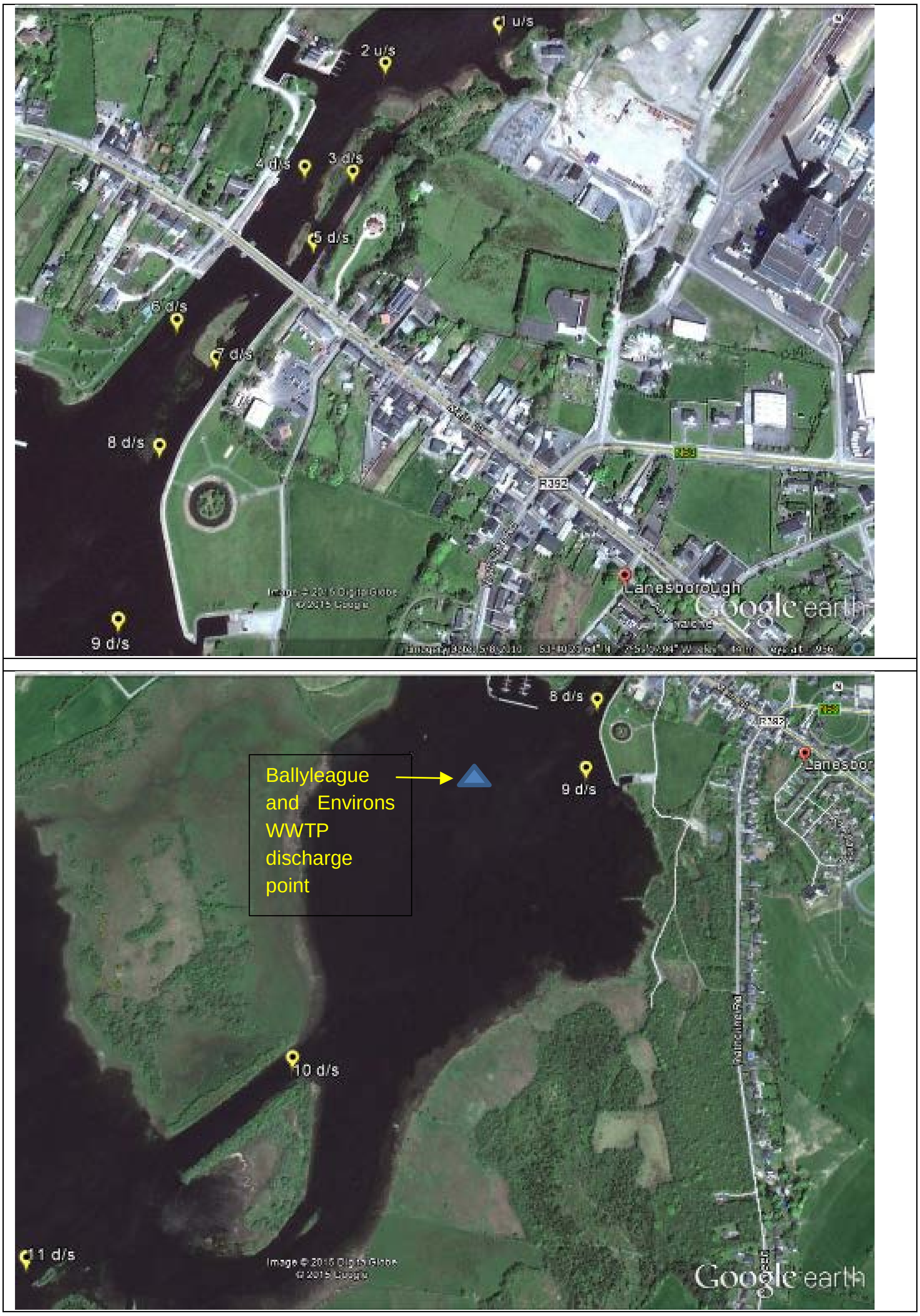


Figure 6-1 Aerial view of LRP stretch showing 2015 & 2016 biological survey locations

One of the most numerous diatom species collected at LRP was *Achnanthidium minutissimum*. This species is recognised to be a prominent diatom at Good and High Status sites. In the survey its proportional abundance either as a percentage or a fraction of the diatom sample at each site was negatively correlated with temperature, being high at upstream sites and much lower at those sites downstream of the discharge experiencing more elevated temperatures. This is illustrated in the following sets of graphs (Figure 6-2 and Figure 6-3). The first graph (Figure 6-2) shows the sharp drop in the relative abundance of the species at sites immediately downstream of the discharge followed by a gradual recovery with distance downstream as the temperature drops. In the graph Site 4 appears to counter this trend, however, this is explained as mentioned earlier by the fact that this site has a lower temperature, much more in line with the range of the upstream sites. This temperature effect is further demonstrated by comparing the normalised temperature at each site with the proportion of the species at that site (Figure 6-3).

The only exception to this trend concerns Site 10 d/s which is situated at the entrance to the navigational cut just upstream of Lough Ree at LRP (Figure 6-3). This site has a lower temperature than those closer to the thermal discharge but nevertheless has a lower than expected proportion of *A. minutissimum*. A similar but less pronounced trend was also noticeable at this site in the 2015 survey. There are a number of possible explanations for this. It may be that the observed trends in this species relate to factors other than temperature that are more or less co-varying with it. If that is the case then one possible candidate would be a nutrient such as phosphorus, given that TDI and the associated metrics are specifically designed to respond to the trophic status of waterbodies. The Ballyleague and Environs wastewater treatment plant (located in County Roscommon), discharges treated wastewater to the bay at Lough Ree above Location 10d/s. The existing population equivalent served by the plant is 882. The WWTP provides secondary treatment with nutrient removal. The treatment plant, (operated by Irish Water) consists of an inlet works, ferric dosing, sequencing batch reactors, clarifier and an outfall to the lake. It holds a waste water discharge licence from the EPA (D0229-01. The location of the outfall is shown in Figure 6-1 above.

6.2 Another possible diatom indicator species

Although TDI is based on a whole community analysis, we have seen by examining the trends in occurrence of a single species namely *A. minutissimum*, that diatoms may also provide valuable indicator information at the level of individual species. This possibility prompted a further examination of the diatom species data for other frequently encountered species that might also act as indicators. This exercise revealed that another diatom *Cocconeis placentula* var *euglypta* was present at most stations both upstream and downstream of the discharge at both stations and in both 2015 and 2016. Unlike *A. minutissimum*, *C. placentula* var *euglypta* increases in abundance at sites with warmer temperatures. In fact the 2 species have an inverse relationship at the LRP sites (Figure 6-4, Figure 6-5) in both 2015 and 2016, and while the strength of the relationship varies somewhat at individual sites between 2015 and 2016 the inverse nature is repeated in both years at all sites. This effect is in keeping with the published literature where *Cocconeis placentula* var *euglypta* has been described as a thermophilic species being a dominant community member in streams downstream of warm water springs (Radea *et al.,* 2010) and in the discharge canal of a power station (Squires et al, 1979).

6.3 Summary

The 2014, 2015 and 2016 surveys have all shown clear trends in various diatom metrics at sites influenced by the thermal plume. The effect was detectable in 2014 for nearly 2km downstream of discharge. In 2015 and 2016 when water levels were higher the effect was generally more confined and detectable for about 600m downstream of the discharge. While, the strongest driver of these changes may be temperature, nutrients cannot at present be ruled out as also having some influence. It would be a relatively straightforward task to test this alternative hypothesis with a limited amount of focussed water chemistry.

Diatoms offer many advantages over both macrophytes and macroinvertebrates as a monitoring tool. (i) They are very easily collected without the need for specialised sampling equipment, from macrophytes growing at the sites, (ii) they are not impacted by issues of substrate or light penetration, which have a very significant effect on invertebrates and macrophytes which as a result can be spatially very patchy and (iii) they also have a much shorter generation time and therefore reflect fairly recent changes in the environment compared to either macrophytes or macroinvertebrates.

Site		**Ecological Status**		
2014	**2015/2016**	**2014**	**2015**	**2016**
2u/s	**1u/s**	G	G	**1u/s**
3/us	**2u/s**	G	H	**2u/s**
	3d/s		M	**3d/s**
4d/s	**4d/s**		G	**4d/s**
5d/s	**5d/s**	M	M	**5d/s**
	7d/s		M	**7d/s**
	8d/s		M	**8d/s**
6d/s	**9d/s**	M	H	**9d/s**
7d/s	**10d/s**	M	G	**10d/s**
8d/s	**11d/s**	G	G	**11d/s**

Table 6-1 Diatom determined ecological status at LRP sites 2014-2016

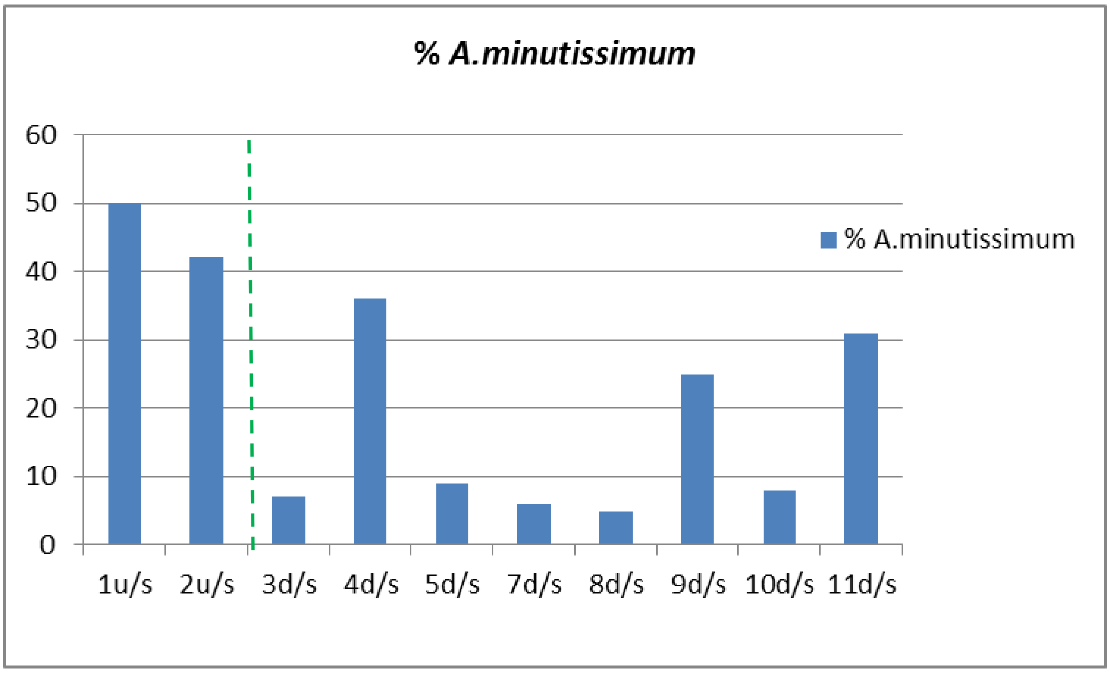


Figure 6-2 LRP 2016 Relative abundance of *A. minutissimum* (thermal discharge = green dashed line)

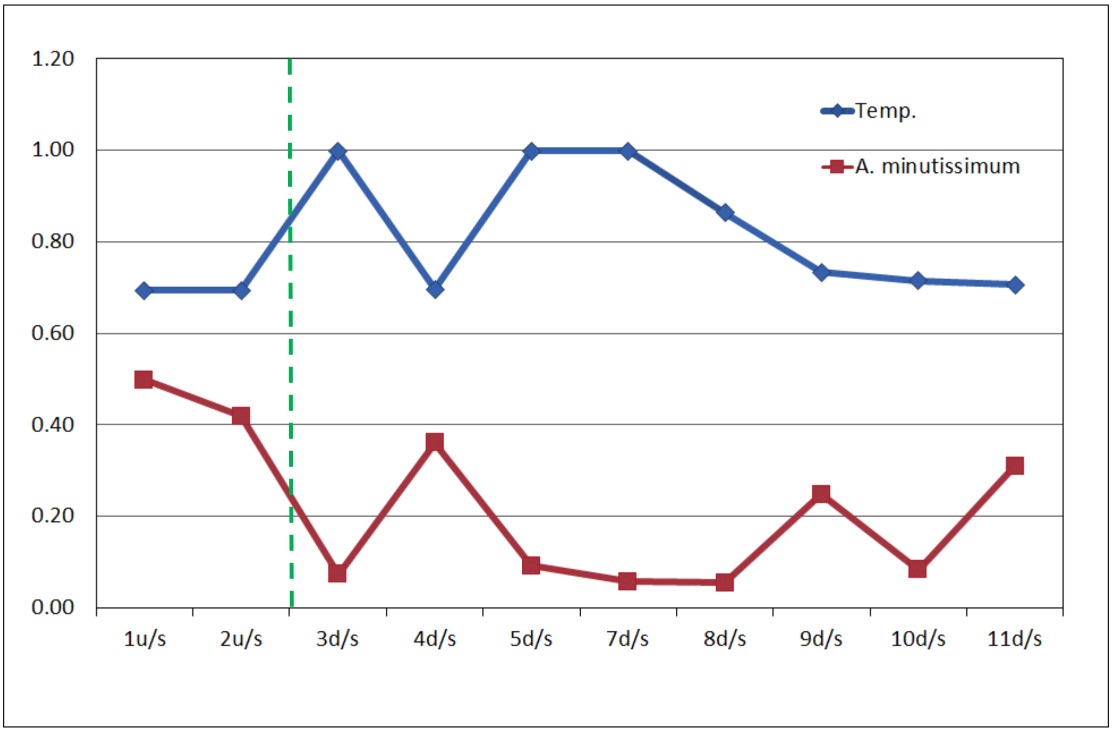


Figure 6-3 LRP 2016 Relative abundance of *A. minutissimum* vs temperature (normalised), (thermal outfall = green dashed line)

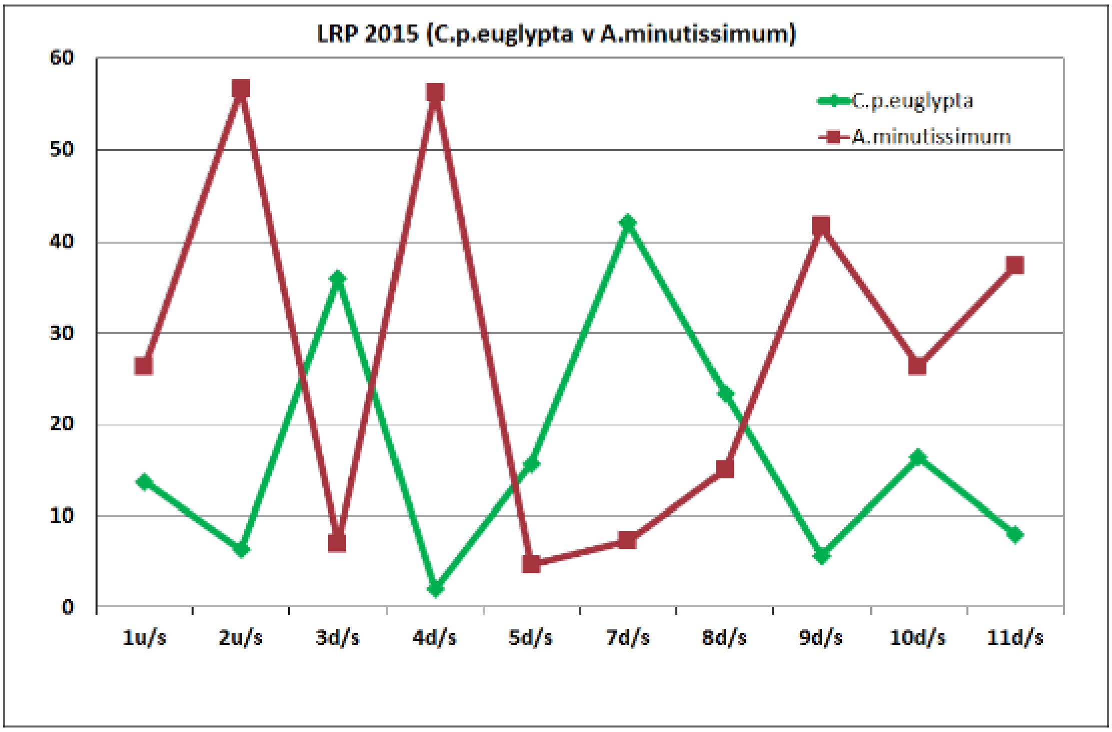


Figure 6-4 Proportional composition of *C. p. euglypta* and *A. minutissimum* in diatom samples at LRP sites in 2015

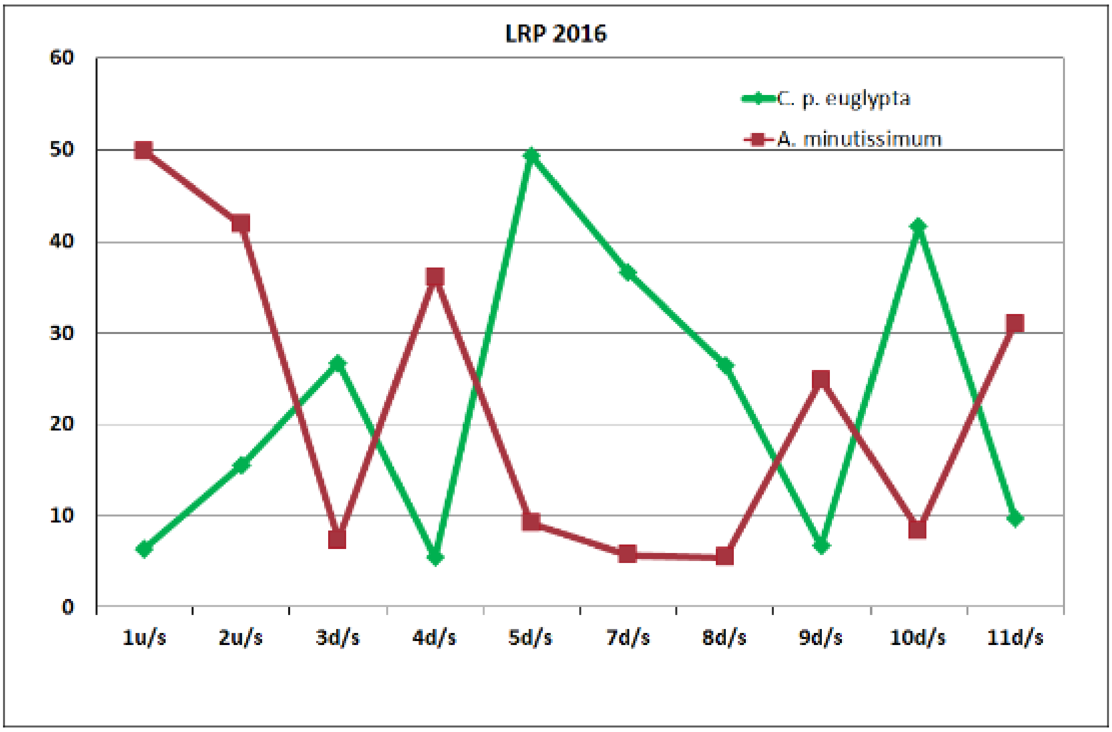


Figure 6-5 Proportional composition of *C. p. euglypta* and *A. minutissimum* in diatom samples at LRP sites in 2016

7 Macrophytes

Aquatic macrophytes were sampled by ASU in each of the three annual monitoring events in August 2014, 2015 and 2016 at LRP along with observations on macroalgal cover and freshwater sponge. The surveys comprised percentage cover assessment of 2 to 5 quadrats along transects of variable lengths, one at each sampling site. The precise length of each transect as well as the number of transects along varied between years depending on the water levels in the river at the time. In all 3 sampling events, the photic zone seemed only to penetrate to about 2m, below which no plants were present.

The macrophytes were represented by a limited list of species, the majority of which are very common in lowland rivers in Ireland which are also quite common in fairly eutrophic conditions. They can therefore be described as tolerant species in the wider sense. They included:

Higher Plants
 Phragmites australis
 Phalaris arundinacea
 Schoeloplectus lacustris
 Equisetum fluviatile
 Sparganium erectum,
 S. emersum
 Myriophyllum spicatum
 Nuphar lutea
 Nymphoides peltata
 Saggitaria saggitifolia
 Potamogeton perfoliatus
 P. lucens
 P. bercholdii
 P. obtusifolius
 Eleodea canadensis
 E. nuttali
 Lemna trissulca
 L. minor
 Mentha aquatica
Mosses
 Fontinalis antipyretica
 Octodiceras fontanum
Algae
 Blue-green algal mats
 Cladophora
Freshwater sponge

The distribution and cover values of the vast majority of these plants depended on factors such as substrate type, depth and flow and in general could not be linked in any obvious way to the thermal discharge. The only exception to this was aquatic sponge which was very well developed downstream of the thermal outfall, most obviously in August 2014, the warmest of the 3 surveys, where the sponges proliferated into long finger-like growths, whereas the normal growth form for the species is a low mat closely oppressed to the substratum. It is possible that if there was less variation in the depth, flow and substrate types within the survey reach, that subtle shifts in macrophyte community structure might have been discernible at. However, in the absence of such conditions the macrophytes as a whole showed very little response to the thermal discharges.

8 Macroinvertebrates

Macroinvertebrates were sampled at seven sites in the River Shannon at LRP in 2014 and at nine sites in 2015 and 2016 using a small van veen grab (2014) and a dredge (2015 and 2016).

The dominant species at all sites were typical of EPA Class C, D, and E invertebrates i.e. typical of moderate, poor or bad status waters, with far fewer species and individuals in the A and B classes i.e. species more typical of high and good status waters. The most numerous species were invasive species including the two bivalves: zebra mussels (*Dreissena polymorpha*) and the Asian clam (*Corbicula fluminia*), and a small crustacean (*Chelicorophium curvispinum*), a rare species in Ireland. Other frequently encountered species, usually present in smaller numbers included the molluscs *Theodoxus fluviatilis*, *Bithynia tentaculata* and *Potamopyrgus jenkinsi* , the crustaceans *Asellus aquaticus*, *Gammarus* sp., the flat worm *Dugesia* sp, the cased caddis *Ceraclea* spp, oligochaete worms and chironomid midge larvae, along with several other taxa normally only present in very small numbers.

In none of the 3 years monitoring was it possible to detect any definite thermal-related effect in the samples collected. The main reason for this would seem to be the influence of substrate and its variability within the study reaches. Current speeds and other microhabitat effects may also be contributing.

Patterns of distribution of some of the most common species present appeared to show a negative or positive association with warmer sites. Asian clam for example was most commonly found at site 3 d/s, 5d/s and 7d/s, all within the distinct channel into which the cooling water discharge occurs and with higher average temperatures, while, *Chelicorophium curvispinum* and zebra mussels were most dense at site 1u/s, 2u/s, 4d/s and 6d/s all with lower average temperatures and all outside of the distinct channel into which the cooling water discharge occurs. However, Lucy *et al.* (2004) notes that *Chelicorophium curvispinum* appears to be strongly associated with zebra mussels in Ireland. Its distribution therefore seems to be more dependent on the presence of the mussels than any particular temperature preferences. Zebra mussels themselves tend to prefer hard substrates on which to attach, as well as more sluggish flows, which in turn may also be the greater determining factors in their observed distribution. This is borne out to an extent by the fact that the Asian clam prefers sand and silty substrates and was never present in high numbers where zebra mussels were present in high densities in our samples. While a temperature effect on zebra mussels and *Chelicorophium* cannot be entirely ruled out at this stage, a more targeted approach would probably be required to rule this relationship in or out.

The evidence for a thermal influence on the Asian clam however is more compelling in that an intensive survey undertaken in Lanesborough by IFI in 2014 (Caffrey & Millane, 2014) showed that the species was present in much higher densities and included much higher numbers of larger individuals in the distinct channel into which the cooling water discharge occurs than in paired sites in the main river channel, where the temperatures were cooler. These surveys suggest that while the distribution of the species may not be influenced by temperature (as they were also noted at sites upstream of Lanesborough), elevated temperatures favour their growth rates and probably also enhance reproductive success and survival as they were reported in overwhelmingly higher densities in the distinct channel into which the cooling water discharge occurs (thousands per m^2) compared to sites in the adjoining main channel (few per m^2). The only reference to substrate in that report was the observation that they occurred in ‘coarse substrate’ in the distinct channel into which the cooling water discharge occurs, referred to in the IFI report as the ‘hot water stretch’.

Overall, the monitoring using macroinvertebrates has proved generally to be inconclusive in showing a definite thermal-related effect on the community apart from on *Corbicula* which does seem to be positively affected by the thermal discharge. This may be because the majority of species and individuals both in the cooler and warmer stretches are already quite tolerant and are less sensitive to environmental stress. However, the localised variability in substrate and flow may also be helping to mask a thermal effect. A more intensive sampling regime, focussed on fewer of the more thermally contrasting sites along with a higher number of samples or replicates at each might show up some thermal influence. However, the fact that the community is already so highly impacted by invasive bivalves, in particular, suggests that such an effort might be hard to justify.

9 Assessment of acceptability of thermal plume mixing zone at LRP

The European Communities Technical Guidance (Technical Guidelines for the Identification of Mixing Zones pursuant to Art. 4(4) of the Directive 2008/105/EC) has been followed to assess the acceptability of the thermal plume mixing zone in the Shannon River at LRP.

The Water Framework Directive implementing strategy is underpinned by ensuring compliance with environmental quality standards (EQS) and effluent discharge control regimes are normally designed to ensure that concentrations of polluting substances in the receiving water do not exceed the EQS. However, if the concentration of the contaminant of concern (CoC), heat in this case, in the effluent is greater than the EQS value at the point of discharge there will be a zone of EQS exceedance in the vicinity of the point of discharge. Directive 2008/105/EC allows Member States to permit such zones of exceedance in water bodies when a number of criteria are met. Understanding these is important as it enables the Competent Authority first to identify whether this level of exceedance is acceptable for a proposed mixing zone and then to identify the appropriate location for monitoring points.

The Technical Guidance on the establishment of mixing zones for substances listed in Annex I of the Environmental Quality Standards of Directive 2008/105/EC underpins the Water Framework Directive implementing strategy through ensuring compliance. Although not directly applicable to the thermal cooling water discharge at LRP, where the issue is “heat” for which an EQS has been set by the EPA, the principle of the technical guidance to establish the mixing zone can be applied. It should be noted that the ultimate fate of heat is loss to the air as opposed to Annex I substances, hence the potential impact is confined to the thermal plume footprint and is not persistent.

The Technical Guidance sets out a tiered approach to identifying a relevant mixing zone but it does include several caveats that must also be evaluated in any assessment. These relate to:

- The application of Best Available Techniques as the thermal discharges are regulated under Industrial Emission Licences. The applicable Best Available Technique (BAT) to energy efficiency and industrial cooling systems must be applied to ensure that any potential changes to cooling water regime or plant operation are appropriate and not disproportionate in terms of cost and environmental benefit gained.
- The requirements of Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy (the EU Water Framework Directive (WFD)) must be adhered to in establishing an appropriate mixing zone. The EQS standard does recognise the need to develop a mixing zone outside of which the substance, heat in this case, does not affect the compliance of the rest of the water body with its status requirements into which for example the thermal cooling water load is discharged. The objectives and measures set out in the River Basin Management Plan must also be adhered to and must not be compromised by the mixing zone.
- The requirement to adhere to the thermal conditions set out in Directive 2006/44/EC on the quality of freshwaters to support or enhance fish life. In the case of LRP, the

key question to be answered is whether the mixing zone will constitute a significant impact to fish in terms of migration or overall population.

An assessment of the applicability of the EU Technical Guidance for the identification of mixing zones at LRP and WOP has been carried out and is provided in the separate ESB International report, “Identification of mixing zones to Lough Ree Power and West Offaly Power” {Reference 31] . The assessment assumes that thermal heat can be considered as a contaminant of concern within the receiving water and, as such, the principle of applying a mixing zone as set out in Technical Guidance is appropriate for LRP.

The tiered approach to assessment of the acceptability of the thermal plume was progressed with significant in river bathymetric and thermal assessments carried out since 2014 allowing identification of the extent of the thermal plume and actual mixing zone to be determined under varying climatic conditions.

The in river monitoring also included aquatic ecology and fish assessments which indicate that a localised impact is present but the thermal plume discharges do not effect the overall river water body status into which the thermal plume discharges occur.

Accompanying this was a literature review of the thermal sensitivities of a relevant range of fish species which occur in or pass through the study areas concerned and a risk assessment of how the cooling water thermal discharges might impact on the receiving water and fish community. The current review and risk assessment would suggest that the thermal discharge at LRP is likely to have only minor impacts on the resident fish community. Neither the potential impacts on adults nor that on smolts is likely to result in a significant negative impacts at the population level.

A more specific assessment of the potential impact on migrating salmon (adults and smolts), based on an analysis of the continuous (5-minute) river temperature monitoring from July 2016 to December 2017 combined with more recent adult salmon census data from Ardnacrusha and Parteen (see Addendum in Appendix B) concluded that, on average, fewer than 5% of the annual total number of adult salmon entering the Shannon upstream of the dam would be likely to suffer any delay in migration related to the presence of the thermal discharge at LRP. Additionally, it is considered that the risk to smolts due to LRP is likely to be more minor than moderate in scale at the population level.

10 Conclusions

10.1 Thermal plume surveys

Five thermal plume surveys since August 2014 and continuous temperature monitoring from seven locations since July 2016 have been reviewed.

The EPA has advised the use of recorded water levels at the OPW hydrometric gauge (26088) at Hodson’s Bay as a reference indicator of flow conditions in the Shannon at Lough Ree Power in Lanesborough. There is no active hydrometric gauge on the Shannon at Lanesborough with which to assess flow conditions at that location.

Based on data and observations to date, the following conclusions can be made:

- Two of the thermal plume surveys were carried out during high Shannon flows in February and November 2015. These showed that the thermal plume resulting from the thermal discharge from Lough Ree Power is very small. The other three surveys were carried out during medium and low flow conditions in August 2014, May 2016 and July 2016. The station was in breach of Condition 5.5 of the IEL licence for the August 2014 survey when Shannon water levels were low and in May 2016 when levels were medium. In contrast, the station did not breach Condition 5.5 of the IEL licence during the July 2016 period when levels were similar to those in May 2016.

- During medium to high flows in the River Shannon, the thermal plume from the thermal discharge of Lough Ree Power is small with respect to the river cross-section area.
- The thermal plume increases in size as levels and flows in the river Shannon decrease.
- The thermal plume discharge from Lough Ree Power Station can potentially extend across both channels of the River Shannon when the water level at Hodson’s Bay hydrometric gauge falls below approximately 2.6 m. The OPW long term assessment of the gauge gives the 50 percentile level as 2.61 m.
- Below approximately 2.3 m at Hodson’s Bay, it is likely that the thermal plume from Lough Ree Power will extend across both channels of the River Shannon under all meteorological conditions and vegetation growth at full load.
- Above approximately 2.3 m at Hodson’s Bay, the thermal plume from Lough Ree Power may also extend across both channels of the River Shannon depending on meteorological conditions and vegetation growth.

  Water levels at Hodson’s Bay were similar for the May 2016 and July 2016 thermal plume surveys at 2.52 m approximately. During the May 2016 thermal plume survey, the thermal plume extended across more than 25% of the river cross sectional area at specific locations even though the station load was only 66%. During the July 2016 thermal plume survey, the station thermal plume did not extend greater than 25% across the river channels even though the station load was 98%. The reed beds had increased significantly in size between the May 2016 and the July 2016 surveys and the wind was from the south west in May 2016 and the north west in July 2016.

- At very low flows (flows around or below 30m^3/s at Athlone) the thermal plume covers most of the river at Lanesborough.

- It is not possible to accurately determine the cross sectional area of the thermal plume from the continuous temperature monitoring at seven locations. Nevertheless, at very low river levels, it can be inferred from the continuous temperature data that the thermal plume is present in both river channels. There is evidence of the simultaneous presence of thermal plume at all monitoring locations on a number of occasions.
- Data from the continuous temperature monitoring does substantially verify the results of the thermal plume surveys.

The conclusions above are based on water levels at Hodson’s Bay which is situated at the southern end of Lough Ree. During low to medium flow conditions, the relationship between water level at Hodson’s Bay and flow conditions Lanesborough is unreliable. For the same water level at Hodson’s Bay, there can be significant differences in the flow at Lanesborough.

10.2 Fish

The results of the fyke net surveys demonstrate that, on the dates surveyed, the fish communities present at LRP were typical of that part of the Shannon as determined by previous IFI surveys reported to date and were dominated by Cyprinid fish species.

The detailed analysis of catches in nets on the cooler and warmer sides of the channel, indicate that none of the species recorded as more than a single specimen was excluded from the warmer part of the channel at LRP during any season.

The absence of trout at LRP during August mirrors the findings of IFI surveys in 2010 and 2016 and may be a seasonal effect in the Shannon in general rather than a reflection of any thermal stress derived from the thermal discharges. This is suggested because the 2016 survey which covered 23 sites on the main river from upper to middle reaches, returned no trout.

Some species, seem to show at least a mild preference for the cooler or warmer sides of the channel depending on the season but the evidence from the survey isn’t very strong for any species with the possible exception of tench and to a lesser extent hybrids and roach, all of which may be displaying a degree of attraction to warmer water at times..

The single pollan (normally a lake species) taken near LRP in October 2016 doesn’t tell us much except that fish, presumably from Lough Ree may enter the Shannon at certain times of the year. Whether this is a random event, a directed seasonal feeding foray or part of a larger movement of the species within the Shannon, is unknown.

Overall, based on the data available from the fyke net surveys and the previous IFI surveys, there is no clear evidence that the thermal discharge is having an adverse impact on the resident fish community at LRP. This isn’t to say that there may not be subtle effects at the level of individuals within the population that for example may be stimulated to spawn earlier or perhaps grow faster but such changes would probably not be possible to detect using normal survey methods. This finding is in keeping with the findings of an extensive survey of fish communities in the vicinity of nuclear power stations on French rivers (Daufresne and Boet, 2007) that concluded there was little evidence of a thermal impact at community level.

It is likely that the fyke net results obtained reflect the normal average year in the system, i.e. not very low water levels and not extreme temperatures. A repeat survey during high temperatures combined with low flows might reveal somewhat different trends.

In addition the literature survey and risk assessment of potential impacts on migratory fish species present in the system indicates that no significant impact is likely to occur.

10.3 Diatoms

Diatoms were the only survey technique that clearly and unambiguously demonstrated a biological effect from the thermal discharge at LRP. In 2014, when the river was at its lowest the diatom community showed an effect for 2km downstream of the thermal discharge, whereas in 2015 and 2016 when the flows were higher the effect was detected for 600m downstream only.

Diatoms have much to recommend them as a monitoring tool including ease of sampling and proven effectiveness at both sites in all surveys to date

10.4 Macrophytes

The use of macrophytes for monitoring the thermal impact at LRP has provided very little useful information in detecting a thermal influence. The presence of unusual and luxuriant growth forms of freshwater sponge within the thermal discharge was the only other aspect of the macrophyte survey effort that provided evidence of a thermal response. Overall however, the general tolerance of the existing plant community combined with the heavy influence of hydromorphology on that community (substrate, flow and depth/light) means that the general macrophyte community is unlikely to provide any useful monitoring information.

10.5 Macroinvertebrates

The macroinvertebrate was characterised by species tolerant or very tolerant of impaired water quality. Moreover the community is overwhelmingly dominated numerically by a small number of invasive species two of which are major ecosystem-altering species namely zebra mussels and Asian clams, the latter only recently arrived and still expanding its range. Like macrophytes, the importance of hydromorphological factors including substrate and flow in particular seems to be the main factors determining the nature of the very patchy invertebrate community at any given site and because of that any thermal effects are either not occurring or are masked by these other factors. Some, temperature related trends were noted for species such as the crustacean *Chelicorophium curvispinum* and zebra mussels but it wasn't possible to conclusively rule out substrate preferences as factors giving rise to this apparent effect. The only species that can definitely be said to be impacted by the thermal discharge at LRP is the Asian clam (*Corbicula fluminea*) which was more abundant at warmer water sites. However, because a substrate effect cannot be ruled out in this case either, the corroboration comes from a very intensive study on the distribution of the species upstream and downstream of the thermal discharge in 2014 undertaken by IFI that clearly demonstrated the positive impact of the thermal discharge on the local population both in terms of density per m^2 and size of individuals. Overall, however, macroinvertebrates are fairly poor indicators of a thermal effect at LRP.

11 Overall conclusion

ESBI has followed the Technical Guidance on mixing zone determinations and the following conclusions can be drawn:

- Thermal cooling water discharges have occurred to the Shannon River at Lanesborough since the late 1950's when electricity generating stations utilising peat as a fuel were first constructed. Lanesborough Generating Station was decommissioned in 2003 and its associated Integrated Pollution Control Licence (P0629) was surrendered in 2010.
- Lough Ree Power Generating Station was first licenced under Licence No. P0610-01 in 2002. Although the IPPC licence contained conditions relating to water temperature outside of the mixing zone, no definition of the mixing zone was included until a new Licence was issued in 2013.
- Thermal heat could be considered as a contaminant of concern within the receiving water and as such, the principle of applying a mixing zone as set out in Technical Guidance is appropriate for LRP.
- The tiered approach to assessment of the acceptability of the thermal plume was progressed with significant in river bathymetric and thermal assessments carried out since 2014 allowing identification of the extent of the thermal plume and actual mixing zone to be determined under varying climatic conditions.
- The current WFD status of the river water body into which LRP discharges thermal cooling water is "Poor" as is also the EPA Biological Q value monitoring site at Lanesborough. The location of the monitoring site may be inappropriate as a WFD Surveillance and Operational monitoring site as it is located within the thermal plume mixing zone at this location.
- An assessment of the ecological impact of the thermal plume discharges in terms of impact on macrophytes, macroinvertebrates and diatoms was carried out in 2014, 2015 and 2016 which identified that diatoms were the most reliable assessment species. The ecological impact assessment identified that an impact does occur but that this is within the thermal plume actual mixing zone with the "status" returning to at least Good mainly within 600m of the discharge location and in extreme low flow conditions 2km downstream. The thermal plume impact does not effect the status of the rest of the water body length and is localised in effect.
- A key issue for the acceptability of a mixing zone is that of potential impact on fish migration and river connectivity for fish which is a key objective of the Draft RBMP for Ireland 2018 – 2021. Fish sampling undertaken by IFI and ESB has identified the key fish species present in the system at LRP. A literature review and risk assessment relating to thermal plume potential impacts as barriers to migratory fish has been completed which concludes that there is no significant adverse impact on the resident fish community at LRP.
- LRP operates within the LCP Bref and Industrial Cooling Water Bref and is BAT compliant with respect to cooling technology (once through and nett energy efficiency). Any additional requirement such as mechanical cooling would likely reduce energy efficiency, would entail significant cost and based on the ecological impact assessment to date would not significantly enhance the achievement of water quality status

> requirements under the WFD. The cost would be disproportionate to any environmental benefit that could be achieved.

In conclusion and following the Technical Guidance approach on mixing zones and ecological and fish assessments undertaken to date, a review of the allowable in river extent of the thermal cooling water mixing zone for compliance purposes should be undertaken given that no overall significant impact on the receiving water bodies occurs into which the thermal discharges take place. Larger mixing zones reflecting the actual thermal mixing zones can be defined for Lough Ree Power which should be acceptable in terms of the WFD requirements.

12 Recommendations

The following are the main recommendations with respect to the thermal cooling water discharge from LRP;

- Maintain the programme of continuous temperature monitoring. Download and issue reports on a monthly basis.
- Upgrade temperature recording system to facilitate the transmission of data to a central storage facility.
    - Continue to issue reports on a monthly basis
- Identify and log periods of non-compliance with Clause 5.5

13 References

1. Lough Ree Power Station. Lanesborough, County Longford. Thermal Plume Survey. August 1st 2014. Report. Irish Hydrodata Ltd. 2014.
2. Lough Ree Power Station. Lanesborough, County Longford. Thermal Plume Survey. February 4th 2015. Report - Final. Irish Hydrodata Ltd. 2015.
3. Lough Ree Power Station. Lanesborough, County Longford. Thermal Plume Survey. November 20th 2015. Report - Final. Irish Hydrodata Ltd. 2016.
4. Lough Ree Power Station. Lanesborough, County Longford. Thermal Plume Survey. May 2016. Report - Final. Irish Hydrodata Ltd. 2016.
5. Lough Ree Power Station. Lanesborough, County Longford. Thermal Plume Survey. July 2016 Report – Final-Revision 1. Irish Hydrodata Ltd. 2017.
6. Lough Ree Power Generating Station Review of Thermal Plume Survey Reports. Document No.: QS-000152-01-R001-001. ESB International. March 2015
7. Lough Ree Power Generating Station Review of Thermal Plume Survey Reports. Update of January 2016. Document No.: QS-000152-01-R004-001. ESB International. January 2016.
8. Lough Ree Power Generating Station Thermal Plume Survey May 2016. Document No.: QS-000152-01-R005-000. ESB International. July 2016.
9. Lough Ree Power Generating Station Thermal Plume Survey July 2016. Document No.: QS-000152-01-R006-000. ESB International. September 2016.
10. Lough Ree Power Generating Station Continuous Monitoring Summary Report – Period 1: July 2016 - August 2016. Reference Number QS-000152-01-R101-000. ESB International. October 2016.
11. Lough Ree Power Generating Station Continuous Monitoring Summary Report – Period 2: August 2016 - October 2016. Reference Number QS-000152-01-R102-000. ESB International. January 2017.
12. Lough Ree Power Generating Station Continuous Monitoring Summary Report – Period 3: October 2016 - December 2016. Reference Number QS-000152-01-R103-000. ESB International. January 2017.
13. Lough Ree Power Generating Station Continuous Monitoring Summary Report – Period 4: December 2016 - January 2017. Reference Number QS-000152-01-R104-000. ESB International. March 2017.
14. Lough Ree Power Generating Station Continuous Monitoring Summary Report – Period 5: January 2017 - March 2017. Reference Number QS-000152-01-R105-000. ESB International. May 2017.
15. Lough Ree Power Generating Station Continuous Monitoring Summary Report – Period 6: March 2017 - April 2017. Reference Number QS-000152-01-R106-000. ESB International. June 2017.

16. Lough Ree Power Generating Station Continuous Monitoring Summary Report – Period 7: April 2017 - May 2017. Reference Number QS-000152-01-R107-000. ESB International. August 2017.
17. Lough Ree Power Generating Station Continuous Monitoring Summary Report – Period 8: May 2017 - June 2017. Reference Number QS-000152-01-R108-000. ESB International. August 2017.
18. Lough Ree Power Generating Station Continuous Monitoring Summary Report – Period 9: June 2017 - August 2017. Reference Number QS-000152-01-R109-000. ESB International. September 2017.

19. Shannonbridge and Lanesborough stations cooing water outfall. Fyke Net study By Dr. D. Doherty (ESB Fisheries Biologist). May 2017.
20. Shannon Power Stations Literature Review of Potential Fisheries Impacts. Aquatic Services Unit (ASU). July 2016.
21. Response to EPA Observations on: Shannon Power Stations Literature Review of Potential Fisheries Impacts (July 2016). Aquatic Services Unit (ASU). September 2016.
22. Inland Fisheries Ireland. National Research Survey Programme. Sampling Fish in Rivers 2016. 2017

23. ESB Power Stations Lough Ree (Lanesborough). Aquatic Ecological Monitoring (August 2014). Aquatic Services Unit (ASU). November 2014
24. Appraisal of the Aquatic Services Unit's (ASU) 2014 River Shannon Biological Survey at Lough Ree Power Station Lanesborough, Co Longford. Aquatic Ecological Monitoring. Aquatic Services Unit (ASU). March 2015
25. ESB Power Stations Lough Ree (Lanesborough). Aquatic Ecological Monitoring (August 2015). Aquatic Services Unit (ASU). September 2015
26. ESB Power Stations Lough Ree (Lanesborough). Aquatic Ecological Monitoring (August 2016). Aquatic Services Unit (ASU). October 2016.
27. ESB Power Stations West Offaly (Shannonbridge). Aquatic Ecological Monitoring (August 2014). Aquatic Services Unit (ASU). November 2014
28. Appraisal of the Aquatic Services Unit's (ASU) 2014 River Shannon Biological Survey at West Offaly Power Station Shannonbridge, Co Offaly. Aquatic Ecological Monitoring. Aquatic Services Unit (ASU). April 2015
29. ESB Power Stations West Offaly (Shannonbridge). Aquatic Ecological Monitoring (August 2015). Aquatic Services Unit (ASU). September 2015
30. ESB Power Stations West Offaly (Shannonbridge). Aquatic Ecological Monitoring (August 2016). Aquatic Services Unit (ASU). October 2016.
31. Identification of mixing zones to Lough Ree Power and West Offaly Power. Reference Number QS-000152-01-R401-001. ESB International September 2017.

32. DAUFRESNE, M. and BOËT, P. (2007), Climate change impacts on structure and diversity of fish communities in rivers. Global Change Biology, 13: 2467–2478. doi:10.1111/j.1365-2486.2007.01449.x

33. E. Squires, Lorin & R. Rushforth, Samuel & D. Brotherson, Jack. (1979). Algal response to a thermal effluent: study of a power station on the Provo river, Utah, USA. Hydrobiologia. 63. 17-32. 10.1007/BF00021013.

34. Caffrey, J. and Millane, M. (2004) Status of the Asian clam in the mid- River Shannon and recommendations for its management. Inland Fisheries Ireland, City West Business Campus. Dublin 14, Ireland
35. Lucy, F., Minchin, D and M. Sullivan (2004) First record of the Ponto-Caspian amphipod *Chelicorophium curvispinum* (Sars 1895) in Ireland. *The Irish Naturalists Journal*, 27, 461-464.
36. Radea, C., Louvrou, I., Pantazidou A and Economou–Amilli, A. (2010) Photosynthetic microorganisms as epibionts and euendoliths on biotic substrates in a thermal spring with ferric–iron deposits. *Fottea* 10, 129–140

Appendix A.

Graphical Information Referenced in Main Report

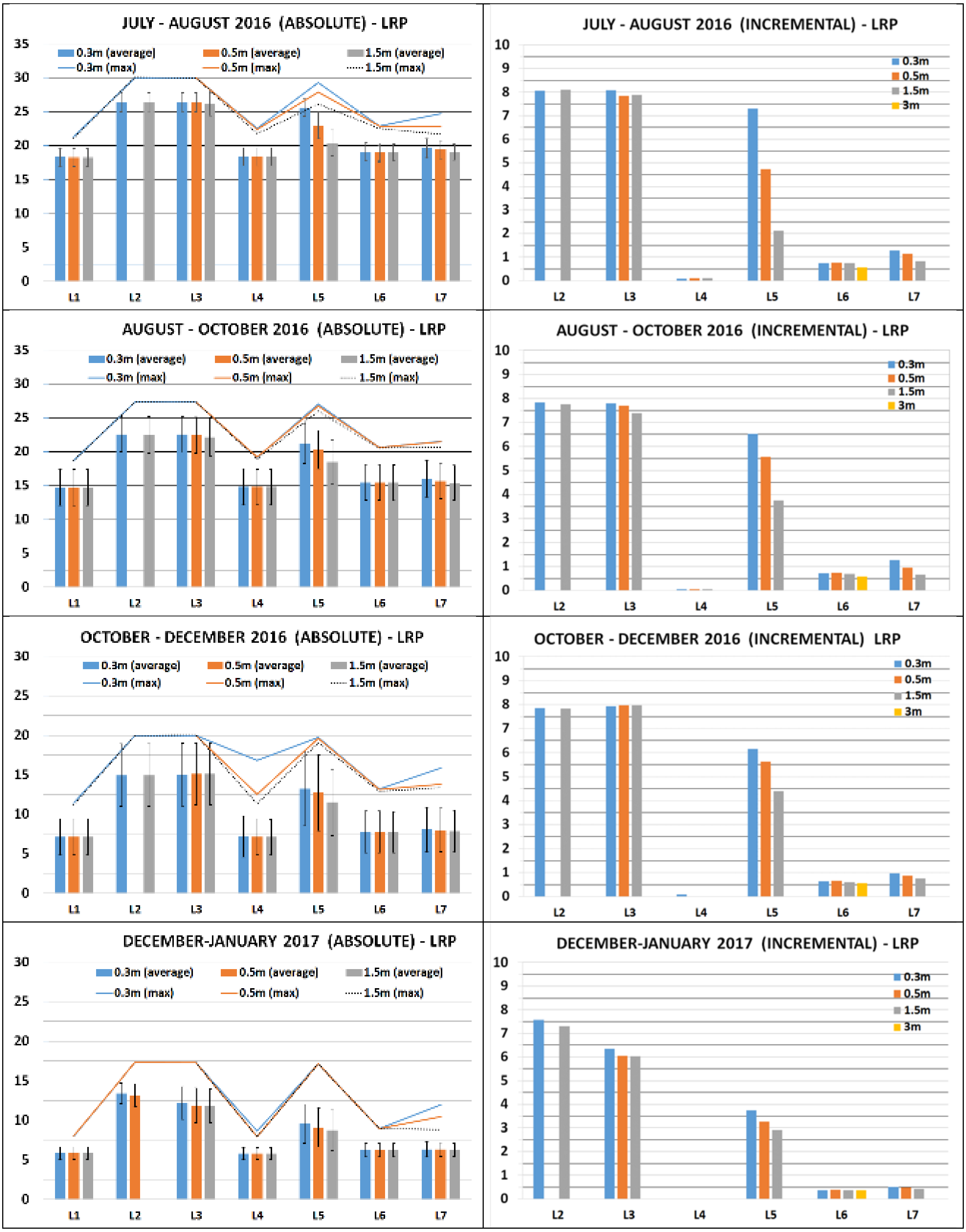


Figure A-1. Summary temperature data at LRP in degrees Celsius (°C) from the monthly continuous in-river monitoring from July 2016 to December 2017*.

Graphs on the left depict average absolute temperatures (with error bars indicating Standard Deviation) at 0.3m, 0.5m, 1.5m depth stations at each of the 7 sites. An additional 3m station was sampled at L6. The right side graphs represent the average incremental increase in temperature at each site when the average temperature at Site 1 i.e. upstream of the thermal discharge is subtracted from the average temperature at the corresponding depths (0.3m, 0.5m, 1.5m) at each downstream site. Data from Irish Hydrodata monitoring.

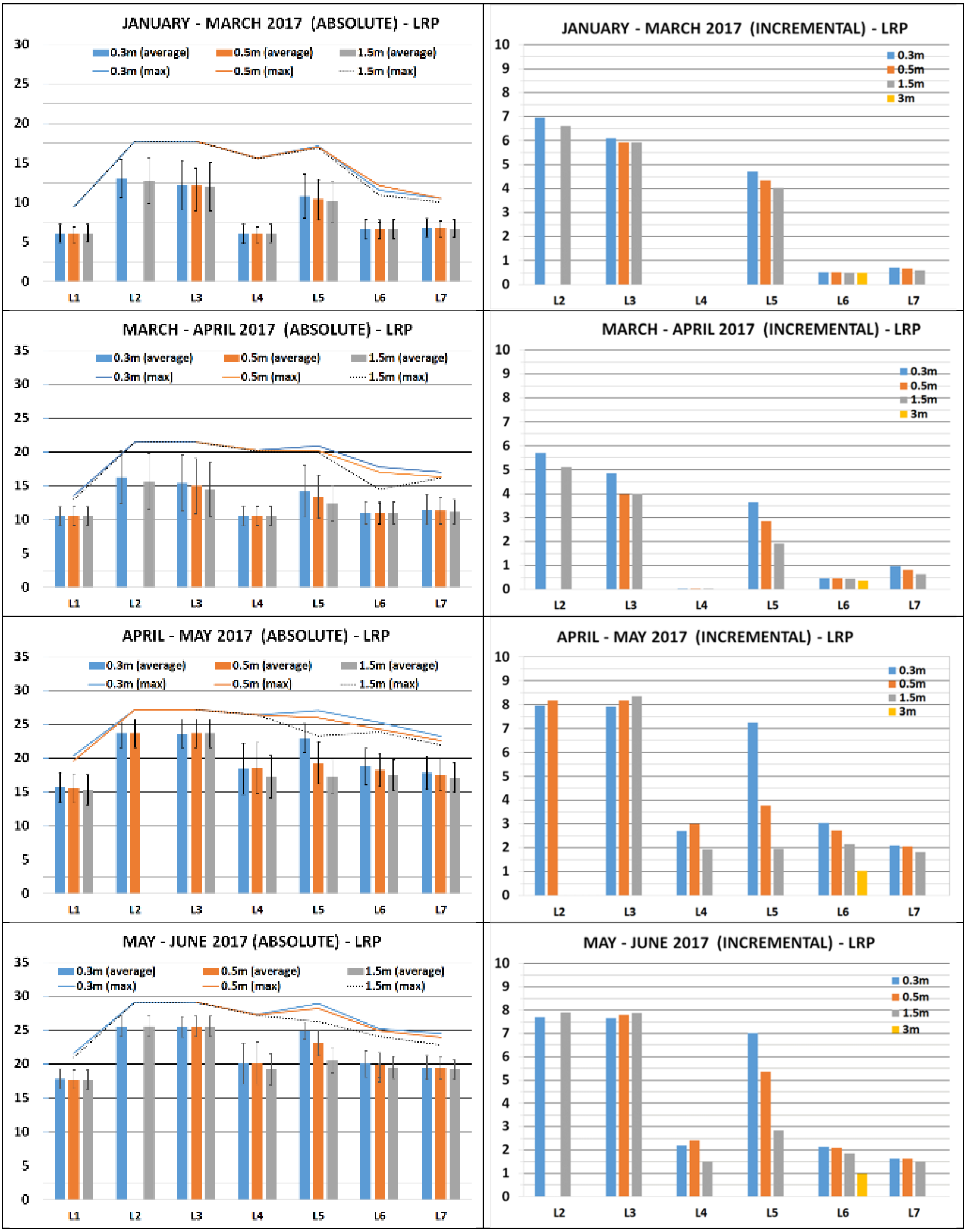


Figure A-1 (contd.)

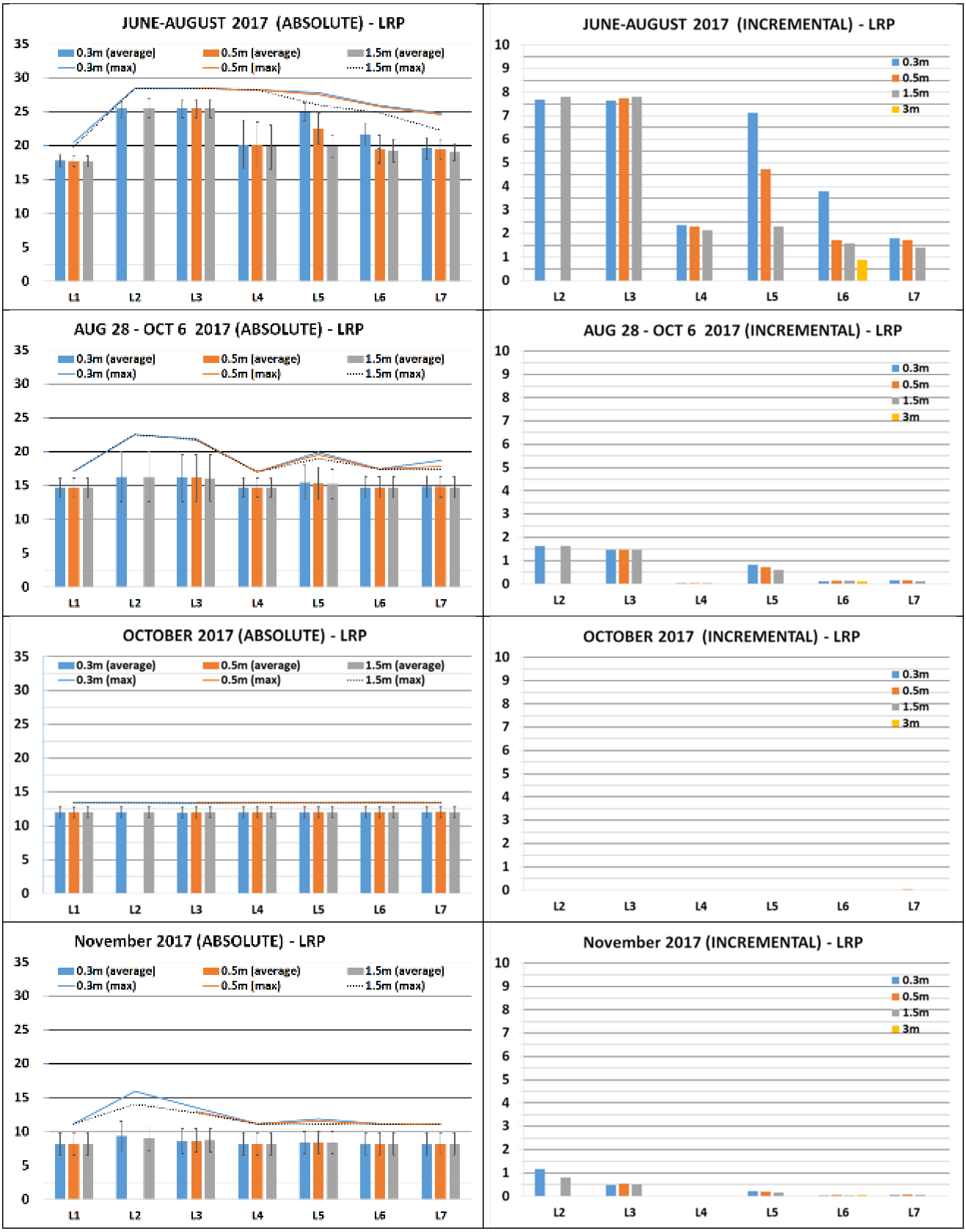


Figure A-1 (contd.)

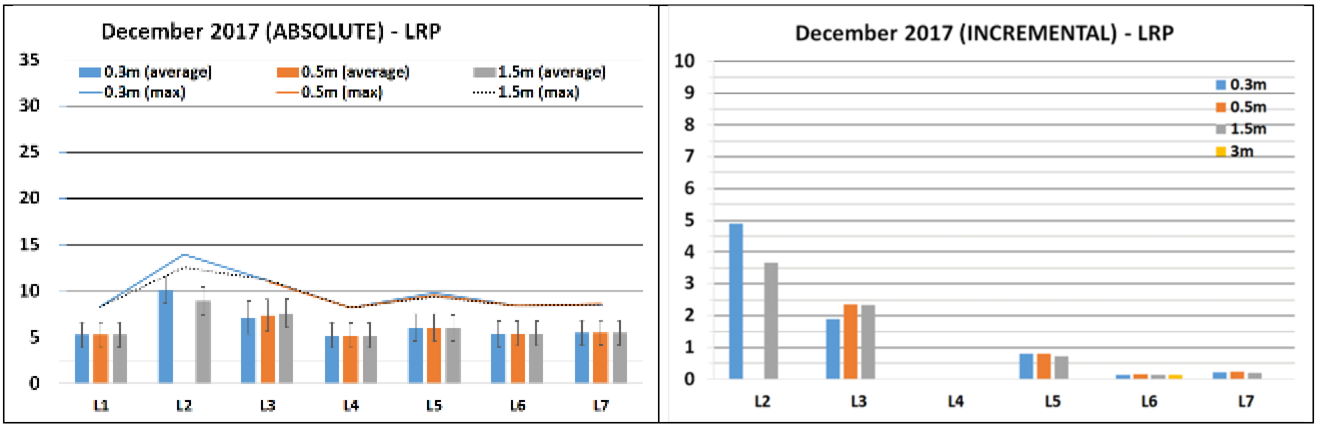


Figure A-1 (contd.)

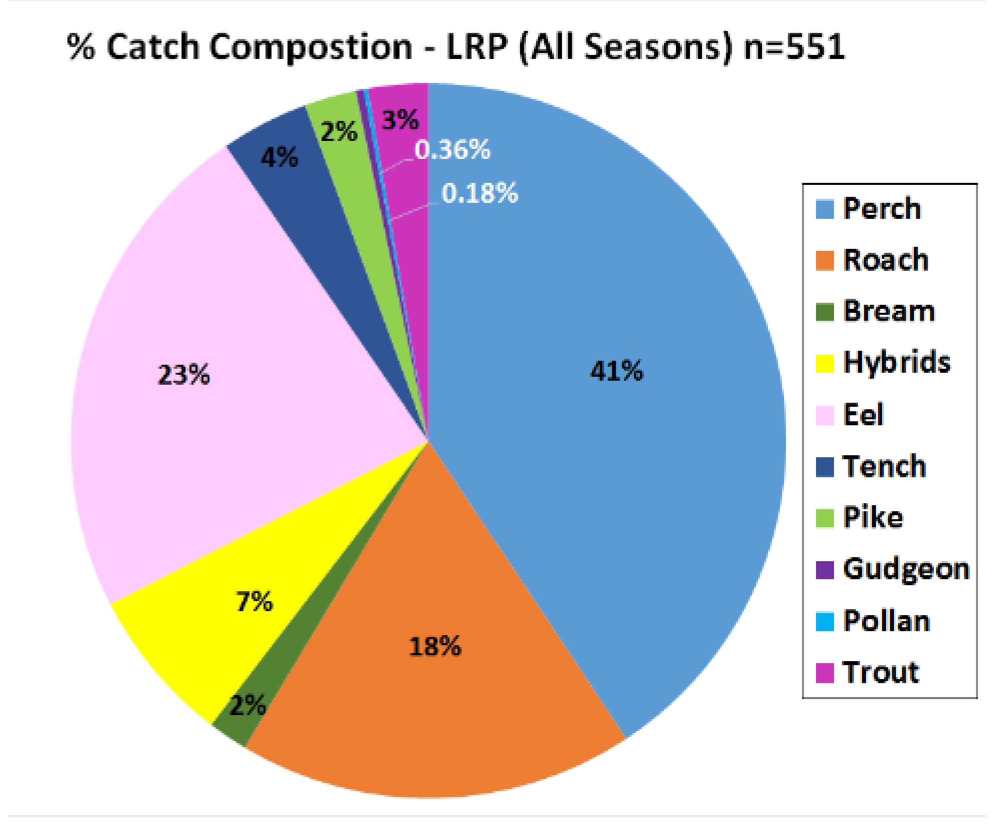


Figure A-2: Proportional composition of the total number of fish caught in all 5 surveys at LRP (2016-2017)

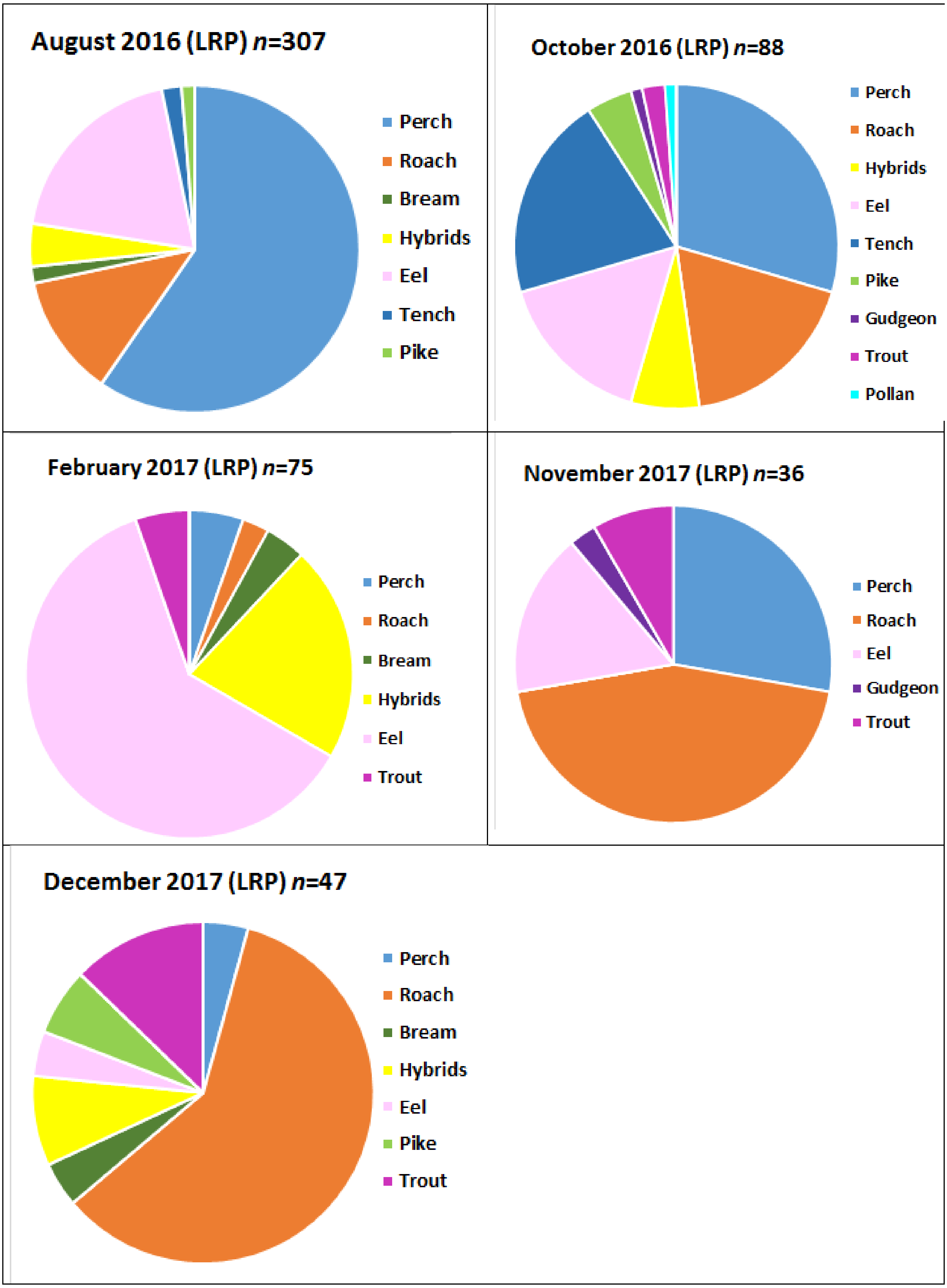


Figure A-3: Pie charts showing the proportional composition of each species taken in each of 5 fyke net surveys at LRP (August & October 2016 and February, November and December 2017)

Appendix B.

ASU Literature Review of Potential Fisheries Impacts - Documentation

Shannon Power Stations Literature Review of Potential Fisheries Impacts

(July 2016)

Commissioned by: ESB International

Carried out by: Aquatic Services Unit (UCC)

(July 2016)

Contents

Introduction 3

Study Approach 3

Fish Community 4

LRP & WOP Station Temperature Record – January 2006-February 2016 5

Assessing Temperature Preferences and Tolerances in Fish – Some Definitions 11

Thermal Optima and Thermal Tolerance of Fish 12

Temporal and Spatial Characteristics of the Plume 15

- West Offaly Power (WOP) 15
- Lough Ree Power - LRP 16

Risk Assessment of Thermal Regime for Resident and Migrant Fish 19

- Brown Trout (*Salmon trutta*) 19
- Eel (*Anguilla anguilla*) 25
- Lampreys (*Lampetra* sp.) 28
- Pike (*Esox lucius*) 32
- Roach (*Rutilus rutilus*) 36
- Perch (*Perca fluviatilis*) 40
- Minor Components of the Fish Community at LRP & WOP 43

Summary 51

Conclusions 55

References 56

Introduction

The Environmental Protection Agency (EPA) requested that the potential for impact on fisheries in the River Shannon of the cooling water discharges from Lough Ree Power (LRP) and West Offaly Power (WOP) power stations should be assessed. In part fulfilment of this condition, the client, ESB Generation & Wholesale Markets, agreed to undertake a literature review of the thermal sensitivities of a relevant range of fish species which occur in or pass through the study areas concerned and to undertake a risk assessment of how the cooling water thermal discharges might impact on the receiving water and fish community. This report presents the findings of that review and risk assessment, which was undertaken by Gerard Morgan M.Sc. of the Aquatic Services Unit.

Study Approach

In undertaking the review, temperature data provided by the client for both sites (LRP and WOP) were analysed and compared with the thermal sensitivities of the fish community resident or migrating through both sites. The temperature data in question comprised 2 datasets for each power plant, (i) the temperature of the cooling water intake and (ii) the temperature of the cooling water discharge having passed through the condensers. In each case data was available from January 2006 to June 2016.

The data includes 2 temperature readings taken daily in the intake and in the discharge, one at 02:00 and another at 14:00. In analysing the data, all the available measurements for the intake were considered, whereas only discharge data where the temperature interval between the intake and the discharge was ≥ 3°C was used in the analysis. The data for the intake is being taken for the purpose of this review as being identical to the ambient temperature in the Shannon at the two study sites, whereas the discharge temperature represents the maximum temperature that could be measured in the thermal plume at any given time, i.e. before any mixing with the receiving water and hence before any attenuation. The data was used to draw up the monthly trends in temperature for the 2 sites using a range of standard summary statistics (i.e. average, median, maximum, minimum, 5%ile and 10%ile) for each. These data were compared with the published thermal sensitivities of the fish species of interest, including variations associated with different life stages in order to gauge potential risk to the species in question. It is important to emphasise that the discharge temperature represents the highest possible temperature in the receiving water to which a fish could be exposed, i.e. before any attenuation has taken place through mixing with the receiving waters. In this respect, the discharge temperature summary statistics represent a worst case scenario in terms of potential risk. This is seen as the upper starting temperature, which will be attenuated to a greater or lesser degree through the dynamic mixing of the discharge flow and the receiving water flow. To date this interaction has been assessed quite comprehensively using thermal plume surveys which have consisted of mapping the extent of the discharge plume temperature both in the horizontal and vertical plains for up to 2.5 km downstream of LRP and 1.75km downstream of WOP during a wide range of river flows and ambient temperatures. These studies, which will be discussed in detail later in this report, reveal a plume which retains some fundamental characteristics under high, average and moderate river flow regimes, which only alters significantly during condition of low or very low flow. The assessment of potential risk to fish from the discharge will take as its 'worst case' starting point the temperature in the cooling water discharge i.e. BEFORE any mixing of the discharge takes place. This pre-mixing (i.e. discharge) temperature will be assessed in combination with the likely degree of attenuation as revealed by the various plume surveys undertaken to-date, in order to gauge the most likely receiving water temperature actually experienced by any given fish depending on its location within the mixing zone of the plume at any particular time.

Fish Community

Data on the likely resident fish community in the Shannon river at the two sites was based on the findings of two intensive fish surveys undertaken in May 2010 by Inland Fisheries Ireland (IFI) at Lanesborough immediately upstream and downstream of LRP and at Clonmacnoise, 11.5km upstream of WOP, as part of their Water Framework Directive (WFD) fish monitoring programme (IFI, 2010). The list of species recorded at each site and their numbers and densities is presented in Table 1 below. Also included on the list, are salmon, brown trout and sea lamprey, which are also known to occur in the Shannon and about which comprehensive recent and recent historical details were obtained from the ESB 2015 Annual Report on Fisheries. Although the two study sites are situated within Special Areas of Conservation, LRP (Lanesborough) in the Lough Ree SAC (Site Code 000440) and WOP (Shannonbridge) in the Shannon Callows SAC (Site Code: 000216), neither site has fish as a conservation objective. As can be seen from the IFI surveys at LRP and Clonmacnoise, the dominant fish community in these sections of the Shannon are coarse fish (roach, perch, pike, gudgeon, rudd, bream), lamprey and eels. Eel and lamprey densities are likely to be underestimates, given that electrofishing in deep waters isn't the most effective means of capture of these species but the data allows identification of the relevant fish species likely to be present . More details of the relative importance of these species and why they have been included in the list will be addressed as appropriate when the implications for thermal sensitivity is discussed for each.

Table 1 Resident fish community at LRP and WOP (1-6) as revealed from IFI WFD fish survey in 2010 (IFI, 2010a) and known migratory species and brown trout

		LRP (A)		**LRP (B)**		**Clonmacnoise**	
		Nos.	Density (m^2)	Nos.	Density (m^2)	Nos.	Density (m^2)
1	Roach (*Ruitilus rutilus*)	111	0.00243	282	0.0081	87	0.00234
2	Perch (*Perca fluviatilis*)	73	0.0016	66	0.0019	76	0.00204
3	Pike (*Esox lucius*)	26	0.00057	11	0.00032	16	0.00043
4	Lamprey (*Lampetra* sp.)	10	0.00022	7	0.0002	2	0.00003
5	Eel (*Anguilla anguilla*)	5	0.00011	3	0.00009	1	0.00005
6	Gudgeon (*Gobio gobio*)	5	0.00011	-	0.00006	-	
7	Brown trout (*Salmo trutta*)	-	-	-	-	-	-
8	Salmon (*Salmo salar*)	-	-	-	-	-	-
9	Sea lamprey (*Petromyzon marinus*)	-	-	-	-	-	-

LRP & WOP Station Temperature Record – January 2006-February 2016

The summary statistics for the monthly variation in the cooling water intake temperature, which is taken to represent the ambient i.e. upstream temperature in the Shannon at each site, and the cooling water discharge temperature, which is the highest temperature that could be experienced in the plume, i.e. before mixing, are presented for LRP and WOP in Tables 2a & b and 3a & b, and Figures 1a & b and 2a & b respectively.

The intake and discharge data for both sites shows almost identical seasonal trends as one might expect. Both sites show January minima and July maxima, with June, July and August being the warmest months. There are some differences between the sites in terms of absolute temperature with average temperatures in the period March-to July warmer at LRP by up to a degree in some months, whereas, the reverse is the case for the period from August to February, when the WOP intake average temperature is marginally higher. December is an exception, with LRP having just marginally a higher average. A similar trend is evident in the temperature of the cooling water discharge at both sites, with LRP having a higher average temperature, up to one degree, from March to September and WOP being higher from October to February, except in December when LRP is marginally higher. The reasons for these apparent differences is not known, although the presence of Lough Ree upstream of WOP may be influential.

Maximum intake temperatures were higher at LRP from January to August, with the greatest differences from February to July (up to 1.24°C). In the discharge the LRP maximum temperature was higher in all months than the WOP discharge except in November and January. The greatest difference was during March when there was 3.5 °C in the difference, but normally these were less than 2°C. As maximum values only refer to a single event, they can be misleading, so an examination of the 5%ile and 10%ile values give a more representative picture of warmer years. The 5%ile data for the intake temperature shows that the LRP values were higher, by up to 1.17°C, from January to August, while in the remaining months the WOP intake temperatures were higher by up to 0.57°C. The LRP 5%ile discharge temperature was higher in all months than the corresponding WOP temperature by a maximum of 1.62°C. The data for the 10%ile temperatures followed a similar trend to the 5%ile data.

While the differences in the intake, i.e. ambient temperatures, between both sites are independent of the operation for both stations, the differences in the discharge temperatures between the two sites are influenced by the particular operational schedule operating at both stations, which isn't always the same. Both stations may not be generating at the same time and when they are they may be generating at different load levels, which in turn would result in different discharge temperatures and thermal loads. It is also important to point out that the summary statistics only used temperatures for the discharge when power was being generated and only when the temperature difference between the intake and discharge was at least 3°C. There were extended periods at both plants when there was no power being generated or generation was at a very low level. This can be appreciated by comparing the number of data points used to generate the summary statistic for the intake and discharge data (see last column Table 2a & 2b). In this respect, the discharge data can be read as very conservative.

The implications of the various temperatures recorded will be addressed in the following section dealing with fish species and groups of species.

LRP

INTAKE	Average	Median	Max	Min	5%ile	10%ile	95%ile	90%ile	Count
Jan	4.74	4.71	8.32	0.17	7.27	6.91	1.46	2.74	682
Feb	5.20	5.10	9.45	2.30	7.55	7.03	2.94	3.41	621
Mar	7.15	7.21	12.74	3.36	9.65	9.23	4.06	4.74	682
Apr	10.88	10.82	15.92	3.74	14.43	13.83	7.26	8.38	657
May	14.00	13.75	20.29	10.15	17.78	16.87	11.32	11.65	679
Jun	17.57	17.24	21.98	12.20	20.91	20.37	14.82	15.41	657
Jul	18.42	17.85	24.98	15.27	22.82	21.70	16.12	16.35	616
Aug	17.25	17.26	20.08	14.67	19.20	18.69	15.56	15.74	619
Sep	15.24	15.12	17.83	11.57	17.38	17.01	13.02	13.55	599
Oct	11.85	11.80	16.09	7.01	14.71	14.09	9.43	9.82	620
Nov	8.05	7.97	12.77	2.70	10.88	10.40	5.50	6.10	599
Dec	5.11	5.31	9.36	0.08	8.18	7.64	1.06	1.66	620

Table 2a Summary statistics for the Lough Ree Power station cooling water INTAKE temperature from 2006 to 2016

DISCHARGE	Average	Median	Max	Min	5%ile	10%ile	95%ile	90%ile	Count
Jan	11.70	11.80	15.28	6.34	14.16	13.79	7.92	9.61	653
Feb	12.27	12.22	16.87	6.83	14.72	14.22	9.87	10.32	596
Mar	14.28	14.38	20.33	9.39	16.99	16.47	11.08	11.73	642
Apr	17.97	17.88	23.68	10.53	21.67	20.77	13.82	15.49	590
May	20.69	20.22	27.68	15.57	25.10	24.03	17.90	18.38	452
Jun	24.76	24.53	30.08	17.56	28.55	27.90	21.56	22.26	517
Jul	25.90	25.29	31.26	20.90	29.98	28.92	23.39	23.78	484
Aug	24.53	24.70	27.60	20.43	26.28	26.01	22.18	22.93	473
Sep	22.09	22.24	26.89	16.02	24.64	24.25	19.04	19.73	434
Oct	18.84	18.94	23.87	12.46	21.85	21.07	15.40	16.80	560
Nov	14.92	14.92	19.44	9.41	18.58	17.73	11.75	12.43	546
Dec	12.12	12.12	16.82	4.84	15.36	14.61	8.21	9.09	607

Table 2b Summary statistics for the Lough Ree Power station cooling water DISCHARGE temperature from 2006 to 2016

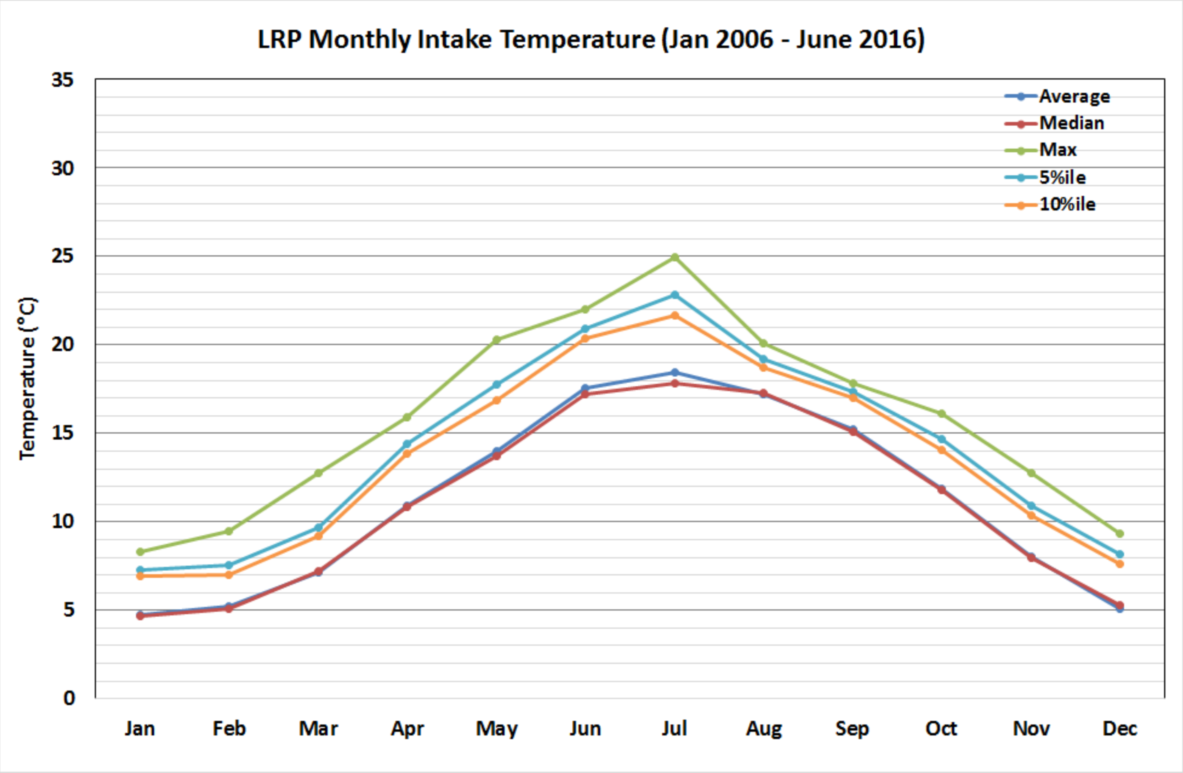


Figure 1a Graph of summarised monthly temperature variation at LRP cooling water INTAKE (2006-2016)

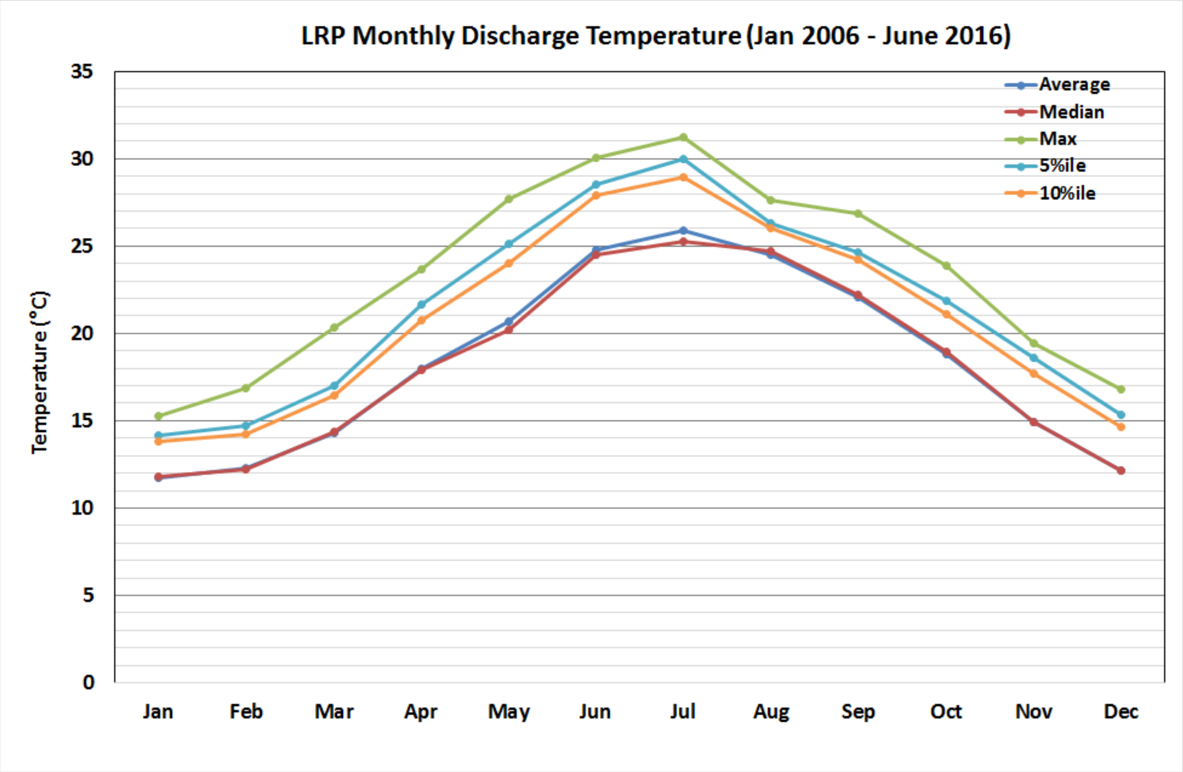


Figure 1b Graph of summarised monthly temperature variation at LRP cooling water DISCHARGE (2006-2016)

WOP

INTAKE	Average	Median	Max	Min	5%ile	10%ile	95%ile	90%ile	Count
Jan	5.00	5.11	8.30	0.74	7.18	6.93	1.84	2.94	676
Feb	5.31	5.30	8.77	2.65	7.50	6.85	3.25	3.56	622
Mar	7.02	7.23	11.55	3.86	9.10	8.65	4.42	5.04	682
Apr	10.32	10.30	14.89	4.12	13.25	12.61	7.17	8.15	653
May	13.53	13.37	19.05	9.98	16.74	15.92	11.21	11.49	681
Jun	17.02	16.81	21.33	12.18	20.30	19.76	14.12	14.85	657
Jul	18.19	17.74	24.10	14.17	22.30	21.19	15.95	12.29	620
Aug	17.34	17.31	19.90	15.34	18.83	18.45	15.94	16.20	620
Sep	15.58	15.47	17.95	12.59	17.53	17.28	13.76	14.04	601
Oct	12.54	12.67	16.40	7.40	14.93	14.23	10.39	10.83	617
Nov	8.77	8.76	12.89	3.65	11.46	11.03	6.10	7.00	601
Dec	5.68	5.87	9.37	0.34	8.39	7.80	2.40	2.82	620

Table 3a Summary statistics for the West Offaly Power station cooling water INTAKE temperature from 2006 to 2016

DISCHARGE	Average	Median	Max	Min	5%ile	10%ile	95%ile	90%ile	Count
Jan	11.27	11.66	15.74	5.65	14.13	13.76	6.86	8.16	620
Feb	11.85	11.97	15.72	7.48	14.36	13.90	9.12	9.48	601
Mar	13.45	14.12	16.82	7.74	15.93	15.47	9.89	10.39	569
Apr	16.92	16.99	21.88	9.28	20.06	19.45	13.13	14.92	411
May	20.31	20.32	25.80	14.20	23.82	23.15	16.69	17.42	524
Jun	23.64	23.46	28.56	18.66	27.65	26.77	20.25	21.14	427
Jul	25.22	24.74	30.06	20.13	28.94	28.24	22.48	22.79	450
Aug	24.12	24.14	27.36	19.23	25.75	25.49	22.13	22.88	371
Sep	22.06	21.95	25.31	16.95	24.48	24.07	18.93	20.34	400
Oct	19.08	19.14	23.47	13.10	21.58	21.07	16.03	17.21	544
Nov	15.34	15.35	19.46	8.96	18.42	17.75	12.45	13.24	591
Dec	12.09	12.45	16.29	4.71	15.17	14.63	7.51	8.85	614

Table 3b Summary statistics for the West Offaly Power station cooling water DISCHARGE temperature from 2006 to 2016

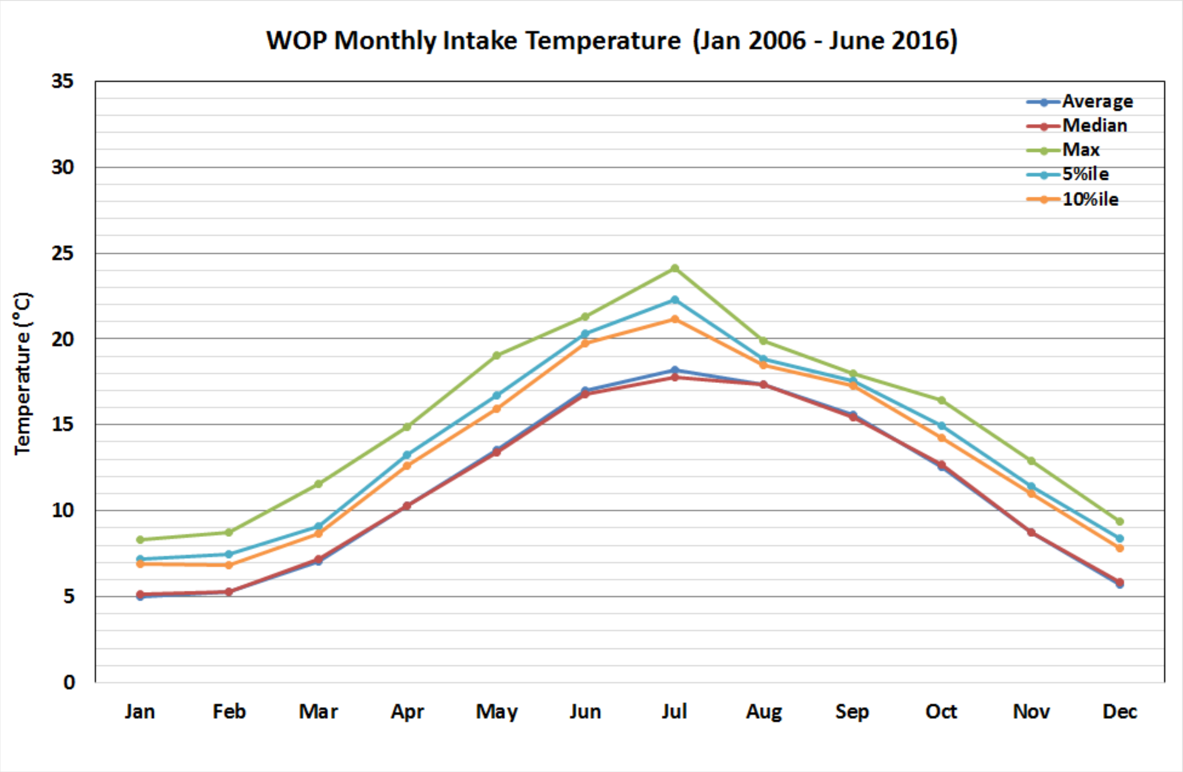


Figure 2a Graph of summarised monthly temperature variation at WOP cooling water INTAKE (2006-2016)

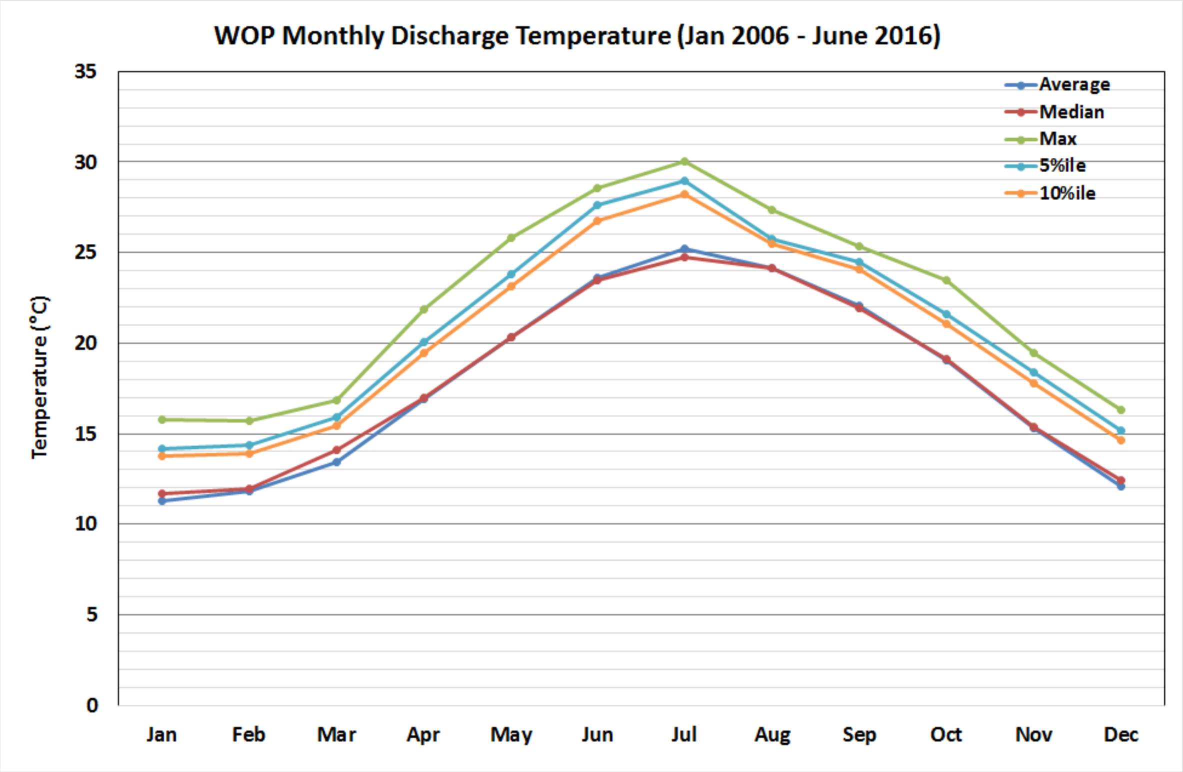


Figure 2b Graph of summarised monthly temperature variation at WOP cooling water DISCHARGE (2006-2016)

Assessing Temperature Preferences and Tolerances in Fish – Some Definitions

Methods for assessing the temperature preferences and tolerances in fish are discussed by Jobling (1981), who also reviews some of the terminology used and it is worth briefly discussing this as part of the review. According to Jobling the temperature responses of fish can be divided into tolerance, resistance and preference. Jobling illustrates the thermal responses of fish relative to acclimation temperature by the schematic in Figure 3. In order to define the zones of tolerance and resistance, plots of incipient lethal temperatures (tolerance limit) and temperatures at which death is rapid (resistance limit) are made against acclimation temperature. The upper and lower incipient lethal temperatures (IULT and LILT) represent the temperature at which theoretically, 50% of the population could survive indefinitely. Outside of the tolerance temperatures lies the zone of resistance within which there is a strong interaction between temperature and exposure time. The upper boundary of this zone is represented by the critical thermal maximum (CTM). Survival times above this temperature are virtually zero. The IULT, LILT and CTM are dependent upon acclimation temperature and the previous thermal history of the fish (Figure 3). The figure also shows that the boundaries of the tolerance zone are given by the IULT, LILT and the ultimate upper incipient lethal temperature (UIULT), which is the highest temperature to which the species can be acclimated. Within the tolerance zone delimited by these boundaries, a fish will tend to gravitate to preferential temperature zone within which the fish will make 'exploratory movements' into waters of higher and lower temperature.

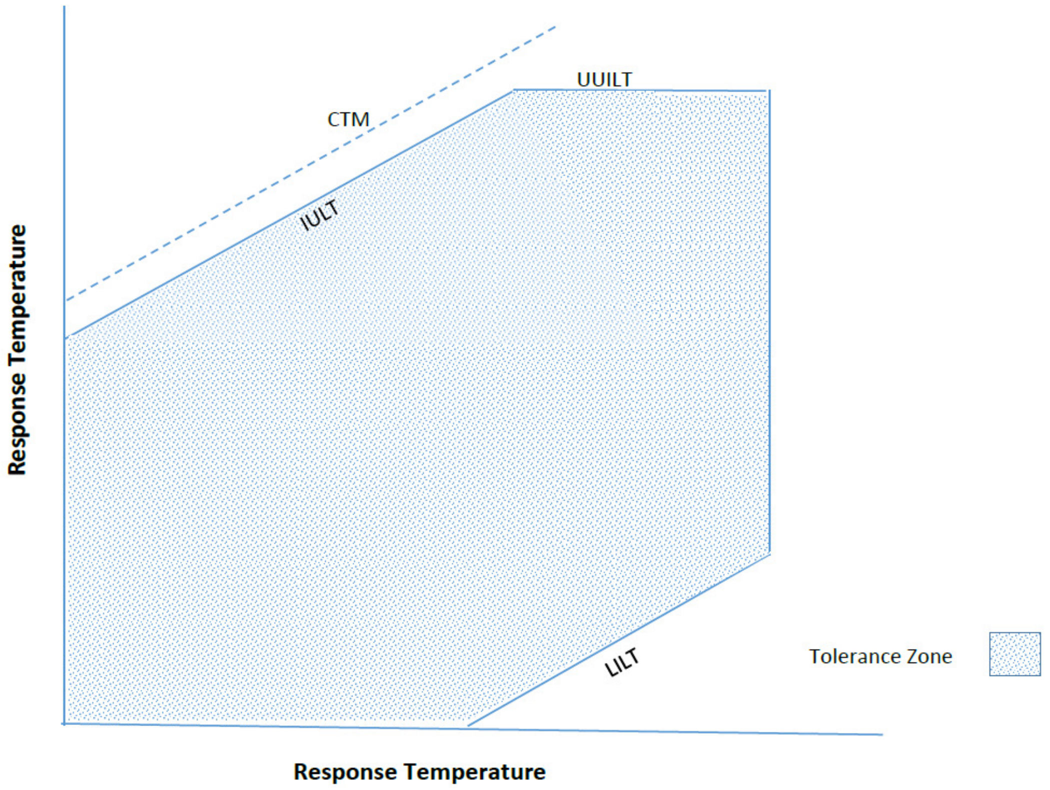


Figure 3 Schematic of theoretical fish thermal response limits (after Jobling 1981)

In the following section the published thermal optima/preferences and tolerance limits for the fish species of interest will be addressed. At this stage it is worthwhile briefly elaborating on acclimation temperature and its significance in determining what a given species can tolerate. In the context of determining what the IULT is for a species, the acclimation temperature is the temperature at which the test fish are held, usually for at least 1 week, before being exposed to fairly rapidly rising temperature increments until the IULT is reached, i.e. the temperature at which 50% of the test fish reach the nominated end point, which is usually some form of disorientation or loss of equilibrium, which will eventually be lethal. The exposure time set for the IULT test is generally about 1000 minutes i.e. a little over 16hours, although in some cases it may be longer. If removed from this temperature and placed in water of a lower temperature, fish would be expected to fully recover. The relevance of the acclimation temperature at which test fish are held is that as it rises the IULT also rises. However, there is a limit to which the IULT can be raised by raising the acclimation temperature and the resultant IULT for this highest acclimation temperature is referred to as the UIULT as referred to above. Therefore, in any given species, the IULT will naturally rise as the ambient temperature rises up to a maximum. In the context of the Shannon sites, this means in effect that as the temperature gradually rises in the river on a seasonal basis the tolerance of each species to higher temperatures also rises up to an absolute limit. This also means that in warmer years, the temperature tolerance of most species will also tend to rise. However, within these tolerance ranges (bounded on the upper side by the IULT), fish will naturally gravitate toward a preferred temperature zone (lower than the IULT) which itself will also tend to rise as the background temperature (i.e. acclimation temperature) rises. In the following analysis the IULT with acclimation temperatures, generally no higher than 22 to 25°C have been chosen as the upper limits of tolerance of the species under discussion. Higher IULT's e.g. derived for higher acclimations temperatures, where these have been reported, have not been used in the species risk assessments.

Thermal Optima and Thermal Tolerance of Fish

A large body of research into the thermal tolerances of a very wide variety of fish has been undertaken over the decades, especially in the 60's 70's and 80's but also more recently. This work has been undertaken in order to assess the impacts of thermal effluent from power stations, to determine the optimal temperatures for fish culture, and more recently in relation to the impacts of global warming. Much of these data have been conveniently gathered into reviews such as those of Alabaster and Lloyd 1980 (across the species range), Elliott and Elliott (2010) with salmon and trout, and Souchon and Tissot (2012) for a range coarse fish from Western European rivers. Data for eel, which wasn't available in these reviews was obtained from Sadler (1979) and Seymour (1989) and for lamprey ammocoetes from Potter and Beamish (1975). I have relied on these reviews to compile a table of thermal optima / tolerances for different life stages for each of the fish species of interest, using UK data, where available, in preference to continental European data or data from farther afield (Table 4). In the absence of specific data for brook lamprey (*Lampetra planeri*), data for the very closely related river lamprey (*Lampetra fluviatilis*) was used.

The reviews also give upper and lower temperature limits at which spawning takes place and these have been referred to where relevant, e.g. they are not quoted for eel, as they don't spawn in freshwaters. While there are no experimental data on IULT values for fish undertaken in Ireland of which I'm aware, wherever possible data on spawning temperatures (and dates) reported for a given species in Ireland are used in the analysis over data from other sources, although this is also quoted, and used in the absence of Irish data.

Thermal tolerance data for fish can be quite varied even within the same species, with much of the variation relating to either life stage and or the temperature at which the species were acclimated before testing. Generally, when faced with a choice, what appear to be high outliers were avoided and where an author pointed to a more typical value, the latter was chosen.

Species	Life Stage	Optimum	Cessation of Swimming	Upper Growth Limit	IULT	Acclimation Temperature	Observations on IULT
Brown Trout	Parr/adult	13.1-17.4		19.5	25		7-day limit
Atlantic salmon	Parr			22.5	28		7-day limit
	Smolts		20				
Eel	Adults	23-26.5		30-32.5	33-39	14-29	
Sea lamprey	Ammocoetes				29.5-31	5 & 25	
River lamprey	Ammocoetes				27-29	5 & 25	
Roach	Reproduction	10-18 (7-22)					
	Embryos	12-24			26		
	Juveniles	7-21		28	26.9-34.7 (30)		
	Adults	12-25			27.3, 29.4, 31.5	15, 20, 25	
					30.1-35.2	17-31	
Perch	Reproduction	8-15 (5-19)					
	Embryos	7-21 (12-18)			26		
	Larvae	12-25			36		
	Juveniles	10-25			31.4-33.5	25-30	32 considered most consistent upper boundary temperature
	Adults	16-27			24-31.4 (30-33.5)	6-25	
	Reproduction	8-15 (5-19) (Ireland, 9-14, early April to mid-May)					
Pike	Reproduction	8-15 (Ireland, 9.4-15.5)					
	Embryos	8-14 (4-23)					
	Larvae	12-21			28.4		
	Juveniles	19-21			29.4 (33)		29.4 = field; 33 = lab
	Adults	10-24		26-27	34 (31)		31 = most consistent
Bream	Reproduction	(Ireland, 15°C+, mid May-mid June)					
	Embryos	12-23 (upper boundary 28)			32		
	Juveniles	14-28					
	Adult	10-26			30.2	20	
Rudd	Reproduction	17.2-26.6 (Ireland 17-19 mainly, June-July mainly)					
	Adults			28	31.2	20	
Gudgeon	Reproduction	12-17 (24)					
	Embryos	16-20					
	Larvae	20.5					
	Juveniles	7-27					
	Adults				28.6		Possible underestimate

Table 4 Temperature tolerance limits in degrees Celsius for Shannon fish species and life stages (see text for further explanations)

Temporal and Spatial Characteristics of the Plume

The potential risk to the fish communities in the Shannon at LRP and WOP cannot be fully described without an understanding of the vertical and horizontal extent of the cooling water discharge thermal plume at both stations and how that can vary on a seasonal basis. The hydromorphology of the Shannon at both sites differs considerably and this has a bearing on the behaviour of the plume at each site. Recently, at the request of the EPA, several thermal plume surveys have been carried out by Irish Hydrodata (IHD) at both stations including one each in early spring (February 2015), late spring / early summer (April/May 2016) and late summer / early autumn (July/August 2014). The results of these surveys provide a good understanding of the extent and behaviour of the plume under a variety of flow conditions. Based on a combination of these reports, some general characteristics of the plumes at both sites are described below.

West Offaly Power (WOP)

February 5th 2015 (IHD, 2015a & b)

During this survey on February 5th the water level was at 37.4mOD, i.e. the 12%'ile level. This high water level resulted in the banks being over topped and as a result a large portion of the thermal plume discharging on the eastern side of the channel left the river channel within about 50m of the discharge point and flowed into the flood plain flowing parallel to the eastern side of the main river but outside it. The residual portion of the plume which continued along the eastern side of channel was confined to within 10-12m of the eastern bank and didn't extend to any deeper than 1.8m below the surface. The maximum temperatures for most of the plume was no higher than 1-3°C above ambient, which at the time was 3.1°C. The plant at the time was on full load with a cooling water flow of 5.4m^3/s and the incremental increase in temperature of the cooling water was 6.8°C giving a discharge temperature of 9.9°C, which is about 2°C below the 10-year (2006-2016) average discharge temperature at the station for the month of February (see Table 3b). At about 820m downstream of the station a residual portion of the flood plain bypass flow re-entered the eastern edge of the main channel and caused a small increase in ambient temperature for the following 50-100m downstream, before it completely dissipated. Again, the increment above ambient within the plume was no more than 3°C but mainly no more than 2°C.

April 28th & 29th 2016 (IHD, 2016a)

During this late April survey, the plume was confined to the channel as the river wasn't in flood. As in the February survey, the plume hugged the left bank and at most extended 25m into the channel, but closest to the outfall, where absolute temperatures in the plume were at their highest (max ~16°C at 0.3m below the surface) just 75m downstream of the discharge, the plume only extended 10m from the bank. At no stage did the plume extend more than 50% across the river and in terms of cross sectional area of the whole channel the plume never comprised more than 17%. Within the horizontal extent of the plume temperatures were highest toward the eastern bank, declining quite rapidly both in a horizontal direction toward the channel centre and vertically toward the deepest measuring point at 2m. At this latter depth the maximum temperature was generally no more than 2°C above ambient, occasionally spiking to about 2.7°C. But these rapidly dropped to 0°C above ambient (9.5°C) toward the outer edge of the plume and also declined longitudinally in a downstream direction. By 425m downstream the near surface temperature (at 0.3m depth) was no more than 2°C above ambient while at the same site the temperature at 2m depth ranged from 1.2°C close to the bank to 0°C toward the centre at the same depth.

The residual temperature rise in the river may have been about 0.4°C in the river, as this was the temperature measured above ambient at 1.9km downstream of the discharge, presumably after full mixing of the plume by that point.

At the time of the survey the station was on full load with a cooling water of 5.31m^3/s. The ambient i.e. upstream/intake temperature was approximately 9.5°C which is below average by at least 1°C for late April based on the 10-year record for the site provided by the station (2006-2016, Table 3a). The station discharge temperature 17.1°C was marginally above average for the station for the period 2006-2016. At the time of the survey the station was on full load and the incremental increase in temperature between the intake and discharge was measured at 7.3°C by the station. This is about 0.6°C above the April average for the station since 2006.

July 31st 2014 (IHD, 2014a & b)

The July 31st 2014 survey was undertaken when the station was on full load with a cooling water flow of 5.5m^3/s. The ambient temperature at the time was 19.5°C and the discharge temperature at the station was 27°C which is about 1.78 °C above the 10-year average for the discharge temperature but given that the sampling date is on the cusp of August, this may be closer to 2-2.5°C above average for this season. At the same time the flow in the Shannon at Athlone was about 91%'ile (pers comm Annmarie Downey, ESBI) which means that the survey is representative of more thermally challenging conditions in the river at this station.

Initially, although the plume remained close to the east bank, as in the February and April surveys, it then switched direction toward the west bank propelled by the momentum of the discharge flow. It subsequently appeared to move between banks until the first bend at around 650m downstream at which stage the plume mixed with the full flow producing a uniform 2-2.5 degree rise above the upstream ambient temperature which was still evident at 1700m downstream throughout most of the water column. While still intact, i.e. within the first 650m, the plume differed from those of the earlier surveys in that within this stretch it appears to have taken up a greater portion of the channel cross section at times. However, in as much as the highest temperatures were measured in the shallower depths, in this important respect it behaved the same as the April and February plumes. Based on the cross-sectional profiles taken during the survey, higher temperatures in the plume i.e. 4-<5°C were confined to the stretch within 300m of the discharge while the highest temperatures i.e. >5-<7°C were confined to the first 100m downstream of the discharge. In most cases also these more elevated temperatures were confined to the upper 1.5m, often the top 30cm. When the plume occupied the bulk of the channel, the majority of the temperatures in the cross-section were <2°C above ambient.

Lough Ree Power - LRP

February 4th 2015 (IHD, 2015c & d)

On the day of the survey the station was on 66% load with a cooling water discharge of 4m^3/s. The intake (ambient) temperature was just 2.4°C and the discharge temperature 9.8°C, an increase of 7.4°C. The latter was about 0.3°C above the 2006-2016 average for the intake-discharge increment for the month of February, while the actual discharge temperature was 1.9-2.5°C above for that time of year. The level in the river on the day isn't given in mOD, but seeing as on the following day the Shannon was flooding at WOP, it is reasonable to assume that the levels were also at the higher end of the scale at Lanesborough.

The plume was confined to the discharge canal retained there by the force of the flow coming down the main river on the west side of the channel. Within the discharge canal the plume didn't descend below 1m and generally hugged the eastern side of the canal. The highest temperature recorded in the plume (at 0.3m) was <6°C above ambient 50m downstream from the discharge. By 400m downstream the highest temperature in the plume, still at the surface and still hugging the east bank, was no higher than 3-4°C above ambient. At 450m the plume entered the lagoon area between LRP and Lough Ree where the bulk of the plume was <2°C above ambient within the residual plume cross-section. By 550m from the discharge there was no evidence of the plume remaining.

May 1st & 3rd 2016 (IHD, 2016b)

The flow in the Shannon at Athlone on May 3rd was 53.26m^3/s i.e., about the 63%'ile. The station measured the intake temperature on May 3rd at 11.3°C and 17.2°C in the discharge, an increase of 5.9°C. This discharge temperature is about 2°C lower than the 10-year average for the LRP discharge. The intake temperature was about 1°C lower than the 10-year average for the intake. The reason for the lower than normal increment between the intake and the discharge was most likely the reduced load at the station (66%) with a cooling water discharge of 4m^3/s at the time.

The bulk of the plume remained in the discharge canal between the discharge point and the entrance into the lagoon area about 475m downstream. Close to the water surface (0.3m) the water temperatures for the length of the canal were between 5°C and 6°C above ambient and remained so between the surface and the bottom (1.5-2m) throughout the canal. At breaks in the central linear 'islands' the heated water in the discharge canal flowed out into main river channel to the west but didn't extend beyond its centre line. Furthermore, below 0.8m depth within the plume, the temperature dropped rapidly from about 4°C above ambient at 0.3m to less than 1.3°C above at 1m and less than 0.2°C above at 2m, just above the bottom.

As the plume flows out into the lagoon, the surface temperatures were highest at the surface between 4 and 4.8°C above ambient toward the eastern side of the plume at 0.3m depth but by 1m below this had dropped to between 3 and 3.8°C above ambient, while at 2m it was less than 1°C above ambient. By about 600m downstream of the discharge the surface of the plume was less than 1.5°C above ambient, while on the bottom it was about 0.6°C above ambient, indicating effective dissipation at that point.

August 1st 2014 (IHD, 2014c&d)

This survey was undertaken when the station was on about 66% load and the cooling water flow was 4m^3/s. The ambient, i.e. intake/upstream temperature at the time was 19.5°C and the discharge temperature at the station was 27°C which is about 2°C above the 10-year average for the discharge temperature for that part of the season (Table 2b). At the same time the flow in the Shannon at Athlone was about 91%'ile (pers comm Annmarie Downey, ESBI) which means that the survey is representative of more thermally challenging conditions in the river at this station. The main difference in the behaviour and extent of the plume on this occasion compared to the May and February surveys, is that the plume crossed the entire width of the river and extended more or less symmetrically from bank to bank through the full extent of the lagoon at the northern end of Lough Ree. There are no temperature records for the discharge canal on the day because the depth (0.7m) was too shallow to navigate. However, one can assume based on the findings of the May 2016 survey that the plume temperature was close to 7.5°C above ambient for the majority of its length and depth. The plume spread across into the main channel via the 3 main gaps in the central 'island' and continued to the western bank. The temperature of the plume in the main channel at 0.3m below the surface began to increase from about 1.5°C above background at a point 50m downstream of the discharge reaching a maximum of about 7-7.5°C above ambient by the bridge at 175m downstream and remained at or above 6-7.5°C above ambient until the plume began to spread across the entrance section of the lagoon. Thereafter the plume temperature slowly declined toward the entrance to the Ballyclare Cut where it was 2-2.5°C above ambient remaining so through the cut and reaching 1-<2°C above ambient about 100m into Lough Ree proper and 0-<1°C from surface to bottom some 400m into the lake.

In terms of temperatures deeper in the plume, the main channel to about 250m downstream of the discharge remains at or below about 4-5°C above ambient below 2m depth. At the entrance to the lagoon, the temperature at 2m rose to between 5 and <~7.4°C above ambient, presumably because at that point the full flow of the discharge canal has joined the flow from the main channel downstream of the central dividing 'island's; the higher temperatures in this range were toward the eastern side of the entrance, i.e. on the same side as the discharge canal. By about half way through the lagoon at about 850m downstream from the discharge the top 2m was more or less uniformly located within the temperature band 4-<5°C above ambient from bank to bank (i.e. as far as the reed beds on either side). The considerable depth below this 2m contour was not surveyed, so we cannot say with confidence what the temperature at greater depth might have been, although the assumption is that it would have been lower. At 1250m downstream of the discharge (1500m downstream of the intake), the lagoon has become shallow again and the temperature, was within the range 2 - <2°C from 0.3 to the 2m and probably fully mixed from surface to bottom at 2.5m. By the entrance to Lough Ree at about 2000m downstream of the intake, the water column from 0.3 to 2m was in the range 1-<2°C above ambient.

In summary,

In winter, spring and early summer, it is probable that the western side of the main channel contains water at temperatures at or close to the upstream background level for its entire length and that the same pertains toward the western side of the entrance to the lagoon. Later in the summer and early autumn, (July and August) there are times when the plume reaches the western bank of the main channels and covers the entire area of the lagoon penetrating into the first 100-200m into Lough Ree, albeit at temperatures of between 1 and 2°C above ambient in the latter area. In winter and early spring, the plume in the discharge canal can be described as a surface phenomenon mainly, with deeper water in the canal near to ambient. However from early summer on, the plume along most of the discharge canal penetrates to the bottom with little or no temperature attenuation.

The form and relative thermal character of the thermal plume at the two sites, both horizontally and vertically, appears to be principally determined by the thermal load at the plant flow in the river at any given time, while absolute temperatures at any given point will also be determined by the ambient temperature at that time combined with the generating load in the plants.

Risk Assessment of Thermal Regime for Resident and Migrant Fish

In the following section an assessment of the risk posed by the thermal regimes in the Shannon at both power stations is assessed for the main resident fish species and those migrating through on a seasonal basis. To assist in this, the summary statistics for the temperature records of the cooling water intake and corresponding discharge for the 10 year period 2006-2016 (Tables 2a & 2b and 3a&3b) will be compared with the published thermal tolerance/sensitivity of different life stages of the species of interest, as a first step in assessing the potential risk to each. The intake temperature in this case is taken to be representative of the ambient i.e. upstream temperature for each station, while the discharge temperature is taken as the highest possible temperature in the thermal plume i.e. before full mixing and attenuation, thereby representing the worst case scenario. In further discussing the risk, the known behaviour of each species or life stage will also be considered and, importantly, the behaviour of the plume under various flow conditions, as revealed by the various seasonal thermal surveys undertaken to date by IHD, will also be taken into account.

Brown Trout (*Salmon trutta*)

Neither of the IFI WFD river surveys (IFI, 2009 and 2010a) encountered brown trout or salmon in the Lanesborough stretch of the river, or at Clonmacnoise on the Shannon 11.5km kilometres upstream of WOP. It isn’t surprising that salmon are absent, as they would only be present as smolts migrating seaward in spring and early summer or as adults migrating upstream in summer, autumn and early winter. Brown trout however do form a continuing small proportion of the Lough Ree fish population, so one might expect that they would be present on occasion at least at Lanesborough. However, the dominance of coarse fish and pike in all surveys of Lough Ree (IFI, 2010b, Kelly et al, 2014 and Delanty et al., 2016) as well as in the Shannon (2009, 2011) at or near the power stations would suggest that the Shannon at LRP and WOP could reasonably be classified as being cyprinid waters.

This seems to be borne out by the published data on the temperature preferences and tolerances of the species when compared to the ambient temperature record for both sites (Figures 4a & 5a) which indicate that during the warmer months of June, July and August, that optimum temperatures for the species growth are only achieved under average temperatures and in warmer years (i.e. with above average temperatures), the growth rate is likely to be suboptimal or even halted, and this is before the influence of thermal discharges. These data do not indicate that trout are absent but rather that during high summer in warmer years conditions for the species appear to be sub-optimal at both study sites. When the same data is considered in the thermal plume (Figures 4b & 5b) it is very obvious that conditions at both stations could be sub-optimal from as early as April and as late as October depending on whether the year is warmer or cooler. This is more pronounced at LRP where the Upper Incipient Lethal Temperature (IULT) for the species (25°C) coincides more or less with average plume temperatures in June, July and August derived from historical (10-year temperature record provided by the station). At WOP, this is only the case in August. These data suggest that the species is likely to be entirely absent from the discharge canal at LRP in the period June to August in most years and only sporadically present between May and October in warmer years. Because it is a deep and open system and trout cannot be 'trapped' in the Shannon like they can be in very warm years in natal streams where they can be confined to deep pools. Under such conditions trout are known to descend to the deeper cooler parts of pools as a survival mechanism (Elliott, 2000). It is possible, following the same logic that trout in the LRP lagoon would retire to deeper waters in that water body in warm years, assuming that temperatures at the bottom are coolest. To date, however, we cannot say that with certainty because the deepest measurements to date have only penetrated to 2m. Any trout present could also just drop a little farther downstream into the main lake. In WOP any trout present could drop back down to cooler conditions in any warmer year, as temperatures began to rise seasonally.

There are no references to date for the existence of a Lough Ree version of the 'croneen' a brown trout population that occurs in Lough Derg and which migrates into the Little Brosna and on to the Camcor River to spawn. The migration usually begins around July. A much awaited comprehensive genetic study of brown trout in the mid-Shannon system is due for publication in 2017 which is expected to elucidate the relative importance of various spawning rivers for the species in Lough Ree (among other lakes). Until that is published we can only speculate as to how the operation of LRP might be affecting some or all populations of the species that occurs in Lough Ree.

None of the IFI surveys indicates that the LRP or WOP sites is likely to have a significant brown trout population.

Historical ambient temperature data at both sites would suggest that trout experience sub-optimal temperature conditions during warmer summers in the months of June, July and August, quite apart from any influence from the two power stations.

Any brown trout present in both station reaches are likely to avoid much of the area of the discharge plume, in the period June to August in years of average temperature and possibly for the period May to September inclusive during warmer years.

It is extremely unlikely that the thermal plume poses any serious disruption to the annual spawning migration of brown trout or the Shannon 'croneen' trout.

Atlantic salmon (*Salmo salar*)

Salmon are not a resident species in either the LRP or WOP reaches of the Shannon and the potential significance of the thermal discharges is for the migratory smolt stage on its seaward journey and the inwardly migrating adult fish either grilse or multi sea-winter fish.

The following data on salmon in the Shannon was taken from the ESB's 2015 Annual Report on Fisheries provided by Dr Denis Doherty, ESB's Fisheries Scientist who wrote the report and from whom some additional clarifications were also obtained. Apart from figures of about 3,800 and 2,800 in 2007 and 2008 respectively, total adult salmon numbers ascending the Shannon in the past ten years have averaged around 1,500 per annum. In 2015 the total was 1,456. Of these about 40% ran in the months June, July and August while 58% ascended from September 1st to December 31st. According to the 2015 ESB Fisheries Annual Report, the majority of the wild salmon spawning is located in the lower Shannon (particularly Lough Derg). Taking account of these details would suggest that perhaps as few as half of the salmon that began their ascent of the river in the warmer months of June, July and August i.e. around 300 fish would travel on toward Shannonbridge at ~75km from Parteen Weir and fewer again on to Lanesborough a further ~75km upstream. Thus only a portion of the fish returning to the Shannon is exposed to the potential risks of elevated temperatures from the thermal discharges in any given year. It may only take these fish a few days to reach Shannonbridge and Lanesborough if they move rapidly through the system, equally, however, it might take weeks. Their progress is likely to depend on a number of factors including: the number of physical barriers encountered, (perhaps the most significant being Athlone weir), ambient temperature, river flow and frequency of increases in river flow, physiological condition of the fish and proximity to the spawning season, among others. In short, it would be difficult to predict the average transit time of upstream migrants from Parteen Weir to the power station reaches. Furthermore, as the controlling factors will naturally vary from year to year the average transit time will also likely vary, at least somewhat. This would mean that fish entering in mid to late August for example might not arrive until well into September when on average temperatures would be cooler.

Salmon are significantly more tolerant of higher water temperatures than are trout and the highest ambient temperatures recorded at the two stations (24-25°C, Figures 4a & 5a) are 4 to 5°C lower than the IULT for the species (28°C), while the highest monthly average in July at both stations is about 10°C lower than the IULT. However, within the plume, during the months of June and July, in warmer years, the IULT is reached or exceeded (Figures 4b & 5b). In these situations adult salmon, especially during periods of reduced flow, could drop back down the river to avoid thermal stress and wait there until water temperatures decreased sufficiently and or there was an increase in river discharge to take them upstream past the affected reach. The thermal plume surveys undertaken in July-August 2014 (IHD, 2014a-d) at the two stations would suggest that the conditions at LRP would be more challenging during warm years than at WOP because vertical temperature profiles at WOP indicated that there were more stretches with cooler bottom water that would allow salmon travelling at depth to avoid the warmer surface layers of the plume. However, in the warmest years both sites could give rise to delays during periods of low flow. It’s important to point out that delays in upriver migration are not uncommon in the species and don’t automatically imply any adverse outcomes for the fish affected.

The other life stage that might be affected by the thermal discharges at LRP and WOP are seaward migrating smolts. The ESB operate a ‘smolt protocol’ at the dam at Ardnacrusha between mid-March (i.e. once the river temperature rises to around 8°C to 10°) continuing to around mid-June. This is an operating procedure using a particular power generation turbine (Kaplan) which is designed to facilitate the movement of smolts down past the dam with minimal mortality rates rather than have them delayed just above it. According to Denis Doherty ESB Fisheries, the duration of the smolt run varies quite a bit from year to year. Depending on whether the year is cooler or warmer the run might begin later or earlier, be of short and fairly concentrated duration or extended in a stop-start fashion. The latter will also be influenced by river flow, which research has shown is probably the most important factor affecting the rate of seaward migration. It usually stops in any case once water temperatures reach 18°C.

Smolts are likely to have the same upper thermal tolerance limits as adult salmon. Under ambient conditions smolts are never exposed to these temperature levels at LRP and WOP but in exceptionally warm years, late running smolts i.e. in late May or early June could in theory be exposed to these level in the plume. Against that, in warmer years one would expect that the bulk if not all the smolts would have already migrated, so the likelihood of any significant number of fish being exposed to this level of temperature in the discharge plumes is considered relatively remote. A more significant impact of the discharges however could relate to the rate of passage of smolts in warmer years. Research has shown that the optimum swimming speed of smolts is achieved at 13°C and that above 17°C this rate is reduced by up to 80%, while at 20°C smolts stop swimming actively (Martin *et al.,* 2012). These temperatures are not encountered in March in the discharge plume at either station and tend to be the exception in April, but occur regularly in May and are the rule in June at both stations with the effect being a little more pronounced at LRP (Figures 4b & 5b). We know from the 2016 thermal plume surveys undertaken in May 2016 that the plume at both LRP and WOP is mainly confined to the discharge canal and the eastern side of the main channel at the former and the eastern side of the channel at the latter, with very little impact on the western side of the channel in both cases. This means in effect that smolts can travel down past both stations along a parallel western stream where the temperatures are more or less at ambient and where they would be unaffected by the thermal discharge. This conclusion however is based on the assumption that the flow in the main channel is sufficiently high to ensure that the thermal plume is forced over toward the eastern side of the channel at both sites. The May survey undertaken in 2016 was not undertaken during conditions of seasonally low flows. Under low flow conditions, like those which pertained during the July/August 2014 thermal plume surveys (IHD, 2014a-d), the plume at both sites would in certain places occupy the entire channel, at least in certain stretches. If these flow conditions coincided with high cooling water discharge temperatures, then the rate of downstream decent of smolts could slow considerably in the affected reaches and they would be more likely to drift rather than swim downstream. This would in theory at least expose them to a greater risk of predation by pike resident in the affected reaches or to avian predators. Although, overall this risk is believed to be a minor one, it could be better evaluated with additional information about the typical flow conditions in the river during the months of April, May and June and how these flow levels affect the vertical and horizontal extent of the thermal plume.

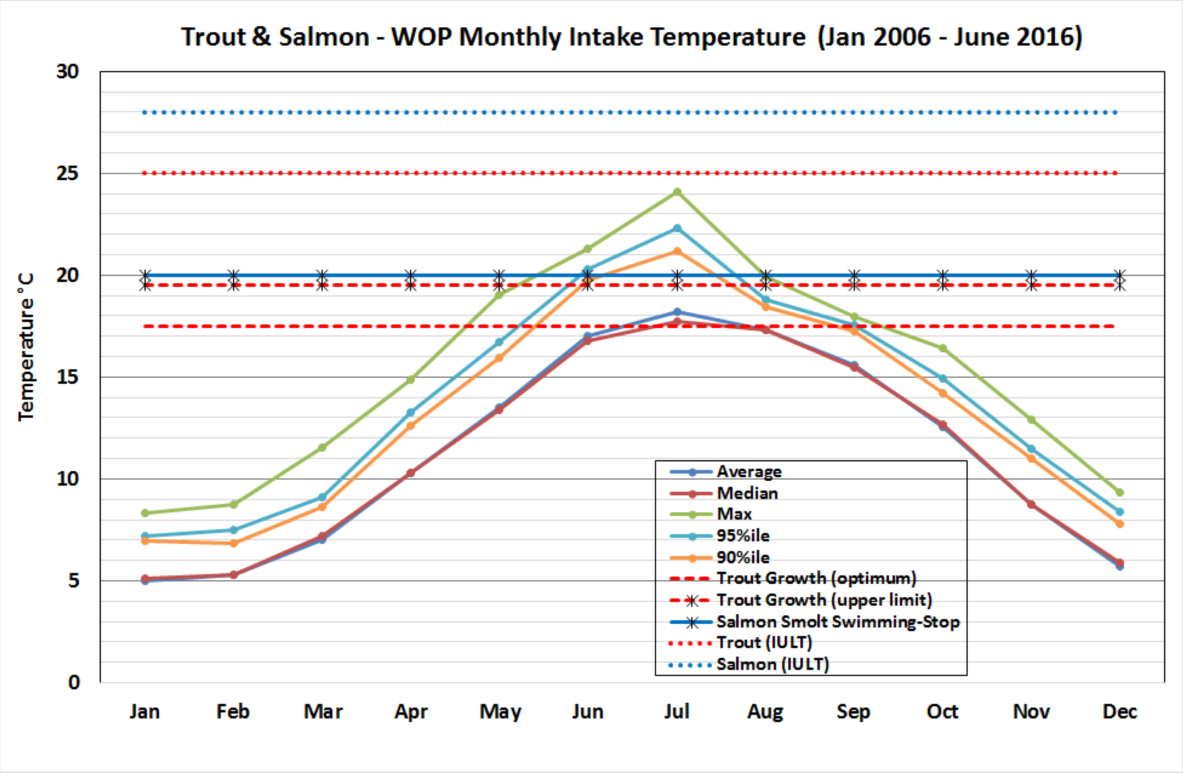


Figure 4a Trout and salmon thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

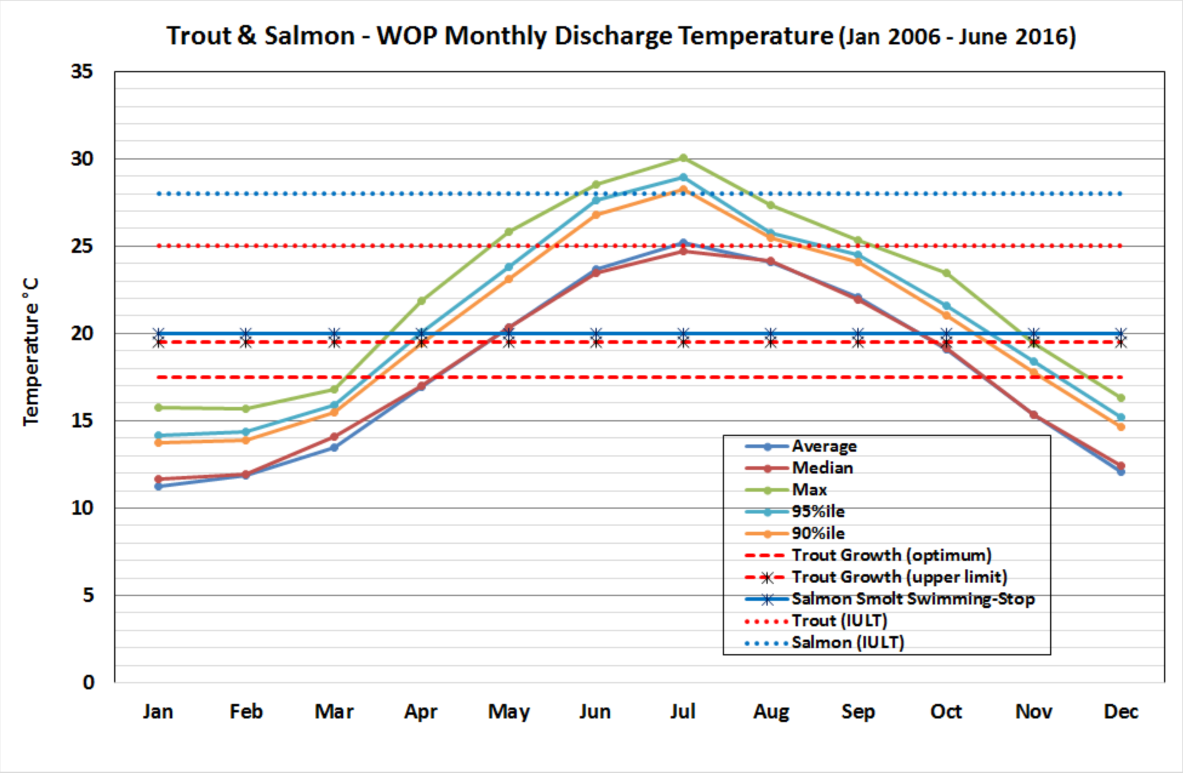


Figure 4b Trout and salmon thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

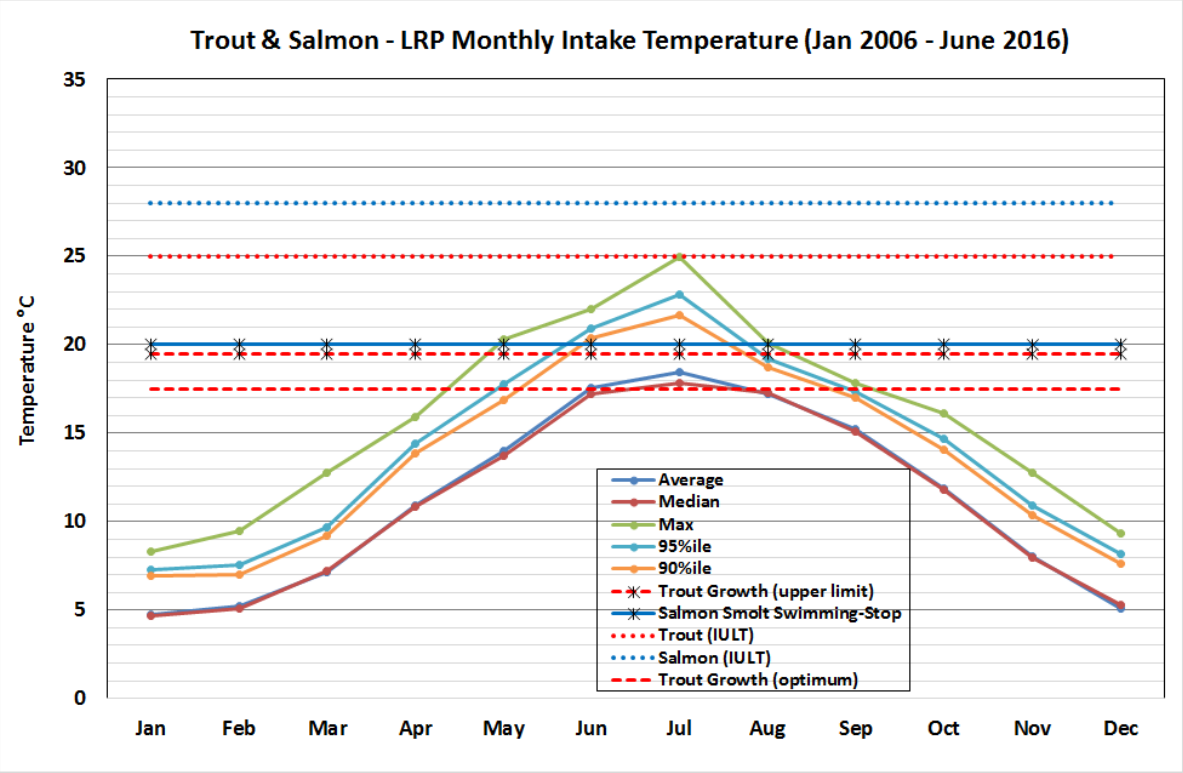


Figure 5a Trout and salmon thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

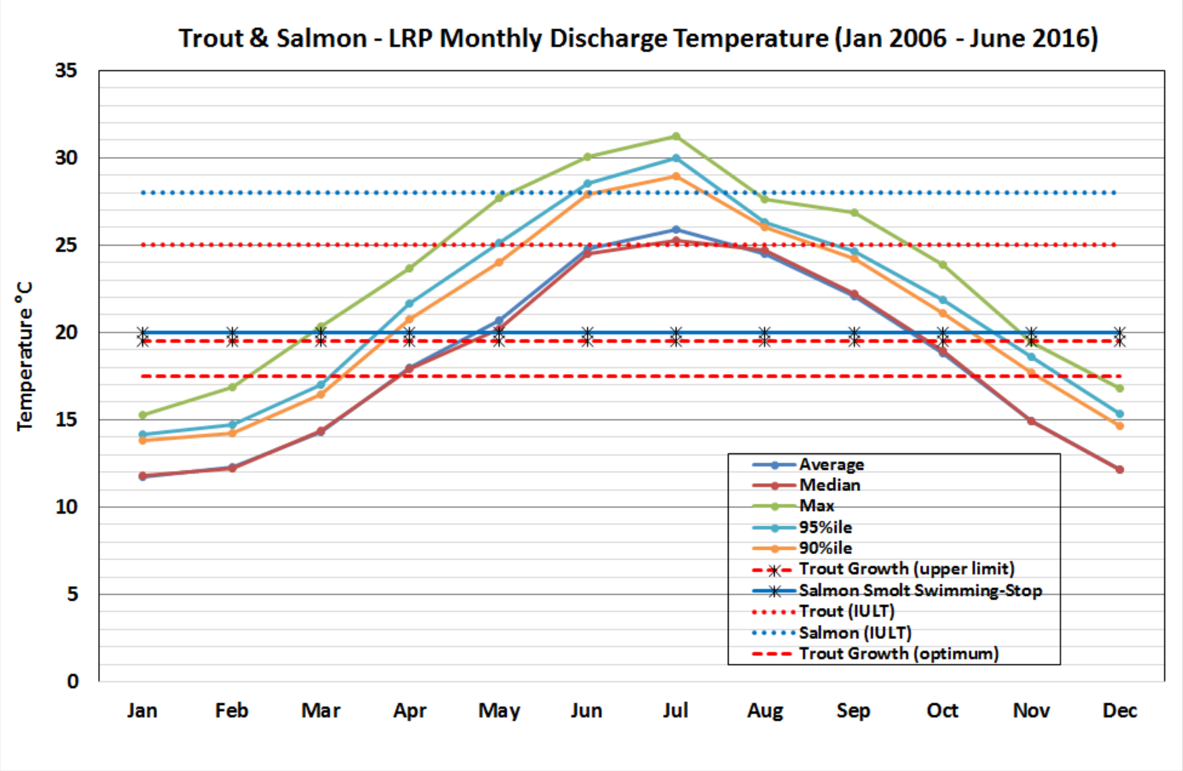


Figure 5b Trout and salmon thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Eel (*Anguilla anguilla*)

The Shannon is one of the premier eel producing rivers in Ireland and the stocks are managed by the ESB. In accordance with the EU Regulation (2009), on eel the migration of silver eels ESB operates a trap & transport programme on the Shannon. The programme is monitored by IFI and the National Standing Scientific Committee on Eel issue an annual report to the Department. The T+T targets are set by NSSC Eel for ESB. A full report on the 2015 programme has been published and is available to download from the IFI website at http://www.fisheriesireland.ie/eels/939-ssce-report-2015-final-report-26-5-2016.

Due to the presence of the Parteen Weir and Ardnacrusha hydroelectric power station, downstream passage of migration-ready adults (silver eels) is facilitated by a system of trapping eels at 4 sites within the catchments above Parteen and their transport for release below the dam. Trap and transport as it's termed is carried out from August to February each year when most of the silver eels undertake their downstream migration. In 2015 no eels were trapped at the Killaloe weir (one of the trapping locations) during the months of August and September because of the low flows. The bulk of silver eels move at night during periods of high or increasing flow and during darkness. Adult eels have a high IULT (33°C) and a high optimum growth temperature 23-26.5°C. These data suggest that ambient conditions at both LRP and WOP are ideal for this species (Figures 6a & 7a). Furthermore, the 10-year historical record for the temperatures at both sites, when plotted against these temperature criteria indicate that even in the highest temperatures in the plume (Figures 6b & 7b) in the months when they migrate (August to February) silver eels are unlikely to encounter any difficulty in passing downstream through the LRP or WOP reaches; this assessment is further supported by the benthic habit of the species, which rest up and feed close to the bottom, where they would be exposed to lower temperatures under most circumstances.

Inwardly migrating juvenile eel (glass eel, elvers and fingerlings) are trapped at two locations in the Lower Shannon (Ardnacrusha and Parteen Regulating Weir), and are then transported upstream of the dam. In 2014 and 2015, 339.47kg and 418.9kg respectively of juvenile eel were trapped by ESB and transported for release above Ardnacrusha. These are trapped between March and September and released at into the Lower L. Derg catchment area and gradually disperse throughout the vast upstream drainage network of the river. According to ESB's records the recruitment of elvers to the Shannon, continues to decline, in common with rivers in the rest of Europe. At any one time a catchment may contain 10 to 20 age cohorts of eels, which mean that the bulk of the River Shannon's eel stock at any given time is resident rather than migratory. In this respect, the greatest potential effect of the thermal discharges would be expected to affect the resident rather than the migratory stocks of the species. The fact that this population is resident and has been a frequent component of the surveyed stock noted in IFI WFD surveys at LRP (IFI, 2009, 2010a) indicates that it has the opportunity to become acclimatised to the ambient temperature conditions at the sites, a factor which probably helps to reduce potential risks associated with elevated water temperatures. As indicated above, the summary record for the ambient temperature at both sites, when compared with the optimum growth requirements for the species indicates that thermal conditions are ideal for the species including during the warmest summers. Even below the discharges, i.e. within the thermal plume, only during the warmest years could conditions (in the warmest part of the plume) be considered sub-optimal (in terms of growth potential) but even then never approaching incipient lethal levels (33°C), (Figures 6b & 7b) However, as previously mentioned eels are further protected from exposure to higher temperatures by their benthic existence, which means that they are likely to be less restricted in their distribution even during the very hottest years during June and July. One cannot rule out the possibility that eels might avoid the warmest parts of the discharge canal at LRP during the very warmest years, especially in June and July, but this effect is unlikely to be significant when taken over the full period of the freshwater residence of any given eel and at a population levels it's effect would be negligible.

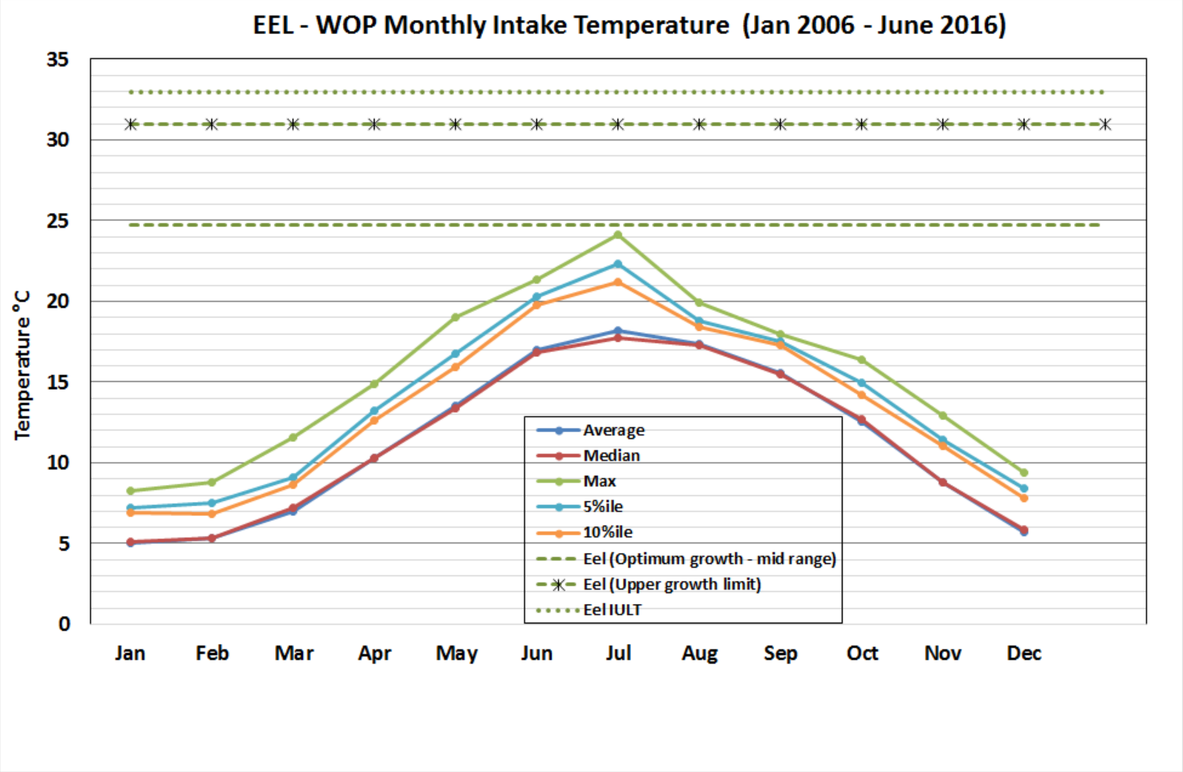


Figure 6a Eel thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

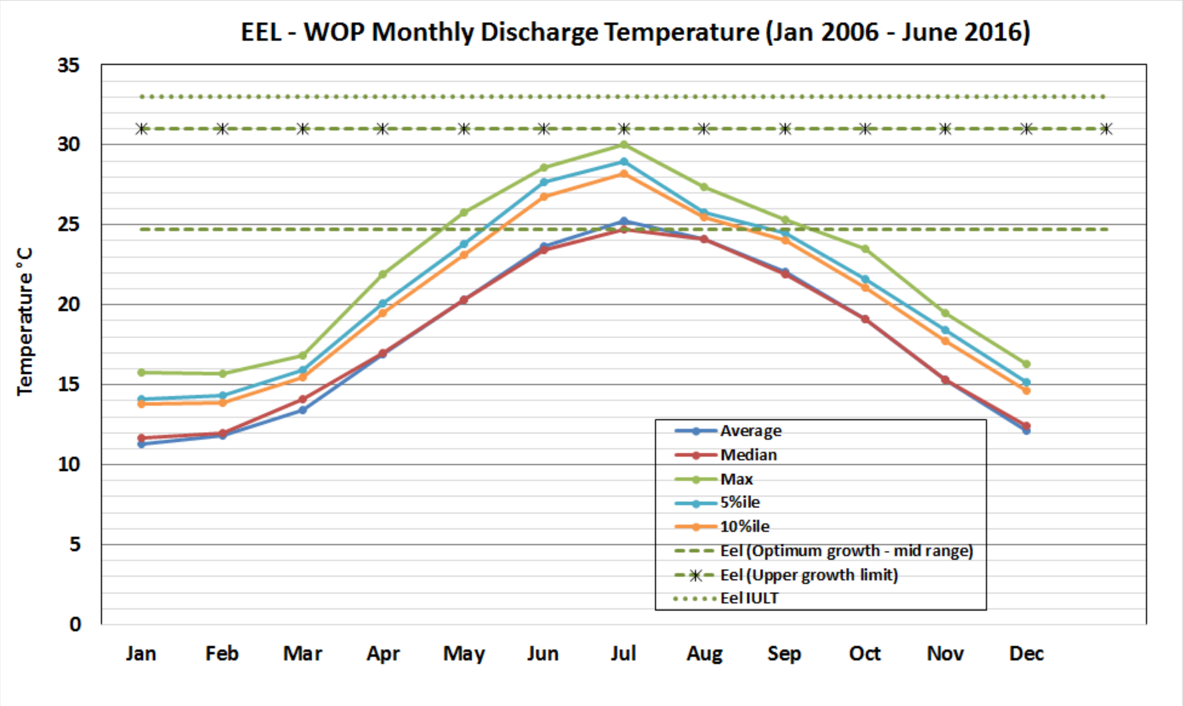


Figure 6b Eel thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

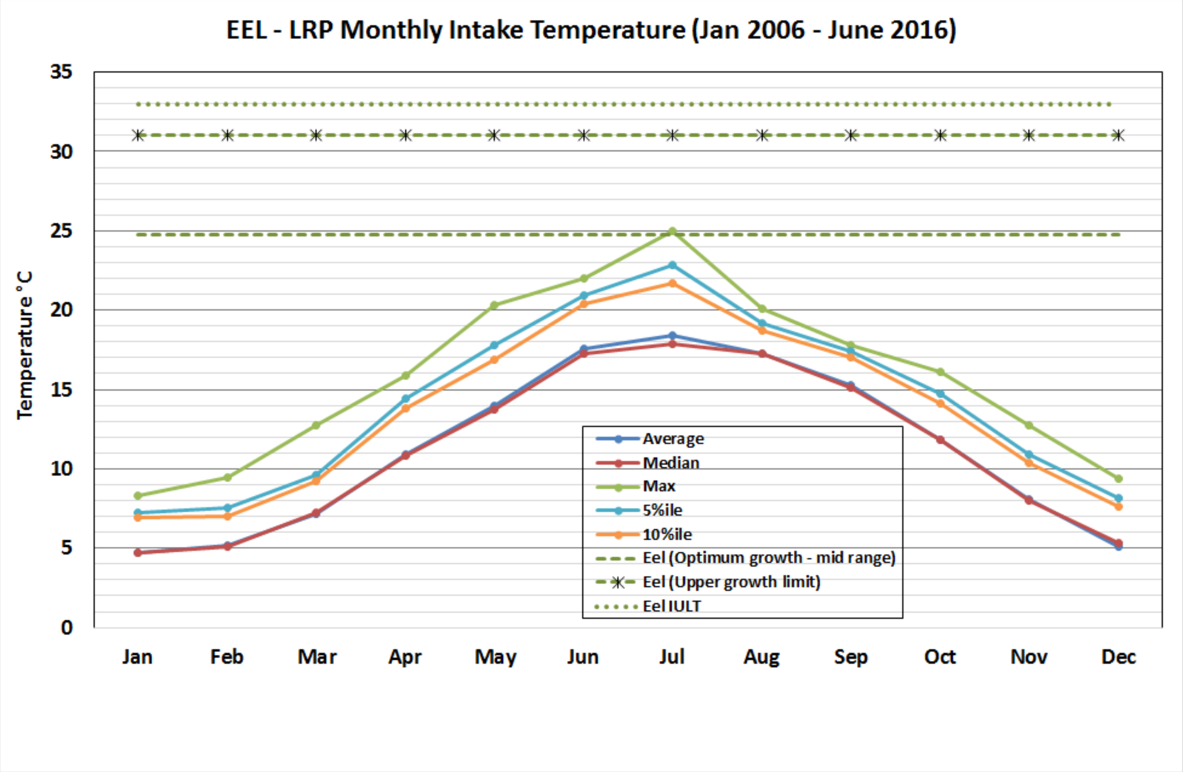


Figure 7a Eel thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

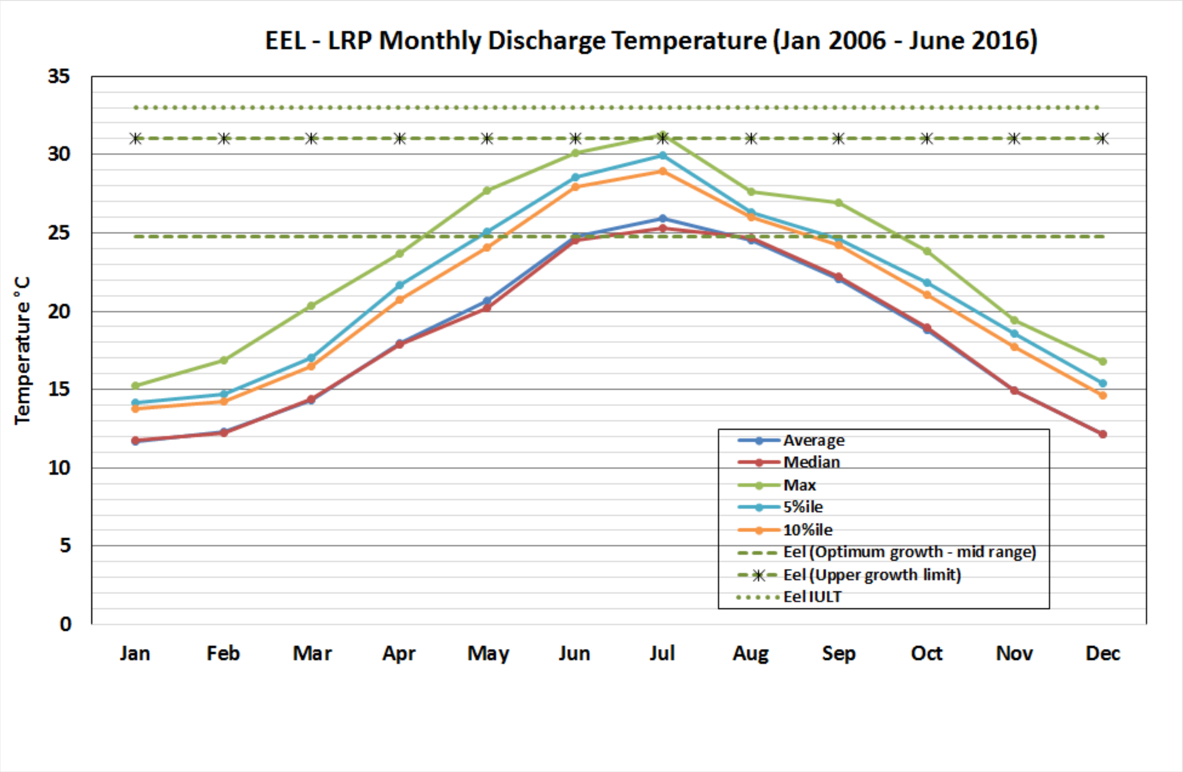


Figure 7b Eel thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Lampreys (*Lampetra* sp.)

According to the 2015 ESB Fisheries Annual Report – the anadromous sea and river lampreys appear to be confined mainly to the Lower River Shannon. This is partly supported by the fact that the IFI surveys at Clonmacnoise and Lanesborough have not encountered sea lamprey ammocoetes, all were belonging to the genus *Lampetra*. While these may also contain river lamprey, which is *Lampetra fluviatilis* and as ammocoetes are indistinguishable from their congener *L. planeri*, the brook lamprey, it is considered likely that if present river lamprey form a negligible portion of the population. The emphasis in this assessment is therefore on the non-migratory brook lamprey which are likely to be well represented at both sites. Neither stretch of river has conditions that would be suitable for lamprey spawning, so our concern here is with the ammocoetes which live buried in fine sediments on the river bed, where they grow for at least 3-4 years before transforming into small adults. Information on the thermal tolerance of the species was not encountered during the literature review however data for the lethal temperature for *L. fluviatilis* was encountered. Its IULT is measured at 29°C for ammocoetes acclimatised at 25°C. During ambient conditions at both LRP and WOP that temperature is never approached, even during the warmest months (Figures 8a & 9a). However, it is reached during the warmest years in July at WOP and June and July in LRP (Figures 8b & 9b) when the cooling water discharge temperature (before any mixing zone) is used as a baseline. Unlike other resident species lamprey ammocoetes lead a very sedentary existence and normally remain in their burrows. Clearly, if temperatures become intolerable they must either move or succumb. The likelihood is that they would move if temperatures began to approach IULT, even though examples of such movement resulting from elevated temperature were not found in the literature. If ammocoetes are displaced intermittently e.g. after high temperature episodes and perhaps replaced with newly arriving larvae during years where average or below average temperatures prevail, one might expect to find smaller i.e. younger ammocoetes in areas of suitable sediment in the discharge canal at LRP and along parts of the eastern bank for the first 300m downstream of WOP discharge which experience the highest temperatures, compared to the western side of both channels where lower temperatures would be the norm.

It may be noteworthy that temperatures in the cooling water discharge from LRP came within 0.5°C of the IULT (29°C) of the species and remained at or above 28°C for the period June 27th to July 2nd 2009, i.e. the year before the IFI carried out their last survey at Lanesborough (IFI, 2010a) where they recorded the same albeit very small density of *Lampetra* ammocoetes (0002/m^2) both upstream and downstream of the power station. It is also worth remembering that their bottom-living habit confers a degree of protection from exposure to highest plume temperatures. Overall, the temperature data suggest that there might be intermittent displacement of ammocoetes and or a possible reduction in their growth rates in areas of suitable habitat within the discharge canal at LRP and within the first 300m downstream of the WOP discharge, during very warm summers. However, bearing in mind the very wide distribution of the species (brook lamprey) throughout the Shannon system, that level of potential impact, were it to occur, is considered minor to negligible.

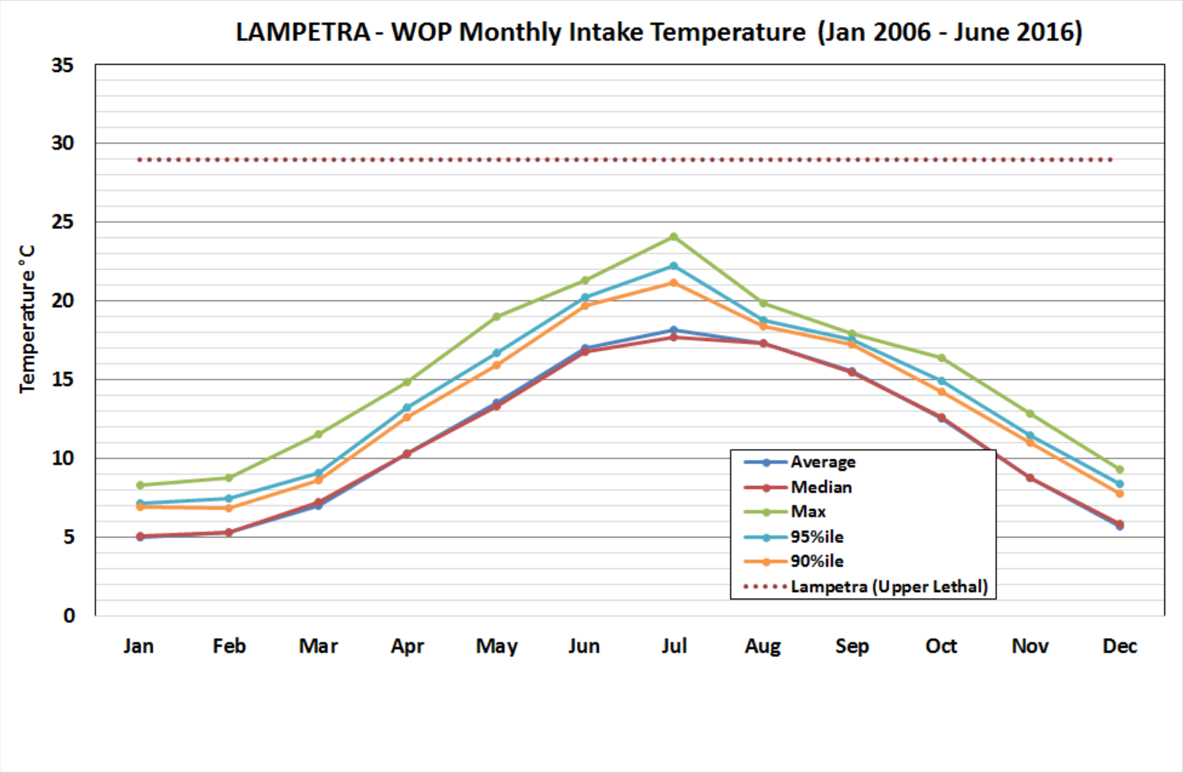


Figure 8a Lamprey (Lampetra) thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

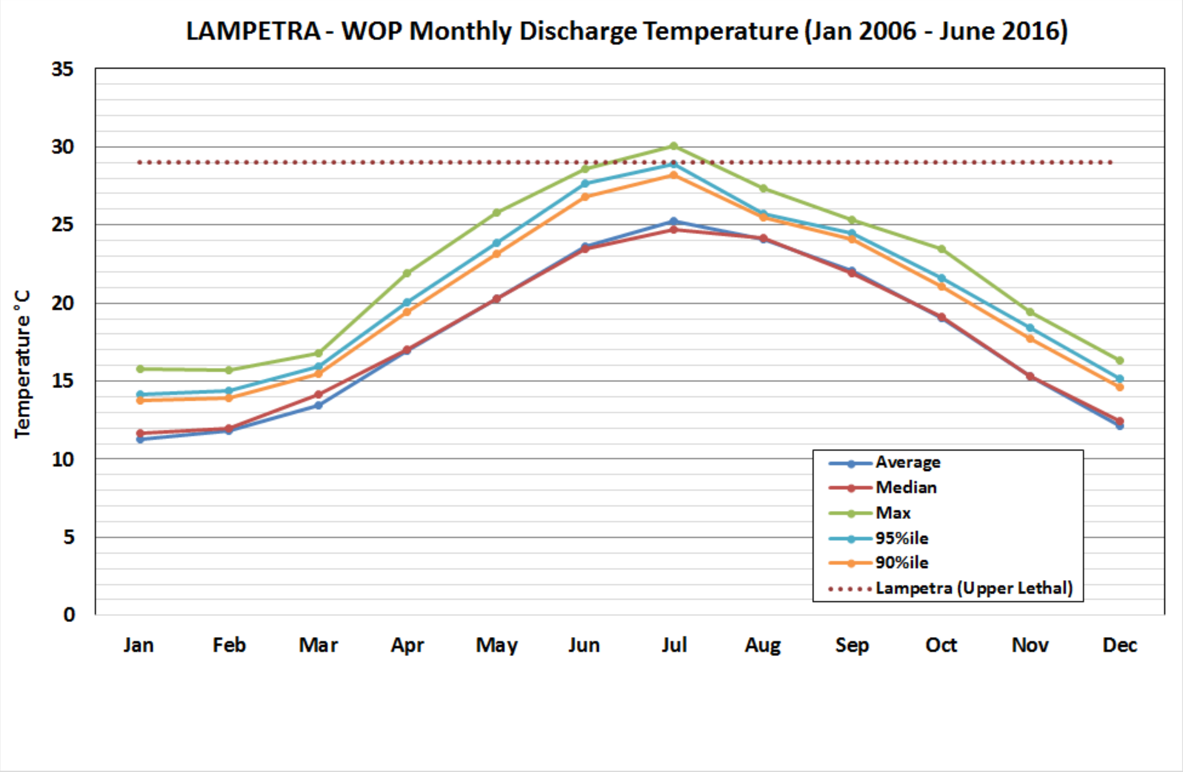


Figure 8b Lamprey (Lampetra) thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

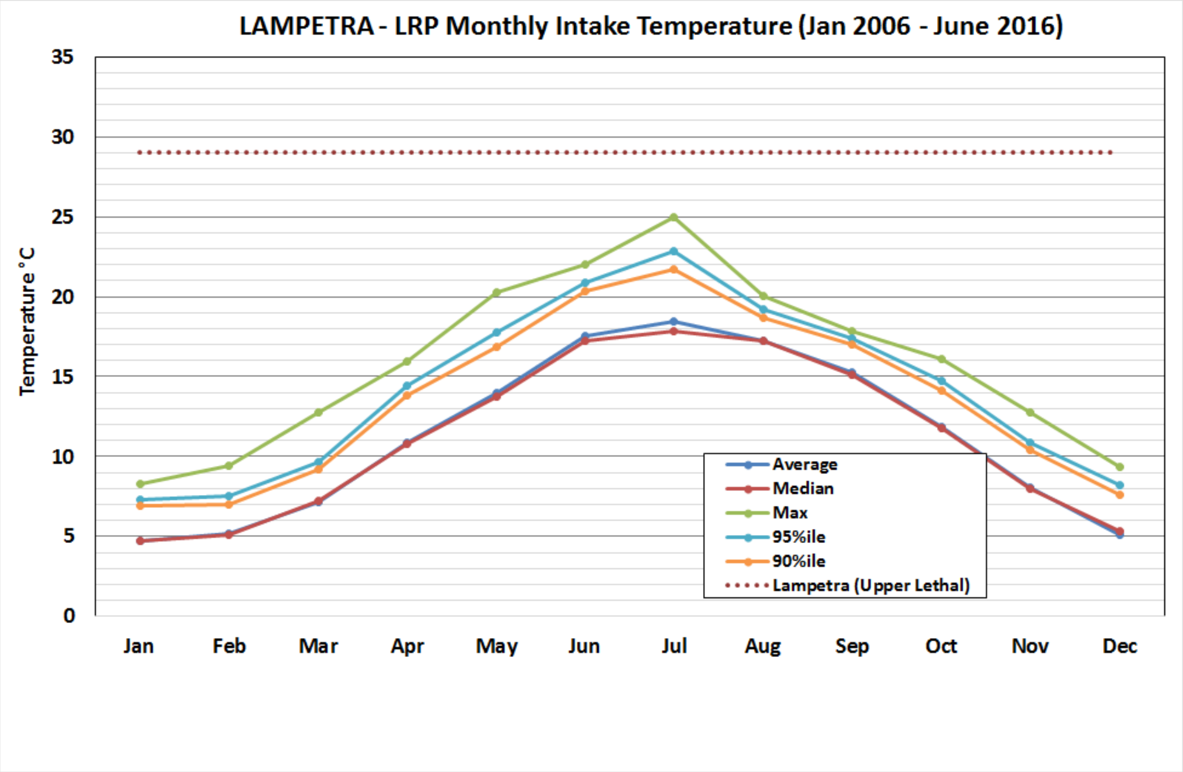


Figure 9a Lamprey (Lampetra) thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

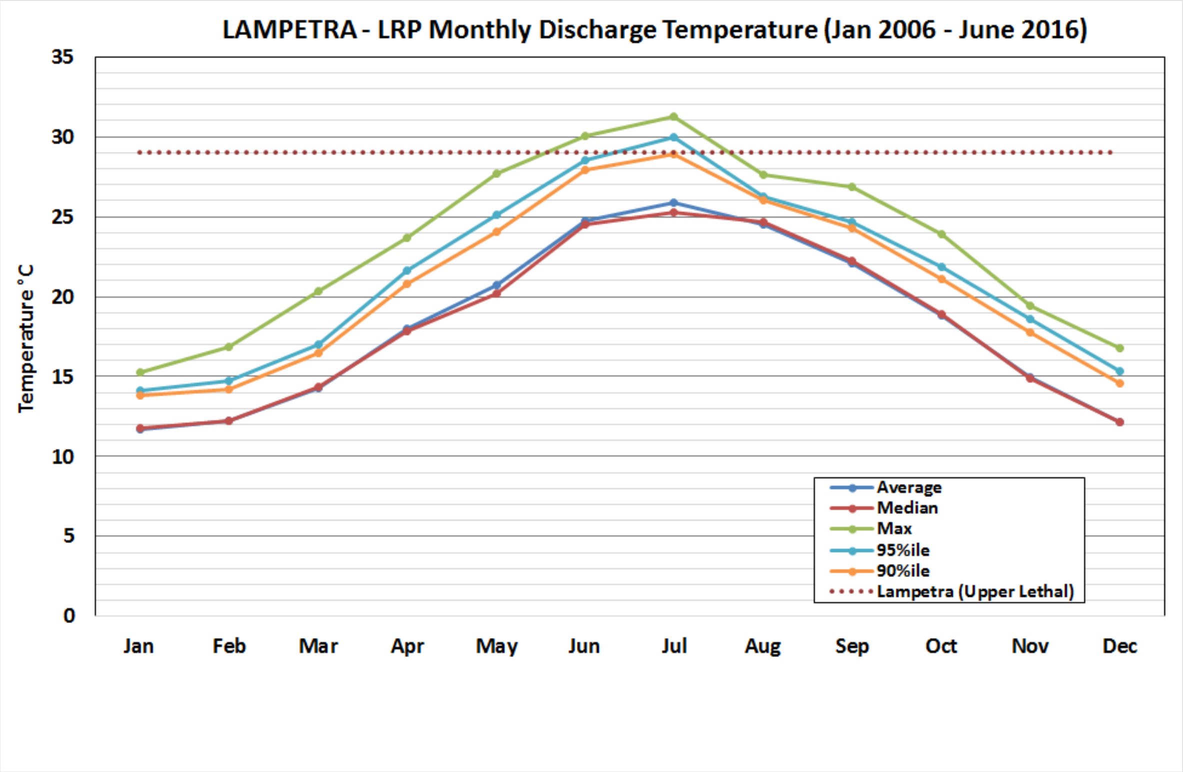


Figure 9b Lamprey (Lampetra) thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Pike (*Esox lucius*)

Pike formed an important component of the fish community both upstream and downstream of the power station at Lanseborough in the 2010 IFI WFD fish survey undertaken in May of that year (IFI, 2010a). It was equally prominent in the findings of the same survey effort at Clonmacnoise about 11.5km upstream of the WOP study site in very similar habitat. Based on data from a very intensive and detailed fisheries survey of Lough Ree in 2014, IFI state that Lough Ree pike are fast growing and long lived and that the population is large, balanced and uncropped (Delanty *et al.,* 2016).

Pike spawning in Irish lakes was observed by Kennedy (1969) to begin when the temperature reached 9 to 10 °C and was observed from Mid-February to late April depending on the year. After having commenced spawning they were observed to stop when the temperature dropped to 5.5°C but resumed again when the temperature rose to 12.7°C. At the LRP and WOP stations average ambient temperature in March is only marginally over 7°C and only reaches 10°C in March in warm years. The highest temperature at which Kennedy recorded spawning was 15.5°C and based on these data therefore it would seem more likely that pike in the LRP and WOP reaches of the Shannon, under conditions of ambient (Figures 10a & 11a), begin spawning sometime in early to mid-April in most years and finish by late May. Based on the summary 10-year data for the discharge at both sites (Figures 10b & 11b), pike could in theory be stimulated to spawn as early as January is some years because the average temperature in the plume at both sites is between 11 and 12°C in those months. For this to occur however, the spawning fish would have to have gonads developed to the correct stage to allow for spawning to occur, which is unlikely to be the case as early as January or even February. Furthermore, there would have to be suitable spawning habitat within the affected reaches as well. Kennedy (1969) observed spawning in the margins of Irish lakes usually in water shallower than 60cm over a bed of dead or living vegetation. However, pike in Lake Windermere are known to spawn also at depths from 2-3.5m. In LRP, the most likely place for pike to spawn would be in the lagoon area downstream from the discharge canal, which is flanked by beds of *Phragmites* and *Schoenoplectus*, but it cannot be said with certainty that pike would spawn here either. In their 2014 survey of 199 nettings sites through Lough Ree IFI found that pike were more or less evenly distributed throughout the lake except for significantly higher densities of fish in the bay just over half way down the lake into which the River Inny discharges, a concentration which the authors' suggest may be related to spawning migration. It is known from other lakes that pike seem to home to particular spawning areas each year. This offers the possibility that pike, particularly in the Lanesborough stretch, might migrate down into Lough Ree to spawn. However, the existence of favoured or large optimum spawning areas doesn't preclude the presence of smaller localised spawning areas spread throughout the system and on a precautionary basis we will make the assumption that at least some pike spawn in the marginal areas of both the LRP and WOP sites. Furthermore, given that the peak spawning time in Irish lakes has been observed to vary by as much as a month in consecutive years due to natural inter-annual temperature variations, it is considered possible that in some years, some pike may be stimulated to spawn earlier as a result of the presence of the plumes. This would be most likely to occur in years when low flows coincided with warmer temperatures, as it is only in such years, that the influence of the plume at LRP would be expected to reach the lagoon, the area where local pike spawning would most likely be expected to occur. However, this combination of factors is rare, i.e. the tendency is more for higher flows to coincide with cooler temperatures earlier in the year and indeed under conditions of low flow earlier in the year, the temperatures are more likely to be colder. In conclusion, it is considered less likely that pike in the main channel of the Shannon would be stimulated to spawn very much earlier than normal as a result of the thermal discharges due to the likelihood that flow conditions would be too high and the extent of the plume therefore too restricted. One possible exception would be if pike, as they have been noted to do elsewhere, spawn in the flood plain of the Shannon. During the February 2015 thermal plume survey at WOP, a substantial portion of the discharge was seen to exit the main channel to the east immediately downstream of the discharge during conditions of high flow and flow as a shallow stream in the flood plain running parallel to the main channel re-joining the latter some 800m downstream. If there were suitable vegetation in this 'bypass channel' there is a possibility that spawning-ready pike from the main channel might spawn there, given that the temperatures would be expected to be higher. Again however, we have no evidence to support this theory, although it cannot be ruled out entirely as a possibility during high flow years in February or March, when ambient temperatures would still be generally too low for spawning (in the river) but would likely be high enough based on the thermal plume survey findings (IHD, 2015a&b), in the 'bypass'. Overall, the possibility of some marginal advancement in the time of spawning of pike downstream of both LRP and WOP cannot be ruled out but if it does occur is only likely to affect a very small portion of the population in either reach and unlikely therefore to be associated with any measureable adverse impacts on the population.

The upper thermal tolerance levels reported for embryos in the literature (23°C) is such that by the time it is reached at both sites, young-of-the-year fish would be well beyond the embryo stage and therefore more thermally tolerant. Kennedy (1969) noted that at temperatures of 16-17°C embryos only took 8-10 days to develop into larvae.

As adults pike have fairly high upper thermal tolerance levels (IULT 30.2°C) and upper growth optima (26°C), they would be little impacted by the discharge in average temperature years (Figure 11b). However, in warmer years, pike may avoid the discharge canal during periods of low flow when the degree of temperature attenuation along the canal would be relatively minor (1-2°C) as seen in the August 2014 thermal plume assessment for the site (IHD, 2014c&d). It is worth noting that this ambush predator would still be likely to make excursions into warmer streams of the discharge plume if there were sufficient attraction in terms of prey availability. Overall, avoidance effects are unlikely to have a significant adverse impact on the local population other than a degree of local displacement during warm years combined with low flows i.e. mainly in June and July, an effect considered more likely at LRP than at WOP, because of the concentration of shallower flow in the discharge canal at the former site.

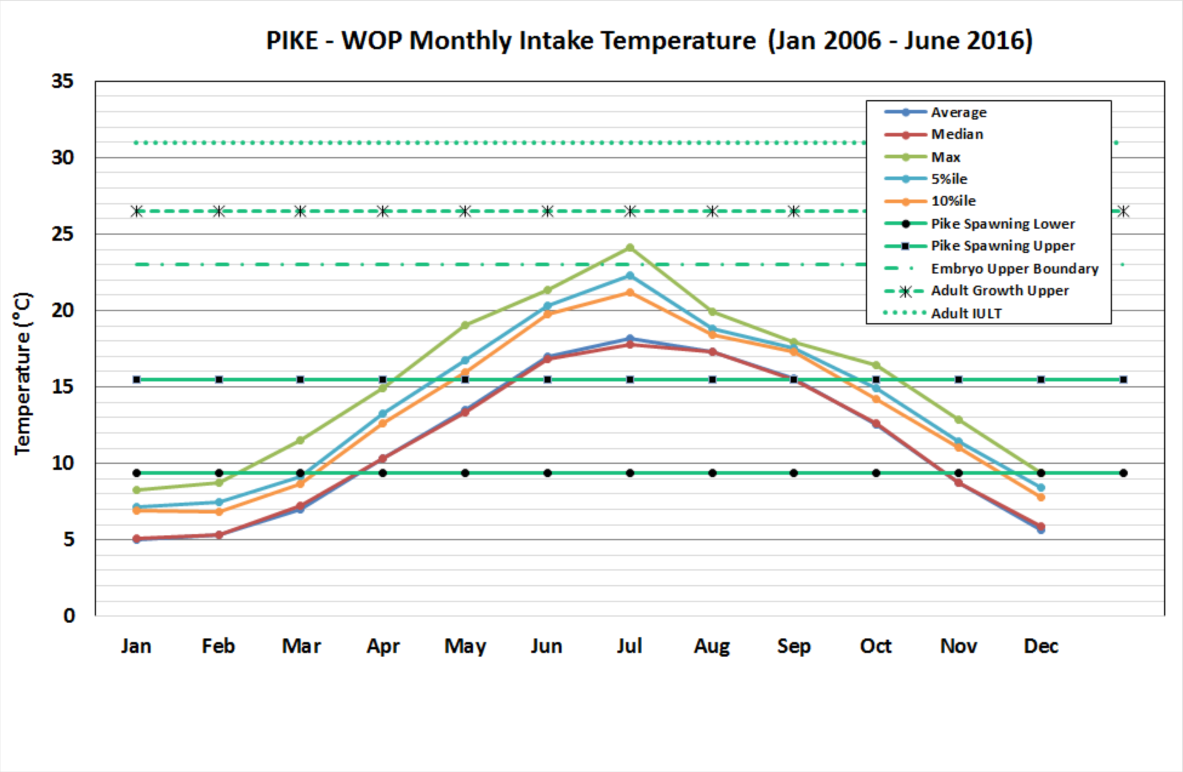


Figure 10a Pike thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

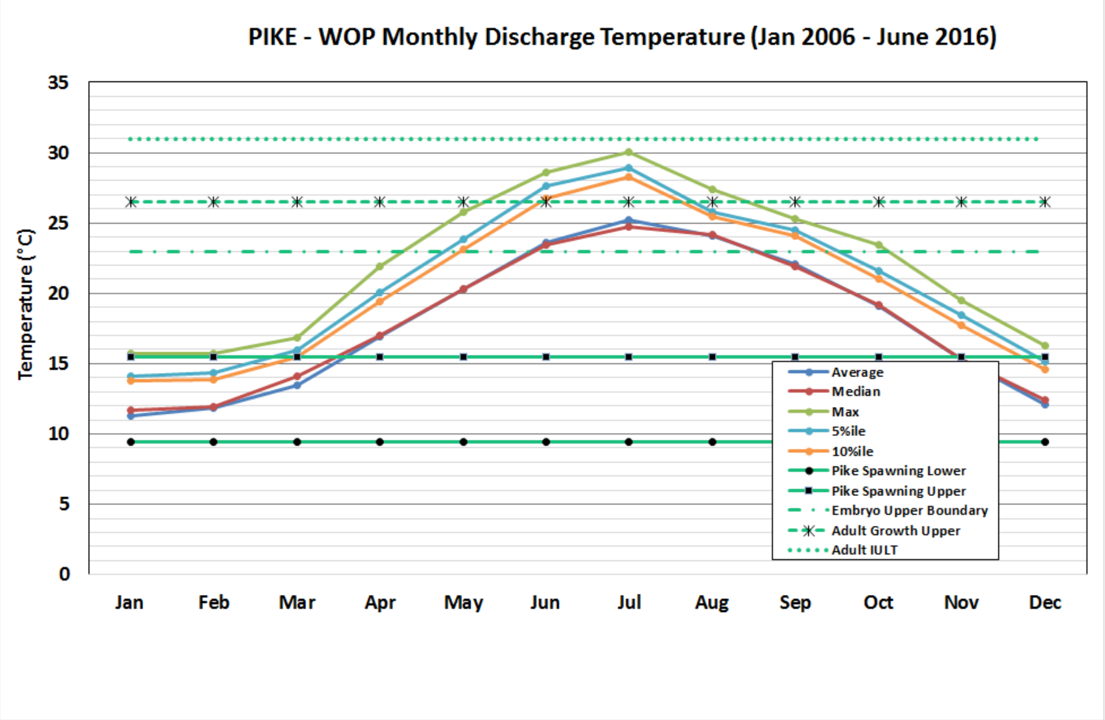


Figure 10b Pike thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

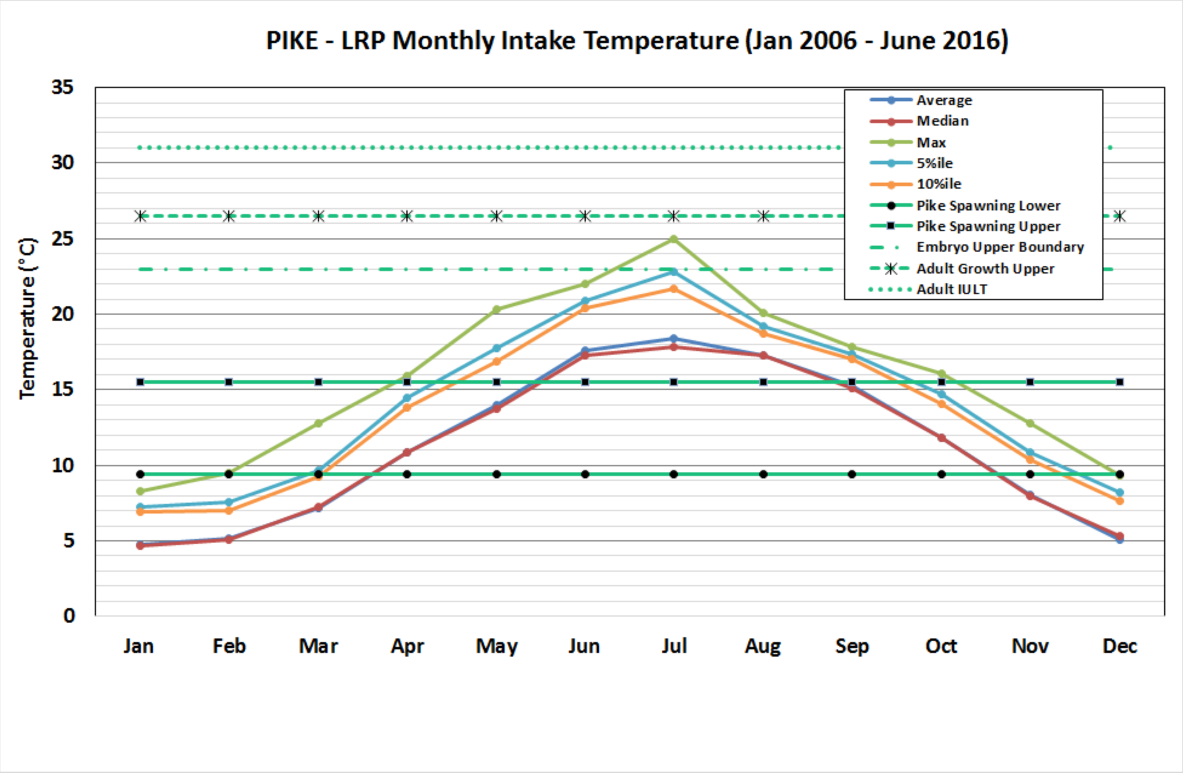


Figure11a Pike thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

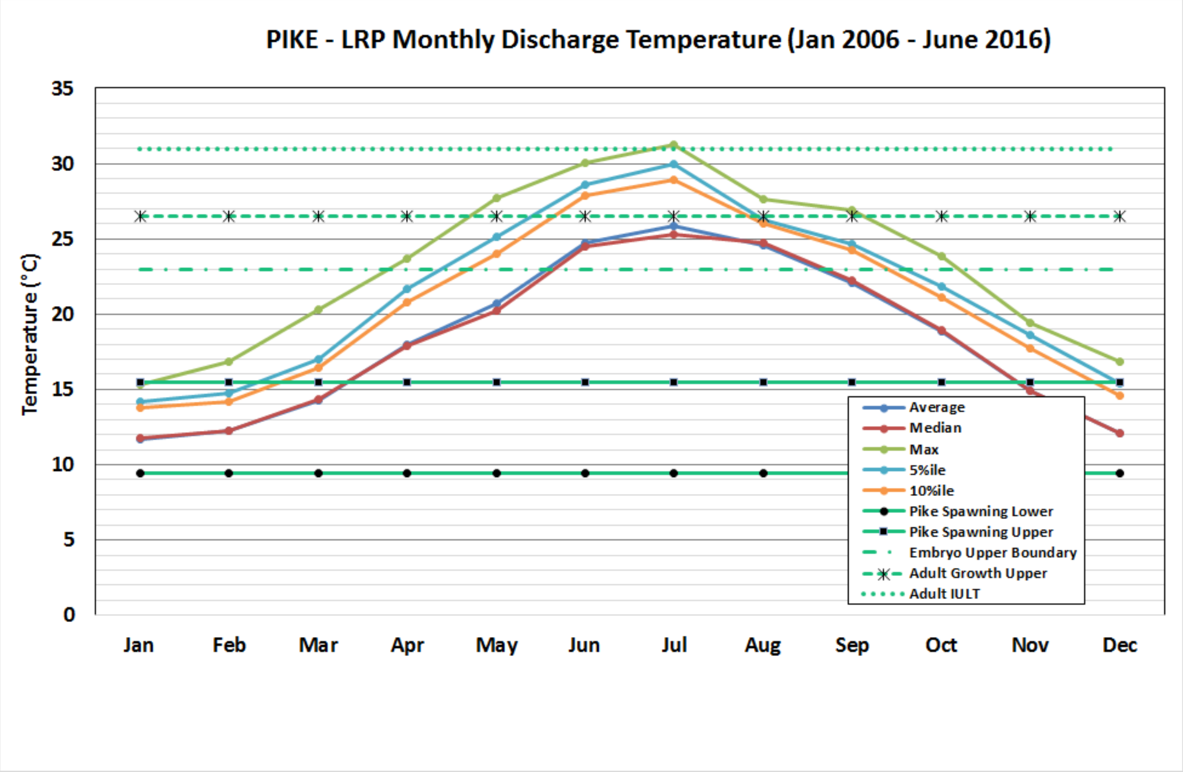


Figure 11b Pike thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Roach (*Rutilus rutilus*)

Roach, which are considered an invasive species, originally introduced to Ireland in the late 19th century, are believed to have entered the Shannon catchment at some time in the 1970's and are now a widespread and dominant component of the fish community there. The IFI WFD fish survey of 2010 at LRP and Clonmacnoise (IFI, 2010a) showed roach to be the dominant fish by a considerable margin at both locations including at sites upstream and downstream of the powers station at LRP. In a recent (2014) very intensive survey of Lough Ree covering 199 netting sites distributed throughout the lake (IFI, 2016), roach were present in more than 85% of sites and in total constituted about 52% of the total number of fish netted, making the species by far the dominant species. The Catch Per Unit Effort (CPUE) for the species at 21.4 is at the higher end of other surveyed lakes in the region but the report suggests that the population is likely to have declined in recent years due to the introduction of the zebra mussel which has had a very heavy cropping rate on phytoplankton. Roach are believed to thrive in culturally eutrophic waters and clearly the conditions in the Shannon must be ideal for the species.

No data on the timing or temperature for roach spawning in Ireland was obtained. In the literature spawning was noted in mid- May on the Meuse in Belgium and in Lake Geneva, while a late May spawning was noted in Manchester in England. In that latter study roach spawned at water temperatures of 12-14°C, temperatures also consistent with the Belgian and Swiss observations. At the Shannon sites, these temperatures are reached on average during May, probably from about the middle of the month on (Figures 12a & 13a). It seems reasonable therefore to assume that roach spawn in the study areas from mid-May to late May although an earlier commencement date cannot be ruled out, as Irish spawning temperatures are sometimes lower than in the UK and in Europe. Roach spawn in river backwaters and shallows where their eggs stick to vegetation and hatch in 9-12 days at 12-14°C (Wheeler, 1978).

It isn't known whether roach spawn within the study areas but some limited spawning may possibly occur in the breaks between the central 'islands' or along their margins in shallow vegetation and / or in the margins of the lagoon at LRP. There is also much marginal vegetation upstream and downstream at WOP but whether it is sufficiently protected from the flow to constitute suitable spawning habitat is not known. As a precautionary approach, it is assumed that at least limited spawning of the species is likely at both sites.

If we assume that roach spawn around mid-May under ambient temperature conditions at both sites, it is possible that downstream of the discharge they could do so in April, as the temperatures in the plume would already have reached those levels by late March in the discharge canal at LRP and also downstream of the discharge at WOP. However, fish would not spawn unless their gonads were already sufficiently developed. Roach spawning on the Meuse in Belgium did so 3 weeks earlier in water of 2-3°C higher than ambient downstream of a power plant discharge (Mattheeuws *et al.,* 1981), so the possibility of this occurring at the study sites would seem reasonable, so that an early to mid-April spawning might occur. In April one would expect the flows on average to be somewhere between what they were during the February 2015 thermal plume studies and the April/May 2016 thermal plume studies at both sites (IHD, 2015 a-d & 2016a&b). In each case temperatures greater than 2-3°C above ambient were confined to the eastern side of the channel and extended for 200m-300m downstream at WOP and between 300-600m downstream at LRP. In the context of the size and extent of the roach population within the Shannon at both sites, these impacts, should they occasionally arise could be described as negligible.

Embryos derived from earlier spawning in the warmer areas referenced above would develop at a quicker rate and would therefore be at a more advanced developmental stage earlier and therefore unlikely to be affected by thermal stress as given by the upper boundary figure of 24°C (Figures 12b & 13b).

Temperatures for adult roach downstream of the discharges would enter sub-optimal territory (>25°C) within the plume during warm years in June, July and August. However, the species is known to inhabit waters of 27.5°C in the River Trent in comparatively large numbers in June (Sadler, 1980) and is known to be attracted to the discharge canal at LRP where in the past at least it was a popular target species for coarse anglers. It seems reasonable to assume therefore that adult fish are unlikely to be adversely impacted by temperatures at least up to 27.5°C. Indeed one of the features of the roach fishery in the Lanseborough discharge canal was the fact that the season was so long, i.e. from April to October, when under natural conditions it would have opened later and closed earlier. During the very warmest years, July temperatures in the cooling water discharge approach the IULT for the species (31.1°C) at WOP and exceed it at LRP (Figures 12b & 13b). Under these conditions some avoidance of the discharge canal and the inner section of the lagoon i.e. within the first 600m downstream of the discharge point, might in theory at least occur. Due to the nature of the plume and its vertical distribution at WOP during periods of low flow as revealed in the July 31st 2014 thermal plume survey (IHD, 2014a & b), roach are unlikely to show any significant degree of avoidance of the discharge stretch although they may drop deeper and congregate in sections of the cross-section which are cooler. Should they occur, these impacts are likely to have very little significance for the roach population, even at a local scale.

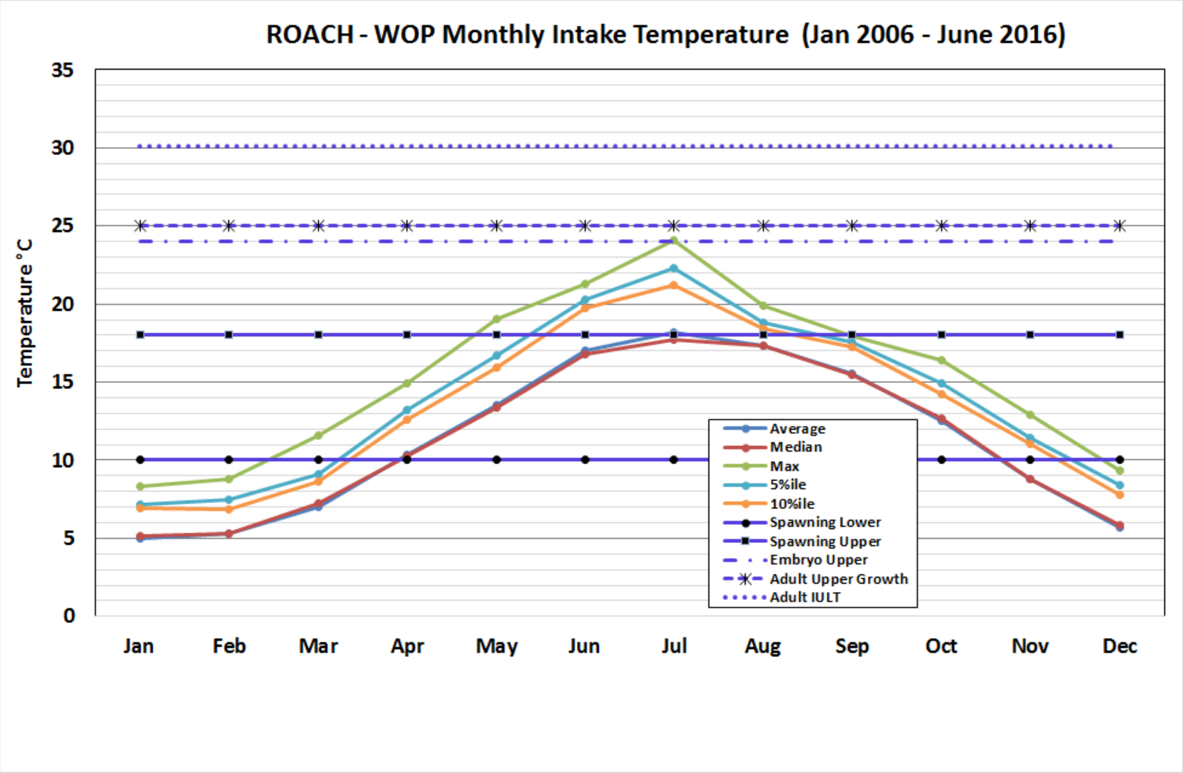


Figure 12a Roach thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

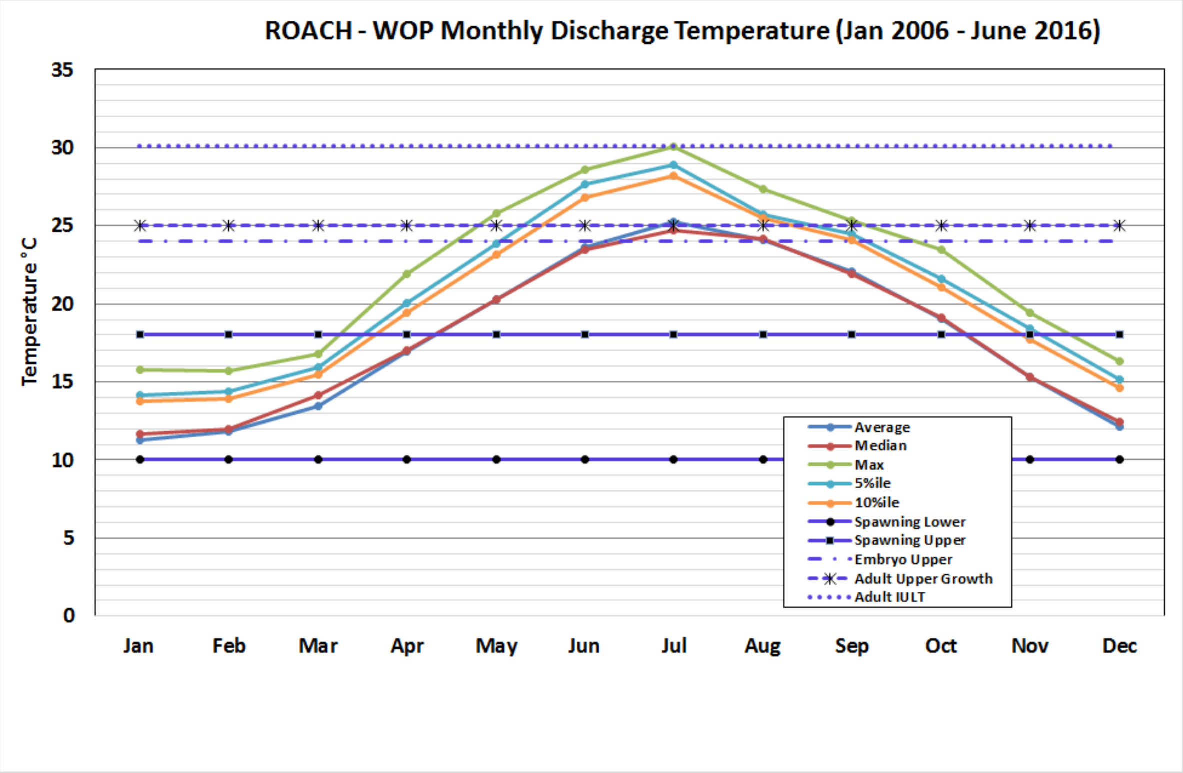


Figure 12b Roach thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

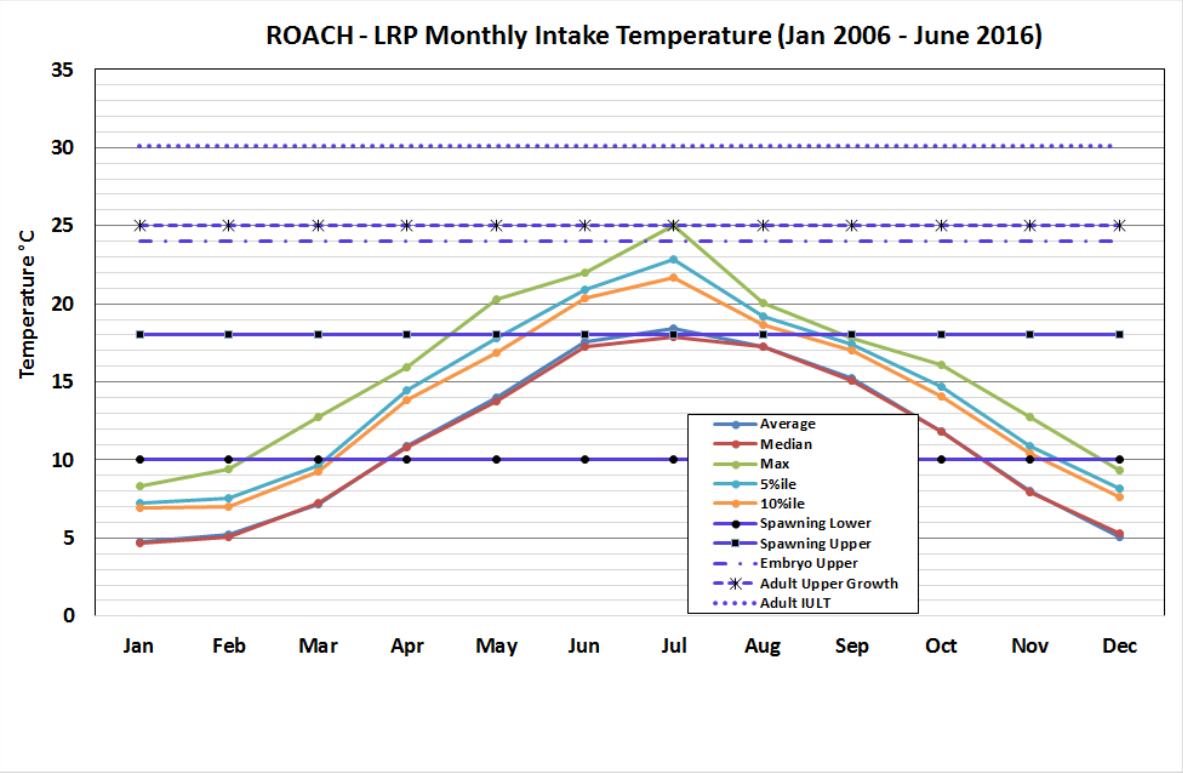


Figure 13a Roach thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

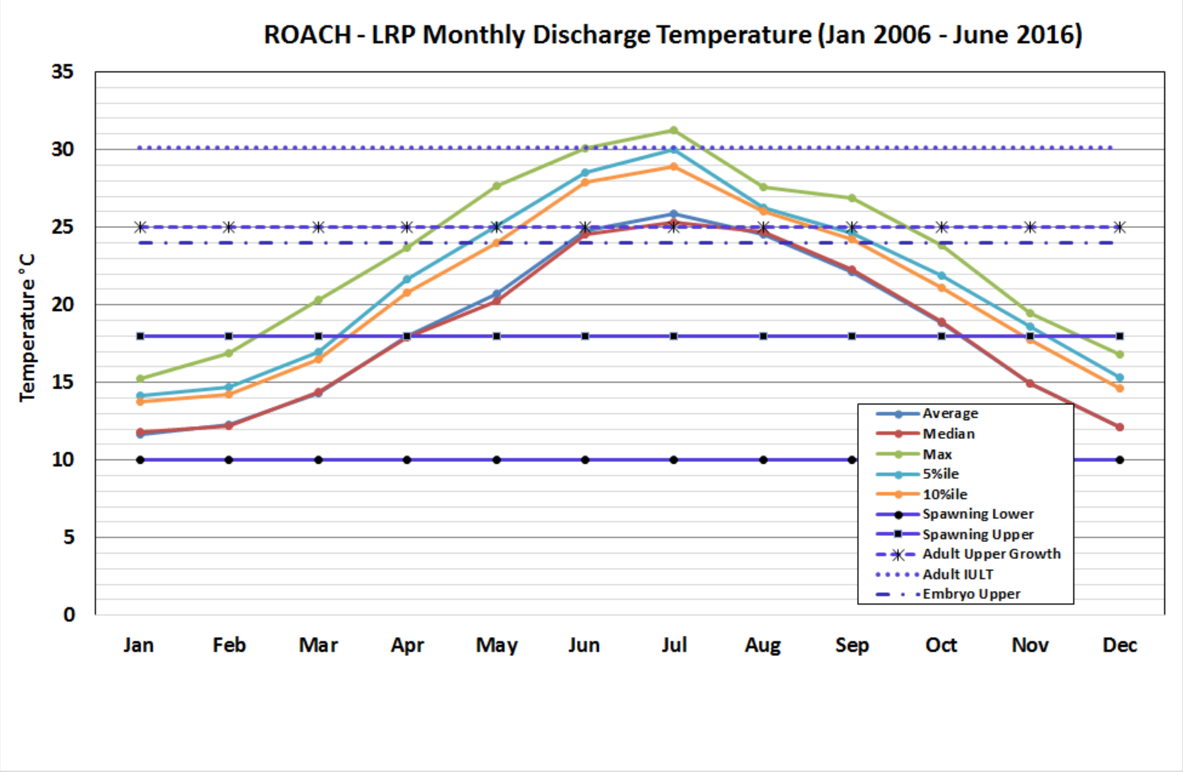


Figure 13b Roach thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Perch (*Perca fluviatilis*)

Returns from the 2010 IFI WFD fish survey at LRP and from Clonmacnoise indicate that perch were the second most numerous species in both locations. An intensive 2014 survey of Lough Ree (Delanty *et al*, 2016) showed perch to be the third most numerous species in the lake at 16% of the catch, compared to roach x bream hybrids at 21% and roach at 52%. The perch were well distributed throughout including in the northern section adjacent to the LPR lagoon. The CPUE (6.44) is considered high by Irish lake standards, which indicates that Lough Ree can be considered a good perch water.

Based on a communication from the Central Fisheries Board reported in a 2008 BIM study on perch farming, the species spawns in Ireland from early April to mid-May in temperatures from 9-14°C. This tally's with work in England which showed perch spawning in mid-May about 10 days earlier than roach at the same site (a canal in Manchester) at temperatures of 12-14°C (Nash et al., 1999) and with Maitland and Campbell (1992) that indicate that perch tend to spawn a few weeks earlier than roach.

In the Shannon at LRP and WOP, the average ambient temperatures in April are 10.9°C and 10.3°C respectively while in May the equivalent temperatures are 13.9°C and 14.0°C respectively. These data suggest that in an average year perch at both sites spawn in late April to early May (Figures 14a & 15a). Downstream of both cooling water discharges (Figures 14b & 15b), the temperatures in January, February and particularly in March would be high enough to trigger spawning, which raises the possibility that if spawning-ready perch were present in these areas in these months they might be stimulated to spawn earlier. However, plume behaviour in all of these months is likely to restrict the area of such an effect to relatively short lengths of the eastern side of both channels over 200-400m. On such a restricted spatial scale, this effect, were it to occur, is considered to be of minor to negligible significance. Perch spawning in Lake Geneva were observed to move to greater depths as the spawning season advanced to avoid warmer surface water, an effect which was most pronounced when the surface water was 14°C. This suggests that spawning perch might avoid the warmer areas while spawning. Although, perch haven't been observed spawning in the study areas, as in the case made for roach earlier, on a precautionary basis it is being taken that they do spawn in marginal vegetation at both sites both upstream and downstream of the power plants.

Based on data in the literature perch appear to have a higher upper thermal tolerance range than roach, and would therefore be unlikely to show significant avoidance behaviour downstream of the discharge at either site, except in very warm years and most likely during July at WOP and June and July at LRP. If it occurred at all, it would be most likely in the discharge canal at LRP and within 100m of the discharge in WOP. However, at this latter site there are sufficient cooler 'streams' within the flow, particular at depth, where the temperature even in the upper discharge stretch would be within the perch's tolerance range. In the LRP discharge canal the flow is more concentrated and there are fewer thermal refuges, during warm, low flow conditions, as revealed by the 2014 August 1st thermal plume survey at that site (IHD, 2014c&d). These effects can be seen as short-term, very intermittent and spatially restricted and for these reasons are unlikely to have any significant impacts even on the local population at either site.

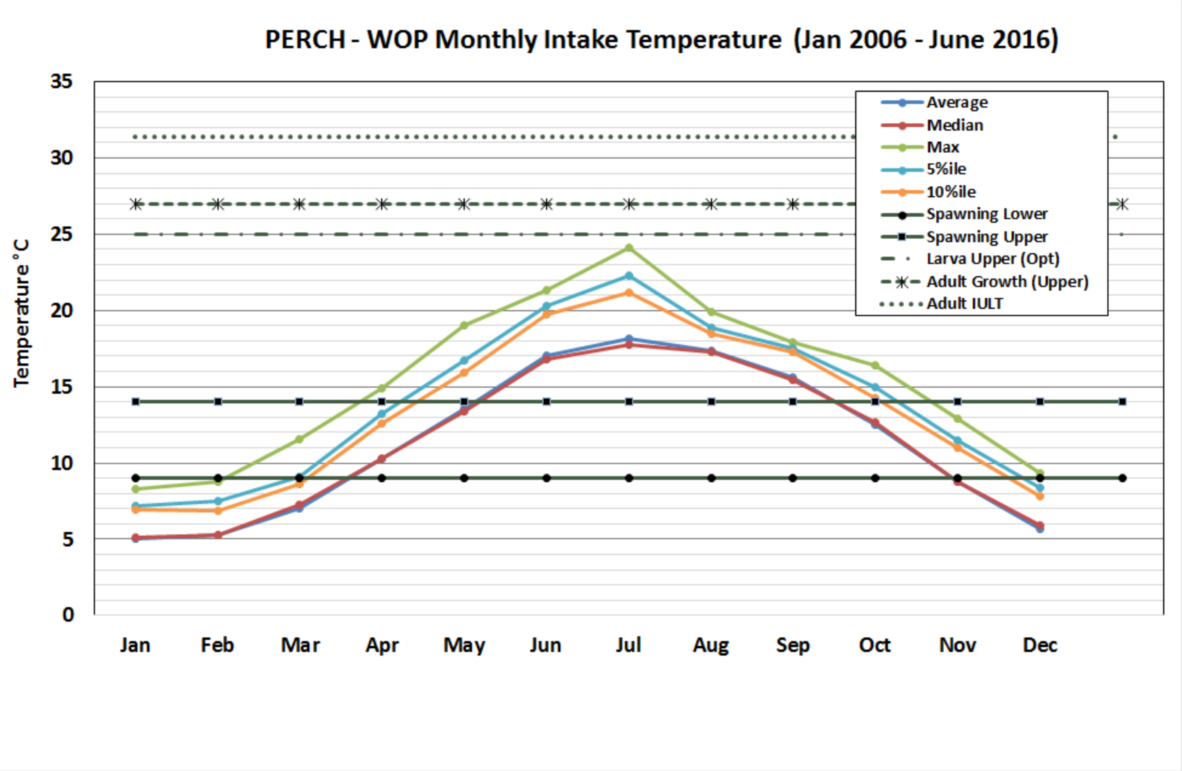


Figure 14a Perch thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

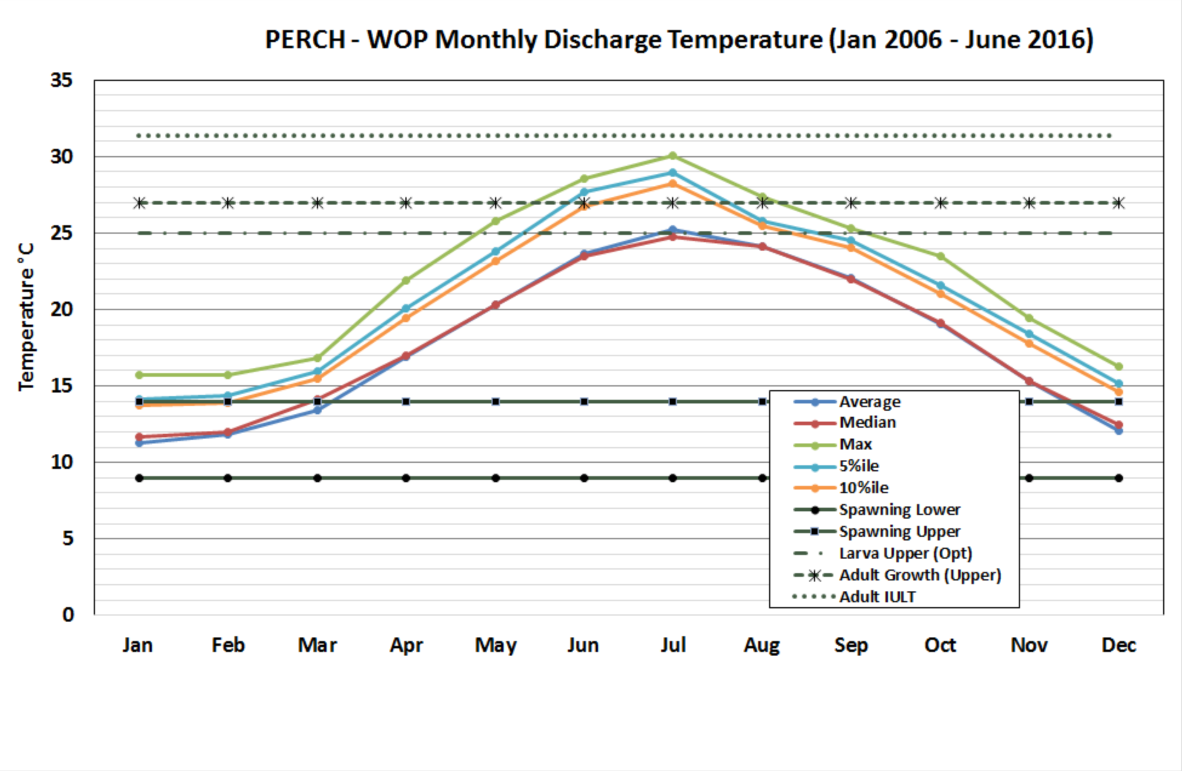


Figure 14b Perch thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

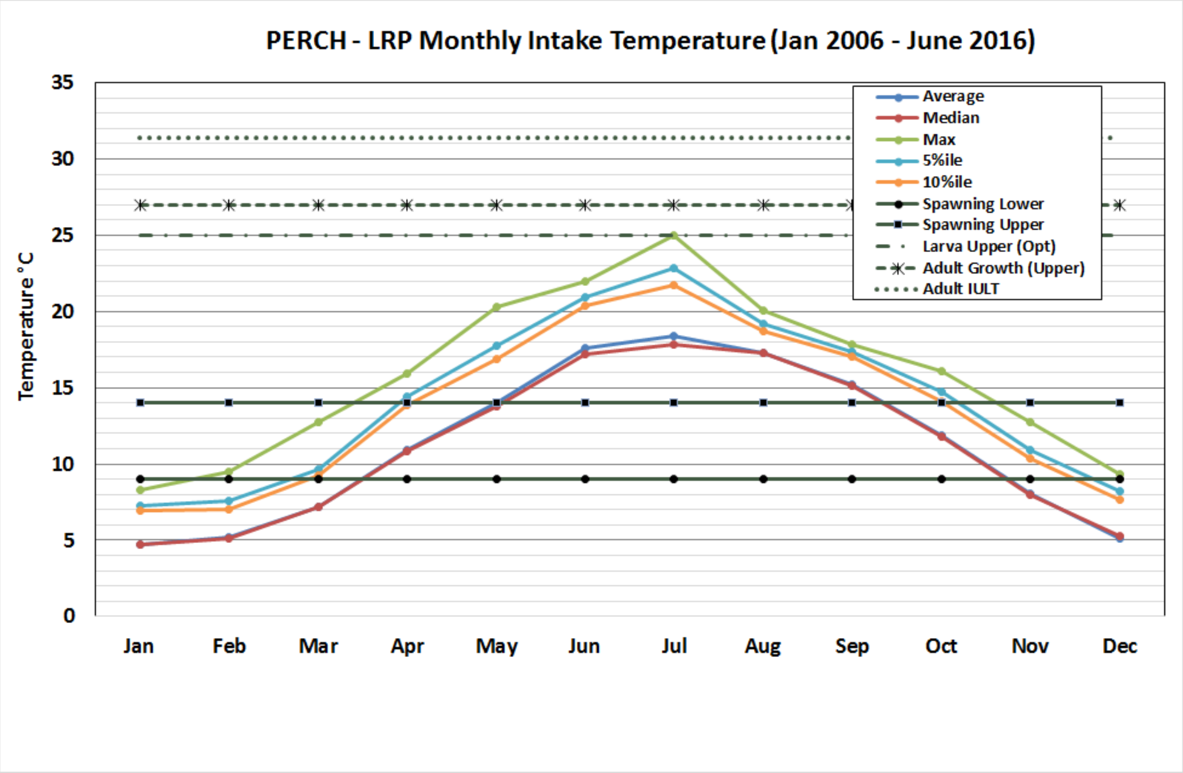


Figure 15a Perch thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

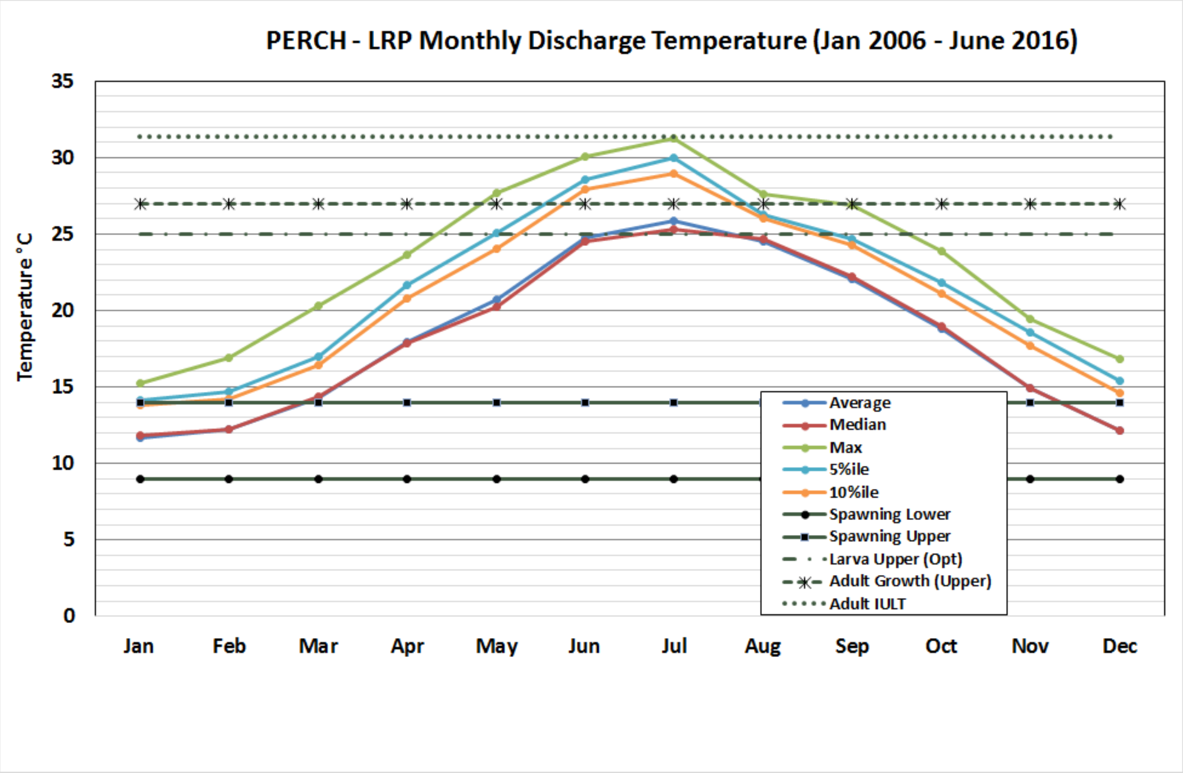


Figure 15b Perch thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Minor Components of the Fish Community at LRP & WOP

Based on the IFI WFD survey of 2010 at LRP, several species were only present in very low numbers at one or both sites. These included gudgeon, which were only found upstream of the plant (5 in total), rudd (4 fish, upstream and 1 downstream), roach x bream hybrids (2 fish downstream) and bream (1 fish upstream and 1 downstream). It seems reasonable to suggest that none of these species forms an important component of the community of either site and they will not be discussed in the same detail as the other species mentioned. It's important to note that although eel and lamprey were also present at both LRP and Clonmacnoise fishing sites in relatively small number in the 2010 survey this is thought more a reflection of the difficulty of fishing these species in deep water using electrofishing gear, especially for eel, than evidence of scarcity. They are also of greater conservation importance, than any of the other less abundant species mentioned. None of the rarer species listed above were encountered at Clonmacnoise 11.5km upstream from WOP site during the same IFI survey. It is worth noting, however, that IFI's online angling information pages (Angling Ireland) indicate that the warm water sections downstream of both plants hold rudd, bream, bream x roach hybrids and tench, all at good levels (see for example quote in box below for Lanesborough discharge canal).

> *`This stretch holds most coarse fish in abundance when conditions are favourable and is particularly noted for its large tench and attracts plenty of pike also in pursuit of the fodder fish present. Many specimen tench who favour warmer waters to spawn have these conditions here where they tend to congregate, best time mid-May onwards. Try the canal stretch, the point where the hot water joins up and close to the embankment down from the car park. Frequent reports of large specimens 6lbs-7lbs have been reported by anglers over the years, a number of which have been verified by the Irish Specimen Fish Committee over more recent times. Like all the other swims pike abound, so come prepared with suitable pike gear as the stretch produces large pike from time to time. Anglers often report snatch takes while coarse fishing here.*
>
> http://www.fishinginireland.info/coarse/shannon/shannonbridge.htm#hotwater

Of the species listed all have upper incipient thermal limits (IULT) in the same range of the cyprinids already discussed (roach and perch) and higher for tench and none are therefore considered likely to stand out as more vulnerable. Gudgeon (*Gobio gobio*) (Figures 16a&b and 17a&b) maybe an exception to this as they have a lower IULT (28.6°C) based on British work quoted in Alabaster and Lloyd (1980), although work in continental Europe (Poland) suggest significantly higher lethal levels (30°C +). I could find no data on their preferred spawning temperatures in Ireland, but Wheeler (1978) considers them an early summer spawner. Kennedy and Fitzmaurice (1972), collected Gudgeon eggs from a 'rivulet', flowing into the Lee Reservoir in early June and late June. They are a bottom feeding species and a therefore have a behavioural trait that will tend to protect them from the extremes of the thermal plume which in most locations has been shown to be a predominantly surface phenomenon. Despite this however, it is appropriate to assume that during the high summer months during particularly warmer years, the species may well avoid most of the discharge canal at LRP, and sections of the first 100 – 300m me downstream of the WOP discharge.

Bream (*Abramis brama*) (Figures 18a & b and 19a & b) is the only species for which there is site-specific data in the published literature relevant to one of the project sites. Bream were observed to be ′splashing in a bed of bulrushes 30 yards downstream from the cooling water outlet from a peat-fired electricity generating station' on May-15th to 17th 1965 (Kennedy and Fitzmaurice, 1968). Bream eggs were collected from the site on May 19th containing advanced embryos, the temperature was 18°C. Bream eggs, 'about to hatch', were also collected a week later (May 25th) in Lough Coosan about 25km south near Athlone where the temperature was 14°C. The latter temperature, based on the ambient temperature for LRP between 2006 and 2016 is average for May. This strongly suggests that the discharge canal at 18°C measured the previous week in the discharge canal at Lanesborough, quoted in the Kennedy and Fitzmaurice paper, was a few degrees above ambient but was nevertheless being used for spawning by the species. This suggests that bream despite their very small numbers may still spawn in the discharge canal in May. As adults, bream are quite tolerant of elevated temperatures with an upper growth optimum of 26°C and an IULT of 31.2°C. These temperatures are exceeded in the discharge plumes of both sites in the warmest years in June –August at which times, the species may tend to avoid the discharge canal at LRP and the warmers parts of the channel within the first 300m of the outfall at WOP.

Rudd (*Scardinius erythrophthalmus*) (Figures 20a & b and 21a & b) are likely to have declined significantly in the Shannon system since the early 1970's with the introduction of roach, which is now the dominant species throughout. It only formed a small portion of the fish community in Lough Ree accounting for just 1.3% of the catch (i.e. 103 individuals) with a CPUE of 0.52. According to IFI (Delanty *et al.,* 2016), this is quite high for spring-sampled lakes e.g. Loughs Arrow, Sheelin, Ennell and Derravaragh where numbers of rudd taken in surveys are usually less than 10. Their small numbers at LRP (4 upstream and 1 downstream) don't allow much to be concluded about the potential impact of the discharge on them. They have a similar IULT (31.2°C) to roach, bream and perch, so are unlikely to be impacted much differently to these two species. Kennedy & Fitzmaurice (1974) indicate that they spawn mainly in Ireland in June and July, and can be therefore be described as late spawner. Despite having a similarly high thermal tolerance to the other cyprinids of interest, its habit of feeding near the water surface would likely expose it to higher temperatures than these other species in the community downstream of the discharge which, would tend to accentuate an avoidance response during very warm weather.

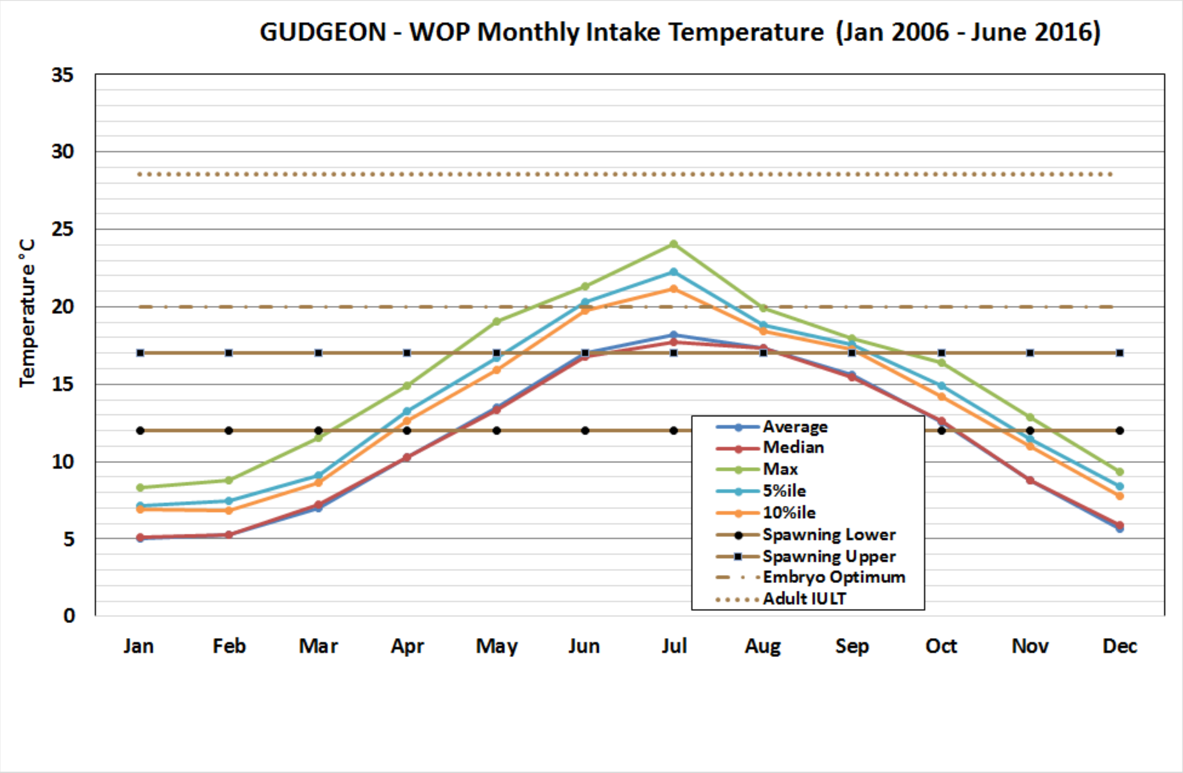


Figure 16a Gudgeon thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

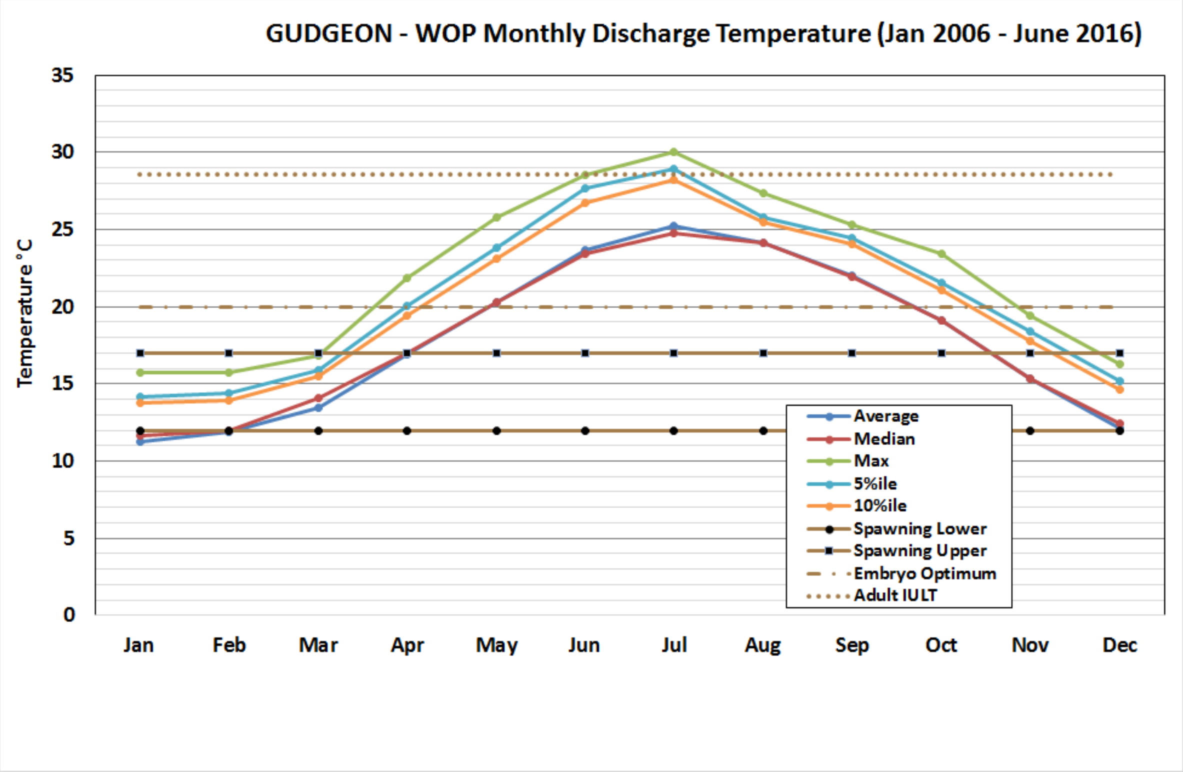


Figure 16b Gudgeon thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

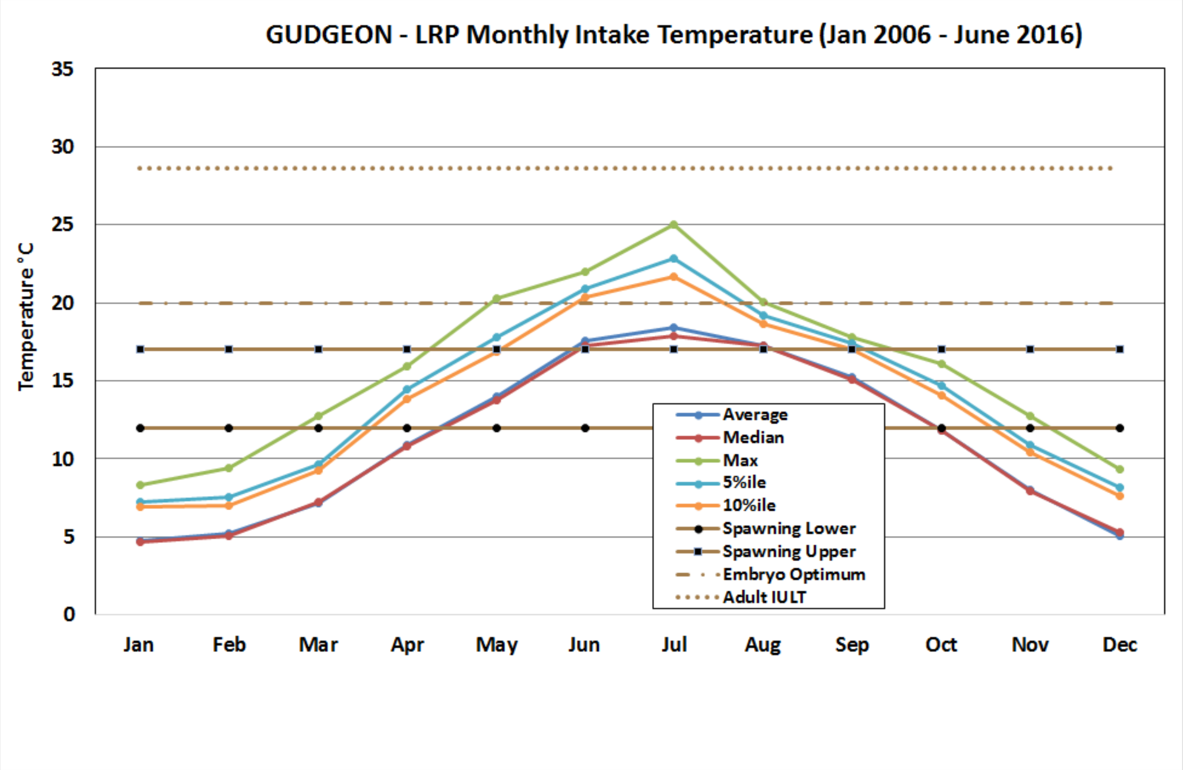


Figure 17a Gudgeon thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

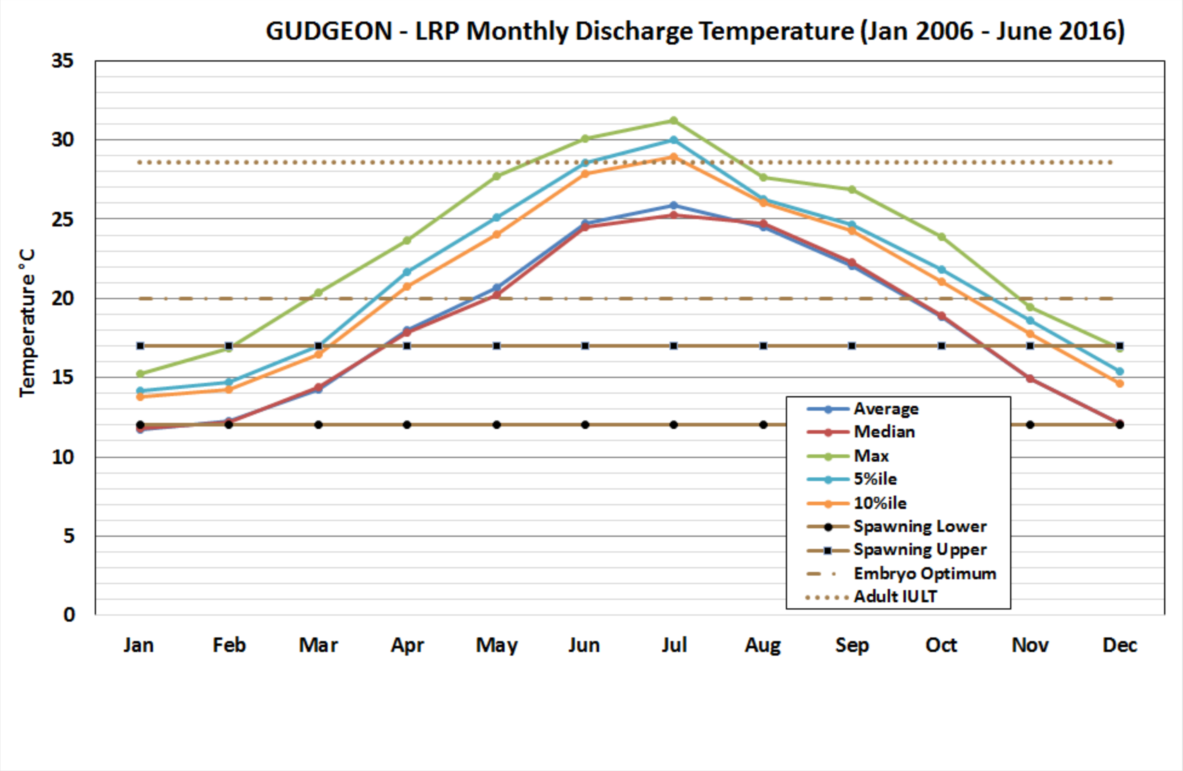


Figure 17b Gudgeon thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

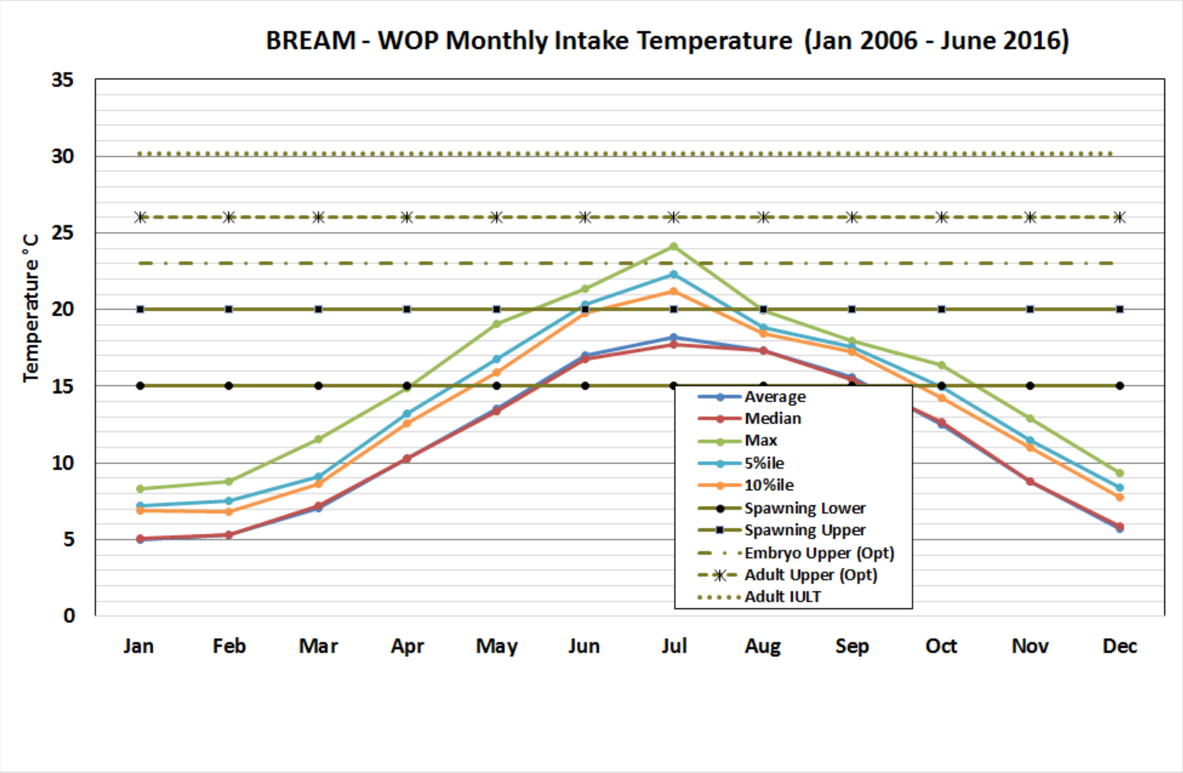


Figure 18a Bream thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

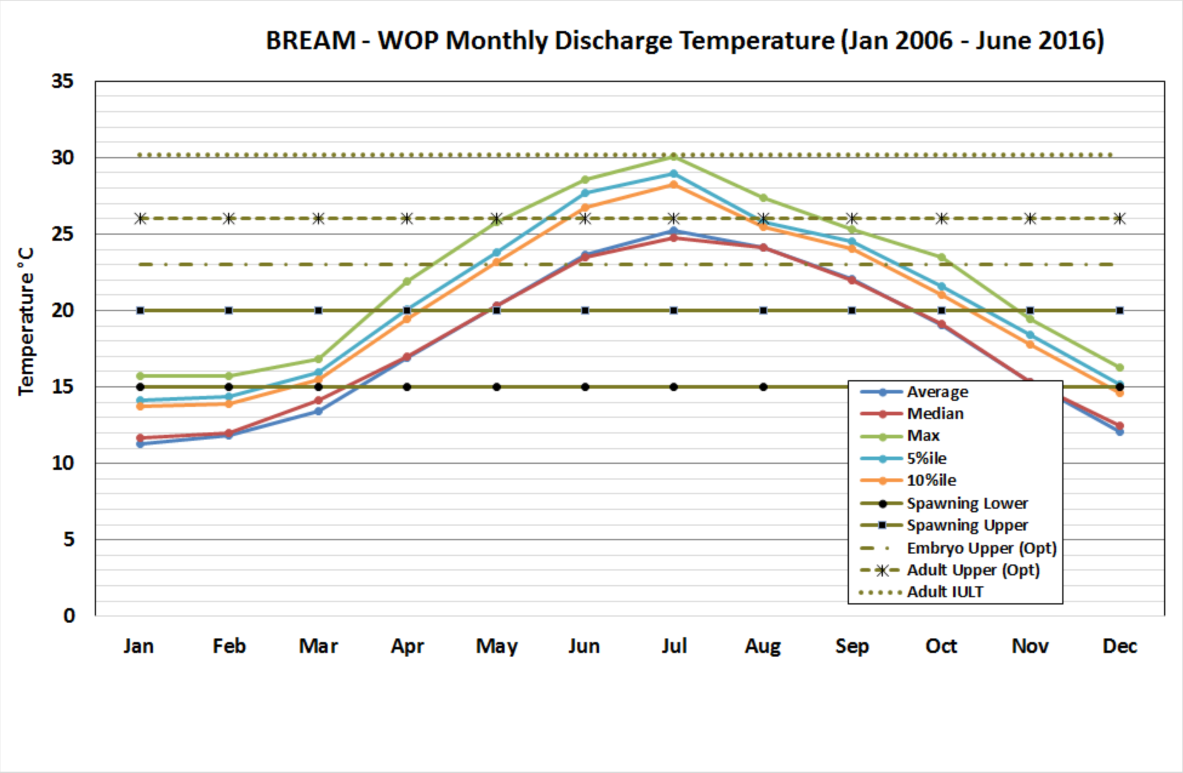


Figure 18b Bream thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

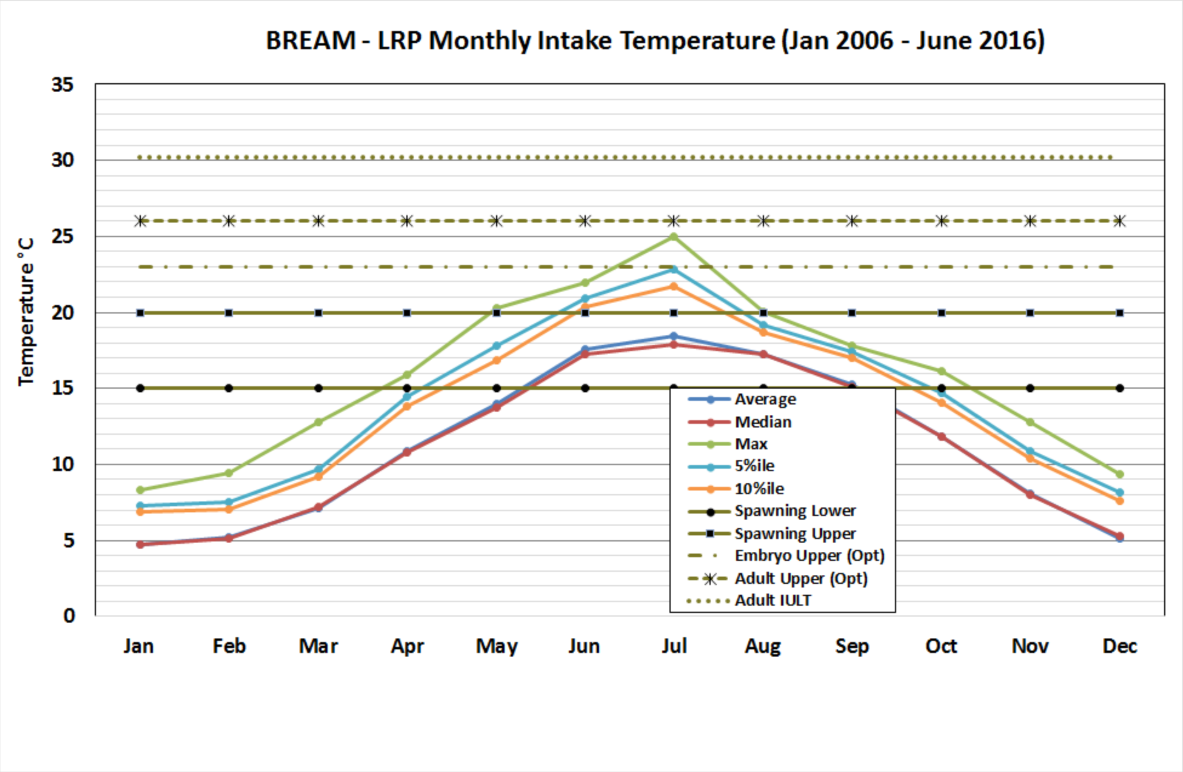


Figure 19a Bream thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

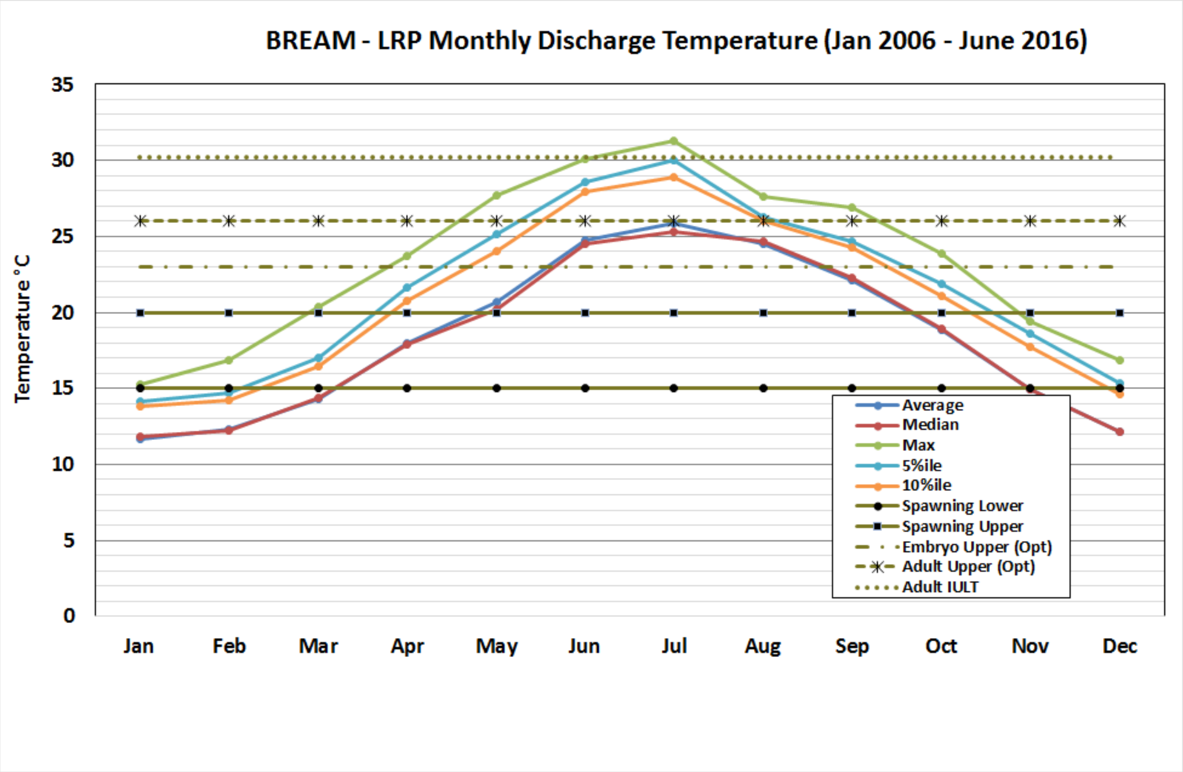


Figure 19b Bream thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

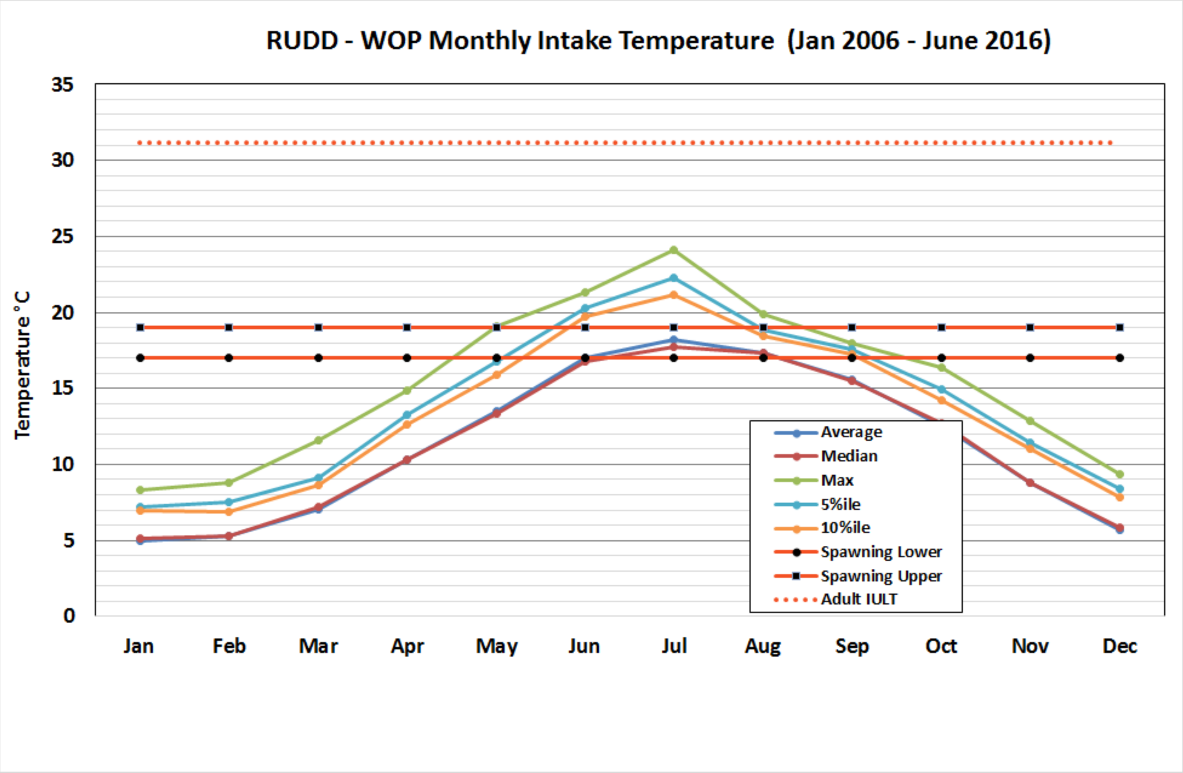


Figure 20a Rudd thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at WOP

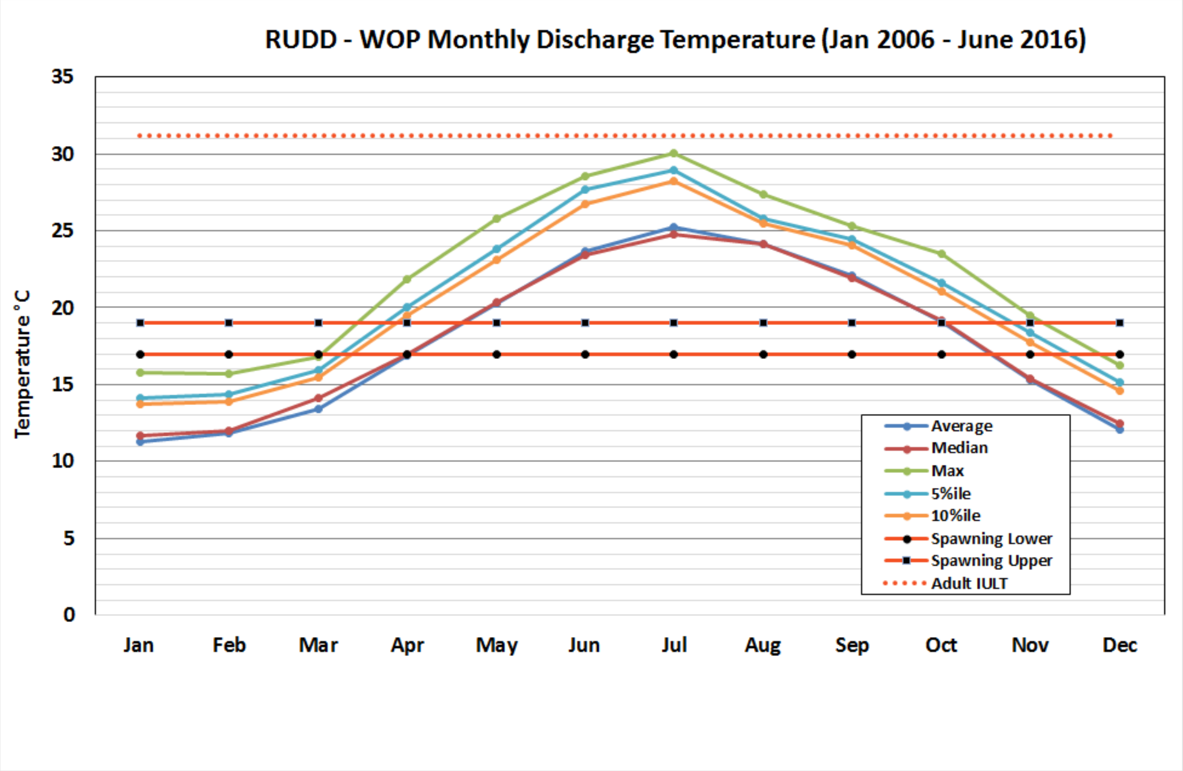


Figure 20b Rudd thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at WOP

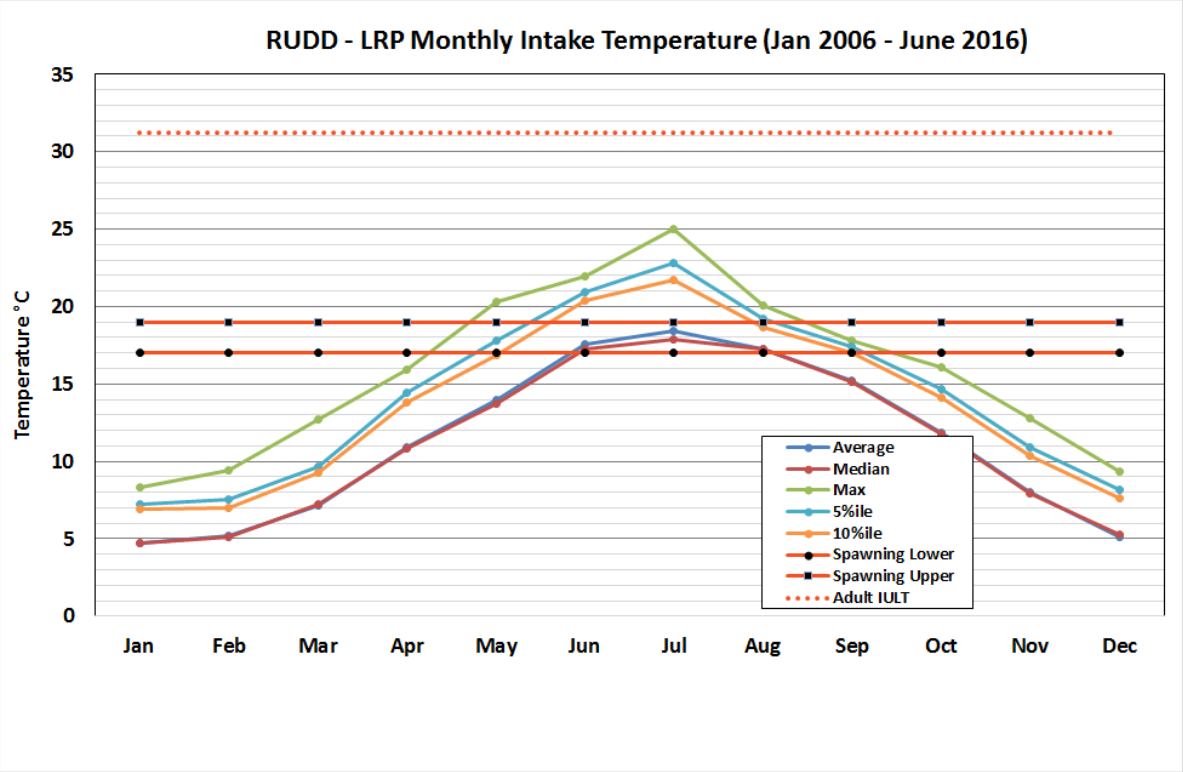


Figure 21a Rudd thermal limits plotted against summarised seasonal intake temperatures (2006-2016) at LRP

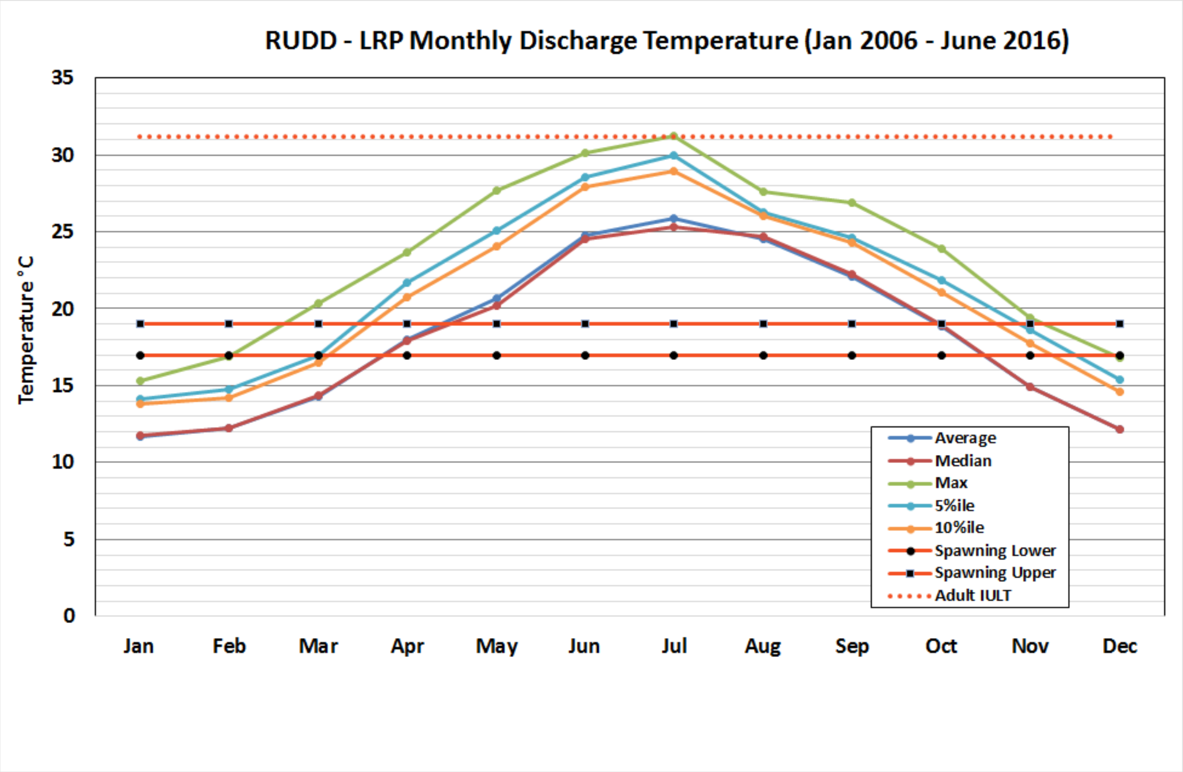


Figure 21b Rudd thermal limits plotted against summarised seasonal discharge temperatures (2006-2016) at LRP

Summary

This report comprises a review of the thermal tolerances, based on a literature review, of the resident and migrant fish at Lanesborough and Shannonnbridge on the River Shannon at the sites of the Lough Ree Power (LRP) peat-fired generating station and the West Offaly Power (WOP) peat-fired station respectively. The report also addresses the potential risks posed to the fish community by the cooling water discharge temperatures and thermal loading from both plants.

At both plants cooling water is abstracted from the river upstream at a rate of ~ 4-5m^3/s and discharged downstream of each at a temperature about 7-8°C higher than the intake.

In order to assess the risks posed by the thermal discharges, historical temperature data for the intake and discharge at both plants was compiled and summarised for the period 2006-2016. For this analysis the intake temperature is taken as being the same as the ambient upstream temperature in the river at both sites and the discharge temperature is taken to be the highest possible temperature in the thermal plume. As the plume mixes and disperses downstream, the impact of the discharge temperature will reduce, limiting the degree of exposure of fish accordingly. The rate and extent of the dispersion involved and hence the degree of risk will depend in particular on the flow in the river at the time. In order to understand the horizontal and vertical spread of the plumes below the cooling water discharge of both power station locations, reports of thermal plume surveys undertaken by Irish Hydrodata (IHD) in late July/early August (2014), in February (2015) and in late-April/early May (2016) under a wide range of river flows and ambient temperatures were examined in detail.

The following fish species were selected as being members of the resident fish community or as migrants: roach, perch, pike, eel, lamprey (*Lampetra* sp.), brown trout, salmon, bream, rudd, and gudgeon. This selection was based on published data from Inland Fisheries Ireland's (IFI) Water Framework Directive (WFD) fish monitoring programme and from the ESB Fisheries Annual Report for 2015.

The thermal tolerances for one or more life stages of each of these fish species was compiled from the scientific literature. These data were used in combination with the 2006-2016 temperature data and plume behaviour data for each of the study sites in order to assess the potential risks to the fish species in question.

The upper temperature cut-off point chosen for each species was the Incipient Upper Lethal Temperature (IULT) which is the temperature at which 50% of test fish would succumb after about 16hours of exposure. Below this temperature the majority of fish would be expected to survive indefinitely. The IULT was taken to be the upper boundary of temperature tolerance for each species. Other limits examined, where available and relevant, were optimal and upper boundary growth limits etc. Particular attention was given to spawning where appropriate, as well as the period of inward and outward migration in eels, salmon and lamprey.

The historical temperature data for the intakes at both sites indicated that during the summer the LRP intake was usually about 1°C warmer than the WOP equivalent, a trend that more or less reversed during the winter and early spring. It was speculated that the presence of Lough Ree upstream of WOP may be influencing these trends. The data also showed that the warmest summer peak ambient average temperature reached 22-23°C

(Max 25-26°C), while the corresponding average cooling water discharge temperatures were in the range 29-30°C (Max 30-31°C).

During the February 2015 thermal plume survey at LRP, undertaken by IHD on behalf of ESB GWM, the plume was confined to the eastern side of the channel with warmer water also generally confined to the shallow surface layers, with attenuation to background about 400m downstream. A variation at WOP was that part of the plume flowed out on to the floodplain and travelled in parallel to the main channel to re-emerge briefly at about 800m downstream of the discharge point.

The spring (April/May) plume survey (in 2016) undertaken at both stations essentially followed the same pattern as the February survey, except that the plume occupied more of the channel at both sites, extended deeper and spread farther downstream before attenuating. Nevertheless, there was a significant portion of the cross-section of the channel toward the western bank at both sites which was either unaffected by thermal discharges or very marginally so, mainly at the downstream end of the mixing zones.

In contrast, the late summer survey of 2014 showed that under conditions of very low flow, in that case 93%'ile, the plume extended effectively from bank to bank at LRP and didn't fully attenuate until reaching the northern end of Lough Ree about 2600m downstream. At WOP, the plume followed a more zig-zag path and showed less depth penetration generally than at LRP and reached full mixing just below the first bend about 650m downstream where the residual temperature had risen to 2-3°C above ambient and remained at that level more or less until the end of the survey length at 1750m downstream of the discharge.

An examination of the published fish survey data for both sites suggests that the river could be regarded as a cyprinid water, more suited to coarse fish such as roach, perch and pike, along with eel.

The temperature tolerance data for brown trout would suggest that in warm summers the ambient temperatures upstream of the power stations at both sites would be sub-optimal in the period June-August. When the same data is considered in the thermal plume it is very obvious that conditions at both stations could be sub-optimal from as early as April and as late as October depending on whether the year was warmer or cooler. This is more pronounced at LRP where the Upper Incipient Lethal Temperature (IULT) for the species (25°C) coincides more or less with average plume temperatures in June, July and August (assuming a worst case scenario that the discharge temperature is the actual in river temperature post cooling water discharge). At WOP, this is only the case in August. These data suggest that the species is likely to be entirely absent from the discharge canal at LRP in the period June to August in most years and only sporadically present between May and October in warmer years.

Of the adult salmon that return to the Shannon each year, as few as 20% may travel past WOP and LRP in the months of June to August (when they would be exposed to the highest annual temperatures). It is suggested that in the very warmest years some of these fish might drop back down to cooler waters *e.g. Lough Der and L. Ree), until conditions improved or for an increase in river discharge that would take them up past the generating plants.. Such delays are not uncommon in the species and they don't automatically mean that the fish would have a reduced fitness to spawn later on.

It is thought that most outwardly migrating smolts descend to sea in the period mid-March to mid-May. However, as smolts are sometimes still observed upstream of the dam at Ardnacrusha up to mid-June some late migrants may still be passing the plants at that stage also. Based on the findings of the spring and early summer plume surveys it is confidently expected that the majority of these smolts would descend past both generating plants keeping to the western, thermally unaffected, side of the channel. If however there was an unseasonably low water level combined with warmer than usual temperatures this might slow the swimming speed of smolts which has been shown to be reduced by over 80% at temperatures greater than 17°C. This in theory might make them more prone to attack by fish and avian predators as they pass down through both sites. Nevertheless, this risk is considered to be a minor one because of the likely infrequency of its occurrence and the small portion of the smolt cohort likely to be exposed in any given year.

Based on the literature review, eel are likely to be one of the most thermally tolerant species in the community at both sites. Most silver eels migrate to sea between August and February on the Shannon once there is a rise in water levels and for this reason and their general bottom moving habit, this stage in life cycle is believed not to be at risk from the thermal discharges at either site.

Resident eels because of their relatively high thermal optima and IULT, combined with their bottom-dwelling habit are believed to be at very low risk of thermal stress except in the very inner portion of the discharge canal at LRP in the warmest summers during June and July when there might be some localised avoidance. This effect is unlikely to be significant over the full period of the freshwater residence of any given individual and negligible at a local population level.

Very little temperature tolerance data was found in the literature for lamprey. That which was found relates to river lamprey and sea lamprey, neither of which is expected to be present in the study sites except perhaps in extremely low numbers. The temperature tolerance for river lamprey was used as a proxy for that of the congeneric brook lamprey which is the only lamprey known to be present at the two sites. The ammocoetes of the species live for at least 3 years in soft sediments before metamorphosing into migratory adults. Overall, the temperature data at the sites suggest that there might be intermittent displacement of ammocoetes and or a possible reduction in their growth rates in areas of suitable habitat within the discharge canal at LRP and within the first 300m downstream of the WOP discharge, during very warm summers. However, bearing in mind the very wide distribution of the species (brook lamprey) throughout the Shannon system, that level of potential impact, were it to occur, is considered minor to negligible.

Pike is an important component of the fish community at both sites. It has a relatively high adult IULT (30.2°C) and upper growth limit (26°C) which means that it is quite thermally tolerant and therefore likely to be little affected by the thermal discharges in average temperature summers. However, in warmer years, pike may avoid the discharge canal during periods of low flow when the degree of temperature attenuation along the canal would be relatively minor (1-2°C) as seen in the August 2014 thermal plume for the site (IHD, 2014c&d).

The current report also considers whether the warmer temperatures in the plume at each plant might cause pike to spawn earlier in the affected stretches than they would in ambient temperature conditions. However, this wasn't considered to be a very likely eventuality because flow conditions would be likely to restrict the plume from reaching the lagoon downstream of LRP which is thought to be the most likely place in the area for pike to spawn, at that earlier time of year i.e. January-early March. The likelihood that some pike might spawn in the thermal flow that was observed to spread out onto the floodplain downstream of WOP in February 2015 is also possible, as pike are known to spawn in such locations. Overall, the possibility of some marginal advancement in the time of spawning of pike downstream of both LRP and WOP cannot be ruled out but if it does occur it is considered likely that it would only likely affect a very small portion of the population in either reach and therefore not be associated with any measureable adverse impacts.

Roach is the dominant fish species in terms of numbers at both sites and is also the most numerous fish in Lough Ree. It is thermally tolerant and has been recorded in 'relatively high numbers' in the River Trent in the UK when the temperature was 27.5°C. It was the main reason in the past that the Lanesborough discharge canal was such a popular spot for coarse anglers. During the very warmest years, July temperatures in the cooling water discharge approach the IULT for the species (31.1°C) at WOP and exceed it at LRP. Under these conditions some avoidance of the discharge canal and the inner section of the lagoon i.e. within the first 600m downstream of the discharge point, might occur. Due to the nature of the plume and its vertical distribution at WOP the degree of avoidance at that site, should it occur, is thought likely to be less pronounced. Should they occur, these impacts are likely to have very little significance for the roach population, even at a local scale due to its dominant position numerically.

Research on roach in Belgium on the Meuse showed that the species spawned 3 weeks earlier in temperatures that were 2-3°C above ambient due to the thermal discharge from a power plant. It was considered possible that this could also occur on the Shannon at both sites along the eastern side of the channel extending 300-600m downstream at LRP and 200-300m downstream at WOP giving rise to an early to mid-April spawning of affected fish that would otherwise be expected to spawn around mid-May. In the context of the size and extent of the roach population within the Shannon at both sites, these impacts, should they occasionally arise could be described as negligible.

Perch were the second most numerous species taken in the IFI WDF fish survey in 2010 at LRP and they are believed to be at the same level in the population at WOP based on the IFI's findings for the same survey in the Clonmacnoise stretch 11.5km upstream. Adult perch are slightly more thermally tolerant than roach according to the literature, and are therefore unlikely to encounter any thermal stress downstream of the thermal discharges except in the very warmest summers close to the discharge points. If it occurred at all, it would be most likely in the discharge canal at LRP and within 100m of the discharge in WOP. These effects can be seen as short-term, very intermittent and spatially restricted and for these reasons are unlikely to have any significant impacts even on the local population at either site.

Based on data for spawning times in the literature, perch at both sites would be expected to spawn sometime from late April to early May. Downstream of the discharge points some early spawning, perhaps in March or even earlier cannot be ruled out. However, plume behaviour in all of these months is likely to restrict the area of such an effect to relatively short lengths of the eastern side of both channels for a distance of about 200-400m downstream of the discharge points. On such a restricted spatial scale, this effect, were it to occur, is considered to be of minor to negligible significance.

Three other species, gudgeon, bream and rudd were recovered in very small numbers by IFI at LRP in their 2010- survey at LRP. However, due to their very low representation at the site it is unlikely that the thermal plume will have measureable adverse impacts on their numbers. These species along with tench, in particular, have been mentioned on the IFI angling web site (Angling Ireland) as being prominent members of the resident fish community downstream of the cooling water discharges of both plants. It is worth noting that bream and rudd have thermal tolerances in the same general range as roach and perch, with tench having a higher tolerance, and none of them are therefore likely to suffer significantly greater adverse impacts than those species. Gudgeon would appear to be less tolerant, but this may be an underestimation.

Conclusions

The current review and risk assessment would suggest that the thermal discharge at LRP and WOP are likely to have only minor impacts on the resident fish community under average conditions of flow and temperature in any given month. In some warmer years during conditions of low flow, particularly in the period June-August, all fish species may exhibit some avoidance behaviour of the upper 300-400m downstream of the station outfall at LRP, especially in the discharge canal and in the first 100-300m downstream of the WOP discharge. In general this effect would be expected to be more pronounced at LRP where slightly higher summer temperatures seem to be the norm and flow in the discharge canal is more concentrated. As trout have been shown to be the most thermally sensitive member of the Shannon fish community, any that may be present downstream of the discharges under these conditions are likely to exhibit the greatest avoidance behaviour.

Out-migrating silver eels are very unlikely to be adversely affected by the discharges because of their mainly late autumn to early spring migration window and the propensity for the greatest rates of migrations to be accompanied by increased discharge in the river.

In the warmest years where these coincide with low flows, a small portion of the returning adult salmon population may be delayed in their upstream migration downstream of both plants. The vast majority of out-migrating salmon smolts are likely to descend past both plants without interruption. There is a slight possibility that during warmer and lower than usual flow conditions in May or early June a portion of the smolts may be exposed to an increased risk of predation by fish or birds due to a temperature-induced reduction in swimming speed. Neither the potential impacts on adults nor that on smolts is likely to result in a significant negative impacts on the population given that only a very small portion of the population should be affected in any one year and the occurrence, especially in relation to smolts is likely to be rare.

References

Delanty, K., O'Grady, M.F., O'Briain, R., Feeney, R., Cooney, R. and Coghlan, B. (2016) A Report on a Scientific Survey of Adult Fish Stocks in Lough Ree - Inland Fisheries Ireland. National Research Survey Programme. Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24.

Alabaster J. S. and Lloyd, R. (1980) *Water quality criteria for freshwater fish* – EIFAC. Published by Butterworth, London

BIM (2008) *Farming of Eurasian perch – Vol 1 – Juvenile Production*, Aquaculture Explained Series – Special Edition No 24, Damien Toner D and Rougeot, C (eds.) An Bord Iascaigh Mhara. Ireland.

Elliott, J.M. (2000) Pools as refugia for brown trout during tow summer droughts: trout response to thermal and oxygen stress. *Journal of Fish Biology*, **56**, 938-948.

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

Frost, W. E. and Kipling, C. (1967) A study of reproduction, early life, weight-length relationship and growth of pike, *Esox lucius* L., in Windermere. *Journal of Animal Ecology*, **36,** 651-693.

IFI (2009) Sampling Fish for the Water Framework Directive – Shannon International River Basin

IFI (2010a) Sampling Fish for the Water Framework Directive – Shannon International River Basin

IFI (2010b) Sampling Fish for the Water Framework Directive – Lakes 2010 – Lough Ree

IHD (2014a) West Offaly Power Station Shannonbridge, County Offaly (IPPC Licence No. P0611-02) Thermal Plume Survey July 31st 2014 Report - Doc. Ref. 1195-14-A

IHD (2014b) Thermal Plume Survey at West Offaly Power station (Shannonbridge) on July 31st 2014 - Cross-sections extracted from TIN models of survey data

IHD (2014c) Lough Ree Power Station Lanesborough, County Longford (IPPC Licence No. P0610-02) Thermal Plume Survey August 1st 2014 Report, Doc. Ref. 1195-14-B

IHD (2014d) Thermal Plume Survey at Lough Ree Power station (Lanesborough) on August 1st 2014 -Cross-sections extracted from digital terrain models of survey data.

IHD (2015a) West Offaly Power Station Shannonbridge, County Offaly (IPPC Licence No. P0611-02) Thermal Plume Survey February 5th 2015, Report – Final Doc. Ref. 1202-15-A_Final

IHD (2015b) Thermal Plume Survey at West Offaly Power station (Shannonbridge) on February 5th 2015, Note Re. Cross-sections

IHD (2015c) Lough Ree power station Lanesborough, County Longford (IPPC licence no. p0610-02) thermal plume survey February 4th 2015 report – final.

IHD (2015d) Lough Ree Power Station – Thermal Plume Survey of 04-Feb-2015 - Note re. Cross-sections

IHD (2016a) West Offaly Power Generating Station Thermal Plume Survey April 2016.

IHD (2016b) Lough Ree Power Generating Station Thermal Plume Survey May 2016.

Jobling, M. (1981) Temperature tolerance and final preferendum – rapid methods for the assessment of optimum growth temperatures. *Journal of Fish Biology*, **19**, 439-455.

Kelly, F.L., Connor, L., Morrissey, E., Coyne, J., Matson, R., Feeney, R. and Rocks, K. (2014) Water Framework Directive Fish Stock Survey of Lough Ree, June 2013. Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24.

Kennedy, M and Fitzmaurice, P. (1968) The Biology of the Bream *Abramis brama* (L) in Irish Waters. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science*, **67**, 95-157

Kennedy, M. (1969) Irish Pike Investigations – Spawning and early life history. *Irish Fisheries Investigations Series A (Freshwater); 5(i)* Department of Agriculture and Fisheries, Dublin.

Kennedy, M. and Fitzmaurice, P. (1972) Some aspects of the biology of gudgeon *Gobio gobio* (L.) in Irish waters. *Journal of Fish Biology*, 4, 425-440.

Kennedy, M. and Fitzmaurice, P. (1974) Biology of the Rudd *Scardinius erythrophthalmus* (L) in Irish Waters. *Proceedings of the Royal Irish Academy*. *Section B: Biological, Geological, and Chemical Science*, **74**, 245-303.

Maitland, P.S. and Campbell, R.N. (1992) *Freshwater Fishes*. London: Harper-Collins

Martin, P. Rancon, J, Segura, G., Laffont, J., Boeuf, G. and S. Dufour (2012) Experimental study of the influence of photoperiod and temperature on the swimming behaviour of hatchery-reared Atlantic salmon (*Salmo salar* L.) smolts. *Aquaculture* **362–363,** 200–208.

Mattheeuws, A., Genin, M., Detollenaere, A. and Micha, J.-C. (1981) Etude de la reproduction du gardon (*Rutilus rutilus*) et des effets d'une élévation provoquée de la température en Meuse sur cette reproduction. *Hydrobiologia*, **85,** 271-282.

Nash, K.T., Hendry, K. and Cragg-Hine, D. (1999) The use of brushwood bundles as fish spawning media. *Fisheries Management and Ecology*, **6**, 349-355.

Potter, I. C. and Beamish, F. W. H. (1975). Lethal temperatures in ammocoetes of four species of lampreys. *Acta Zoologica* **56**, 85–91

Sadler, K. (1979) Effects of temperature on the growth and survival of the European eel, *Anguilla anguilla* L. *Journal of Fish Biology*, **15**, 199-507.

Sadler, K. (1980) Effect of the warm water discharge from a power station on fish populations in the River Trent. *Journal of Applied Ecology* **17**, 349-357.

Sadler, K. (1980) Effect of the warm water discharge from a power station on fish populations in the River Trent. *Journal of Applied Ecology*, **17**, 349-357

Seymour, E.A. (1989) Devising optimum feeding regimes for the warmwater culture of eel, *Anguilla anguilla*, L. Aquaculture and Fisheries Management, **20**, 129-142.

Souchon Y and L., Tissot (2012) Synthesis of thermal tolerances of common freshwater fish species in large Western Europe rivers. *Knowledge and Management of Aquatic Ecosystems*, 405 (03), 1-45.

Wheeler, A. (1978) *Key to the fishes of Northern Europe*, Fredrerick Warne, London. 380pp.

Response to EPA Observations on: *Shannon Power Stations Literature Review of Potential Fisheries Impacts (July 2016)*

(Gerard Morgan - Aquatic Services Unit)

Commissioned by: ESBI

Undertaken by: Aquatic Services Uni (UCC)

September 2019

Introduction

The following were the observations on the literature review provided by the EPA in consultation with Inland Fisheries ireland:

Following a review of the report submitted and consultation with Inland Fisheries Ireland, it is recommended that the following be added to the literature review: (1) Effect of thermal plumes on the migration of diadromous fish species –is there any information on thermal plumes performing as barriers to fish migration. (2) Have any radio tracking studies been undertaken to assess the potential negative effects of thermal plumes on fish passage in freshwater or to assess fish behaviour associated with thermal plumes (3) If thermal plumes have caused delays in migration, what were the effects of these delays on the fish species. Did they have any negative impacts such as exposure to predation and other hazards, genetic fragmentation, etc. (4) There was also no mention of pollan in the literature review, it is known that pollan do migrate out of the lakes on the Shannon, so it may also be worth including a small section on this species. Please provide the revised literature review report by 30th September 2016.

Response

(1) *Effect of thermal plumes on the migration of diadromous fish species –is there any information on thermal plumes performing as barriers to fish migration.*

I have been unable to locate any reference in the peer-reviewed literature, despite searches in a number of large online academic databases (including Web of Science, Science Direct and JSTOR), to thermal plumes performing as barriers to diadromous fish migration, either for anadromous or catadromous species. Nevertheless, it is important to point out that every site should to be assessed on its own particular site characteristics in terms of watercourse hydromorphology and discharge rates, seasonal average and peak ambient water temperature, as well as the volume and thermal load of the discharge. In effect this means that were there to be a reference to a potential migratory barrier at any given site due to a thermal discharge, it wouldn't follow that there would also be one at the Shannon sites.

(2) *Have any radio tracking studies been undertaken to assess the potential negative effects of thermal plumes on fish passage in freshwater or to assess fish behaviour associated with thermal plumes.*

I have been unable to find any reference in databases of internationally peer-reviewed literature to radio tracking studies dealing with the negative effects of thermal plumes on fish passage or fish behaviour.

(3) If thermal plumes have caused delays in migration, what were the effects of these delays on the fish species. Did they have any negative impacts such as exposure to predation and other hazards, genetic fragmentation, etc.

As I have indicated in response to Items 1 and 2 above I have been unable to find any data in the peer-review literature in a number of large on-line databases of peer-reviewed literature specifically dealing with the delays caused by thermal plumes. However, there is a considerable body of literature which deals with the impact of elevated temperatures on salmonid migration and these data can provide us with some useful information in responding to the questions above.

In a recent detailed review, Fenkes *et al.,* (2016) address the potential impacts of 'migratory difficulty' including warmer waters and altered flow conditions on the reproductive success of salmonid fishes. They point out that because salmonids don't feed after they enter freshwaters, they 'rely entirely on endogenous energy stores to fuel return to their native spawning sites and reproduction on arrival. Metabolic rates and cost of energy en-route increase with temperature and at extreme temperatures, swimming is increasingly fuelled anaerobically, resulting in oxygen debt and reduced capacity to recover from exhaustive exercise' In effect, thermal changes and hydrological barriers both affect the amount of energy required to reach spawning sites which in turn reduces the energy available for other aspects of reproduction such as reproductive competition (which impacts on mating success) and gamete production. They note for example that thermally challenged salmonids produce less viable gametes. Overall however, they conclude that there is a gap in our knowledge when it comes to assessing how energetically depleted fish that successfully arrive on spawning grounds fare subsequently. In other words arrival at the spawning ground is just the first essential step, after that there must be successful mating, spawning and survival of viable embryos that will eventually recruit to the population. The Fenkes *et al.*, review has been prompted by the fact of climate change and urbanisation and its effect on water temperatures and current flow velocities in river systems globally.

Much of the literature on the impact of increased water temperatures relates to the elevated temperatures caused by climate change in North American rivers, many of which are heavily regulated, and the effect of such changes on the survival of migrating Pacific salmon in particular. Some of these studies have documented high mortalities among adult migrants in years with higher than normal temperatures (2-4°C above normal) e.g. Mathes *et al.,* (2010). The latter study, dealing which sockeye salmon (*Oncorhynchus nerka*) and using radio tagging techniques showed differential mortality rates among early and late run stocks, in what is a very complex and large river system (the Fraser River) in British Colombia. The study also alluded to the significance of accumulated exposure to temperature during migration in terms of degree days and how that has been shown above a certain value to increase the susceptibility to certain pathogens. Just to clarify, these studies relate to ambient, elevated temperatures and are unrelated to thermal discharges.

In another radio tracking study, this time on the Klamath River in northern California, Strange (2010) showed how adult Chinook salmon (*Oncorhynchus tshawytscha*) can continue to migrate up river in mean daily river temperatures that ranged from 21.8 to 24.0 °C (mean = 22.9°C) and during a whole week of migration experienced a mean average body temperature of 21.9°C with a minimum average daily body temperature of 20.6°C and a maximum average daily body temperature of 23.1°C. The author concludes that temperatures above these maxima completely block migration in nearly all circumstances. Strange (2010) points out that the upper thermal limits to adult Chinook salmon migration noted in his study are substantially higher than those previously reported in the literature, (21°C reported as the upper limit for migration in the species). The author speculates that differences in study methods and study circumstances might indicate that the previous maxima reported for the species could be open to question. What the study shows is (1) that there is an upper thermal limit to migration but (2) that species can migrate for sustained periods (a week or more) at or close to that limit. It is important to bear in mind however, that these upper thresholds vary between salmonid species and Atlantic salmon are more thermally tolerant than Pacific salmon (Jonnson and Jonnson, 2009).

A more recent study, using passive tracking (with PIT tags), dealing with movement of Atlantic salmon parr in high ambient river temperatures (Dugdale *et al.,* 2016) on the Atlantic coast of Canada reveals that parr moved toward cooler water plumes discharging from a 1st and 2nd order stream into a larger tributary with higher temperatures when average temperature reached 24.8 °C in the latter. In this scenario the authors suggest that fish close to a cooler water refuge will utilise it more frequently and readily than fish at a greater distance but that as the temperature continues to rise even fish at greater distance would be forced to actively seek thermal refuges. Which is why they noted that movement of more distant fish from the main stem of the river toward the thermal refugia in this tributary stream wasn't detected until a mean temperature of 29.0°C +/- 0.8 °C occurred. Given that this latter temperature actually exceeds the upper incipient lethal temperature reported for the species (27-28°C) (i.e. temp that 50% of the fish would survive after a 7-day exposure period) shows that acclimated fish can tolerate high ambient temperatures, at least for short periods. The study also suggests that fish will travel significant distances (at least 1.6km in that study) to find cooler water. In relation to the fact that the parr in this study were able to move and search out temperature refugia even at temperatures known to reduce the swimming speed of some salmonids, the authors speculate that the salmon in this particular river may be better adapted to tolerate higher temperatures. Nevertheless, the main point here is that salmon and salmonids in general have been shown to actively seek out cooler water plumes when the ambient temperature rise above a certain threshold and that they will travel significant distances to find them. The study also confirms that Atlantic salmon are the most thermally tolerant of the salmonids.

The implications of the foregoing examples for the movement of salmon past the Shannon Power Stations are as follows:

(i) Once ambient temperatures reach around 23-24°C Atlantic salmon may begin to seek temperature refuges with the likelihood of refuge seeking activity increasing with increasing temperature above this range. This means that migrating fish could gravitate to deeper water and to cooler water streams within the channel, which at Lanesborough (Lough Ree Power) would be on the western bank of the river on the opposite side from the cooling water discharge and at Shannonbridge (West Offaly Power) seems to undulate over and back across the channel downstream of the thermal discharge. However, salmon on spawning migrations can and do swim through water temperatures at or close to their upper temperature threshold for migration or in certain cases (Strange 2010) above temperatures previously reported as marking that limit. Furthermore, we can see that from the study on salmon parr by Dugdale *et al.*, (2016), salmon can still swim close to their IULT in the wild. In such a scenario, adult salmon may just continue to migrate through the relatively very short affected stretches at Lanesborough (LRP) and Shannonbridge (WOP) continuing to spawning areas in the catchment upstream.

(ii) It's important to note that these scenarios are only likely to come into play during years when the river has temperatures well above average i.e. at the 5%ile upper range as measured at the stations, i.e. 22.8 at LRP and 22.3 at WOP. Even under these circumstances however it would seem unlikely that adult salmon migration would be halted at WOP due to the nature of the plume at that site and the greater dilution and lower ambient temperature there. This is because within the mixing zone, plume dispersal surveys for the site have always shown areas of cooler water (no more than 1-2 degrees above ambient) which would afford salmon a route for passage. Only in a short section at the downstream end of mixing zone (Chainage 750-1750m) is temperature in the range 2-3°C above ambient. At LRP, the possibility of delays in migration must be considered as thermal plume surveys at the site have shown that the zone where the channel joins the 'lagoon' at the head of Lough Ree generally experiences temperatures between 5°C and 7°C above ambient across the full channel during conditions of low flow.

(iii) In the case of LRP it is very unlikely that a delay in fish migration, were it to occur could have a significant adverse impact on the species population. Theoretically, any fish that were delayed in their upstream migration at LRP would potentially hold up at the deeper water in the lagoon which goes down to 7.5m or drop back down into Lough Ree and await a drop in temperature before continuing on their migration. This could potentially increase susceptibility of a migratory fish to cumulative temperature stress requiring it to find a cool enough refuge that would reduce its cumulative exposure. At a population level, it would seem very unlikely that delays to migration, were they to occur, could have a significant adverse impact for the following reasons:

(i) The frequency of occurrence of these events is likely to be very low, i.e. only occurring in very warm summers combined with low flow conditions.
(ii) Only a small portion of the population is ever likely to be affected, i.e. those fish that don't spawn in the lower catchment, where most of the wild stock are thought to spawn at present and of those only those that reach the power station locations in the warm period between late June and early August principally. Moreover, given that the river Suck joins the Shannon just above WOP and that the Inny joins the Shannon in Lough Ree it is clear that even fewer adults are likely to reach LRP, as a portion of these are likely to utilise the catchments of these two very extensive tributaries for spawning. This in turn means that an even smaller portion of the population is ever likely to be exposed to potential thermally-related migration delays. Clearly, all fish passing the power stations outside of the warmer months, autumn migrants, will not be affected as there is no potential for adverse impact from the thermal discharges at the lower temperatures recorded at these later times.

(iii) The current genetic profile of salmon in the river upstream of the Ardnacrusha dam emanates mainly from the Parteen hatchery stock, which is the source of large releases of smolts above the dam annually as well as an annual programme of unfed fry re-stocking in the mid to upper Shannon tributaries. Thus any periodic impairment of spawning success in a small number of adults due to thermally induced delays in migration will have no impact on the genetic make-up of the existing Shannon stock, which is currently artificially maintained.

Other Diadromous Species

The European eel is a eurythermal species and an examination of their thermal tolerances as part of the literature review indicated that this species is unlikely to be significantly adversely impacted by the presence of the thermal discharges with at most localised exclusion from the very warmest parts of the channel on the warmest months of the year. This conclusion is partly corroborated by the results of the 1st of 3 fyke net surveys for the species undertaken at 10 sites above and below both thermal discharge locations during August 2016. The survey recorded the species in nets both upstream and downstream of the thermal discharges at both sides of the river, at both stations, including in the discharge canal at LRP. Moreover, during the 2015 Trap & Transport programme for silver eels which is undertaken annually by the ESB, 58.5% of all the eels trapped (11.68 tons) were captured upstream of the WOP station at sites in Athlone, Roosky and Finea. 10% of the total were taken at Roosky (2tons), which was the single trapping site upstream of LRP. These data point to the ubiquitous distribution of the species within the Shannon catchment and the likelihood that the thermal discharges do not present any threat to the species. It is worth noting that eel throughout their European range are considered to be essentially a single panmictic stock so that the operation of the Shannon stations has no significance for the stock's genetics.

> *(4) There was also no mention of pollan in the literature review, it is known that pollan do migrate out of the lakes on the Shannon, so it may also be worth including a small section on this species.*

The recent status of the Irish glacial relict *Coregonus autumnalis* has reviewed by Rosell et al, 2004 and the following very brief account is compiled mostly from that and a recent IFI paper on the 2014 status of Red Data fish species (O'Gorman *et al*., 2015). The Irish population, the only one in Western Europe and possibly a distinct sub-species or species, unlike it's Russian Arctic congeners is not anadromous being confined to a small number of lowland productive lakes including Lough Neagh, Lower Lough Erne, Lough Ree and Lough Neagh. More recently (2014) its presence has also been confirmed in Lough Allen by IFI surveys (O'Gorman *et al,* 2015) where there are encouraging signs of its population size. Historically the species may have occurred in other lakes also including Lough Derravaragh, Lough Iron, Upper Lough Erne and Lough Garradice. The species has declined considerably in all its current lake sites (although we don't have historical data for Lough Allen) and the Neagh population remains by far the greatest in terms of abundance. The Ree and Derg populations once at 5-9% of the fish population of those lakes has declined drastically to less than 1% of the fish population in recent years. Several hypotheses have been offered for the declines but a combination of increased eutrophication, competition from cyprinids such as roach and perch and most recently the introduction of invasive invertebrates, in particular zebra mussels, have all been implicated. Pollan spawn on the stony shorelines of Lough Neagh in December and are likely to spawn on the same substrate and around the same time in each of the other Irish lakes where it occurs also.

There are only very limited references to riverine occurrence of pollan but all those quoted in Rossel *et al.*'s, 2004, review appear to refer to the outfall of lakes i.e. the Shannon at Parteen/Killaloe, the Bann downstream of Lough Neagh and the estuary of Lower Lough Erne. The latter reference from Twomey (1956), indicated that the species sampled in that estuary in July were feeding almost exclusively on the estuarine crustacean *Crangon* and consequently showed scale markings indicative of improved growth as compared to growth rates in the Lower Erne. These occurrences may all be feeding-related, although the Lough Derg ones may have been entirely incidental as some at least tended to be associated with flood events. Clearly they were unrelated to reproduction because each population spawns separately on the lake shore. In the past, there may have been some genetic exchange between the stocks of the Shannon Lakes but there's no historical evidence of which I am aware to support this hypothesis. More detailed genetic studies on all the Irish stocks including Lough Allen may shed further light on this. It's very unlikely that the integrity of any of the current lake stock is dependent on genetic exchange for its survival, with the environmental and biotic threats likely to be much more decisive for the Irish sub-populations.

The upper thermal limit of the specie is variously put at 20-22°C (see Anon 2005) confirming that this is a cold-water species. Recent (2014) survey of Lough Ree (Kelly *et al*., 2014) has indicated that the species is confined to the deeper parts of the lower half to one third of Lough Ree which is well beyond the thermal influence of LRP. Furthermore, none of the likely spawning sites on the lake are affected by the discharge, especially as spawning takes place in the winter when the extent of the LRP plume is at its most confined. For all the same reasons, the WOP thermal discharge it not believed to be having any possible adverse impact on the pollan stocks of Lough Derg.

References

Anon (2005) All Ireland species action plan. Joint Publication of NPWS and NIEA available on line at: https://www.npws.ie/sites/default/files/publications/pdf/2005_Group_SAP.pdf

Dugdale, S. J., Franssen, J., Corey, E., Bergeron, N. E., Lapointe, M., and R. A. Cunjak Main stem movement of Atlantic salmon parr in response to high river temperature. Ecology of Freshwater Fish 2016: **25**: 429–445

Fenkes, M., Shiels, H. A., Fitzpatrick, J.L., and Nudds, R. L. (2016) The potential impacts of migratory difficulty, including warmer waters and altered flow conditions, on the reproductive success of salmonid fishes. *Comparative Biochemistry and Physiology*, Part A **193**, 11–21

Jonnson, B. and N. Jonnson (2009) 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,** 2381–2447

Kelly, F.L., Connor, L., Morrissey, E., Coyne, J., Matson, R., Feeney, R. and Rocks, K. (2014) Water Framework Directive Fish Stock Survey of Lough Ree, June 2013. Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24.

Mathes, M. T., Hinch, S. G., Cooke, S. J., Crossin, G. T., Patterson, D. A., Lotto, A. G., and Farrel, A. P. (2010) Effect of water temperature, timing, physiological condition, and lake thermal refugia on migrating adult Weaver Creek sockeye salmon (Onchorhynchus nerka). *Canadian Journal of Fisheries and Aquatic Science*, **67**, 70-84.

O'Gorman, N.M., Rooney, S.M., Cierpial, D. and King, J.J. (2015) National Programme: Habitats Directive and Red Data Book Species Executive Report 2014. Inland Fisheries Ireland, 3044 Lake Drive, Citywest, Dublin 24, Ireland.

Rosell, R., Harrod, C., Griffiths, D. and McCarthy TK., (2004) Conservation of the Irish populations of the pollan Coregonus autumnalis Biology and the Environment: Proceedings of the Royal Irish Academy, 104B (3) 67-72

Strange, J. S. (2010) Upper thermal limits to migration in adult chinook salmon: evidence from the Klamath River basin. *Transactions of the American Fisheries Society*, **139**:4, 1091-1108

Twomey, E. (1956) Pollan of Lough Erne *The Irish Naturalists' Journal*, 12 (1)14-17.

Adult Salmon Migration on the Shannon – Overview of Trends and Numbers

The Ardnacrusha hydro station and Parteen Regulating Weir both came into full operation in 1929 regulating the upward migration of salmon to the large portion of the Shannon catchment upstream of these structures. In 1959 returning adult salmon numbers began to be recorded for the first time at Parteen Weir as part of the hatchery and re-stocking programme initiated there at that time. The salmon were and still are counted as they enter adult traps and are either removed to the river immediately upstream of the trap or retained as hatchery broodstock for stripping of eggs and milt. At the same time a Borland fish pass (or fish lift) was installed at Ardnacrusha hydrostation which also allowed a census of the fish passing upstream. The results of these counts were supplied by Dr Denis Doherty ESB Fisheries Conservation and are presented in Figure 1 along with the commercial salmon catches since 1940 at Thomond Weir situated just upstream of Limerick City centre but downstream of the dam and also downstream of the confluence of the Mulkear River, an important salmon spawning river on the lower Shannon. It is assumed that had they not been taken in the commercial fishery the majority of the salmon captured at Thomond Weir would have made their way into the Mulkear River and main Shannon catchment above the dam via Parteen Weir and also via Ardnacrusha after 1959 with the installation of the Borland lift. They would also have included ‘stray’ fish from other rivers lower down in the system e.g. the Maigue and the Feale.

These data are presented in order to show the recent historical trend in adult salmon numbers returning to the Shannon and in particular to highlight the dramatic decline in those numbers since the 1960’s when the highest numbers were recorded. Figure 2 extracts the total numbers (including those for Thomond Weir) from 1971 to 2017 displayed as a 5-year running average along with the numbers of returning adult 1-sea winter fish (grilse) for the southern area of the NE Atlantic i.e. fish returning to Irish UK and French rivers in particular, extracted from Chaput (2012) and also presented as a 5-yr running average. These latter data show clearly that the trends on the Shannon are part of a much wider decline in returning salmon numbers in the region which has been attributed to a decline in sea survival rates among other factors. In the case of the Shannon salmon there seems to have been a similar decline to that of the region from 1971 to 1980, followed by a more precipitous decline than in the region between 1980 and 1990 with a similar and more or less levelling trend since about 2000, when the Shannon numbers have been around 2000 or less on average

It is also worth noting that recent genetic studies on all the existing Shannon salmon stocks and on scales from fish caught and archived before the construction of the dam, indicates that all extant populations are from the rivers discharging below the dam or from the hatchery stock at Parteen, which are themselves derived from the lower Shannon tributary stocks. Thus the native ‘above-dam’ Shannon stock no longer exist (pers comm Dr Philip McGinnity). There used to be a very significant run of large multi sea-winter salmon in the Shannon, however, these have gradually declined since the construction of the dam and the vast bulk of returns are now either hatchery origin grilse or 2 SW salmon.

Salmon migrate upstream through the Borland fish lift in the Ardnacrusha dam or via the fish pass located at Parteen weir in every month of the year. However, the numbers vary considerably from month to month. Figure 3 and Tables 1 and 2 present the data for the most recent years (2013 to 2017) which clearly shows that the runs are concentrated into 2 periods namely summer (June & July mainly) and autumn/winter (October and November mainly). These details are relevant when we come to consider the issue of the potential impact of the thermal plume acting as a migratory barrier on these fish. Virtually all of the returning fish are either hatchery reared fish (~45%) or ‘wild’ fish (~55%) which are fish that are the progeny of returning hatchery adults spawned upstream or downstream of the dam that are themselves the progeny of hatchery reared smolts. The native salmon stock that historically occurred upstream of Ardnacrusha, no longer exist.

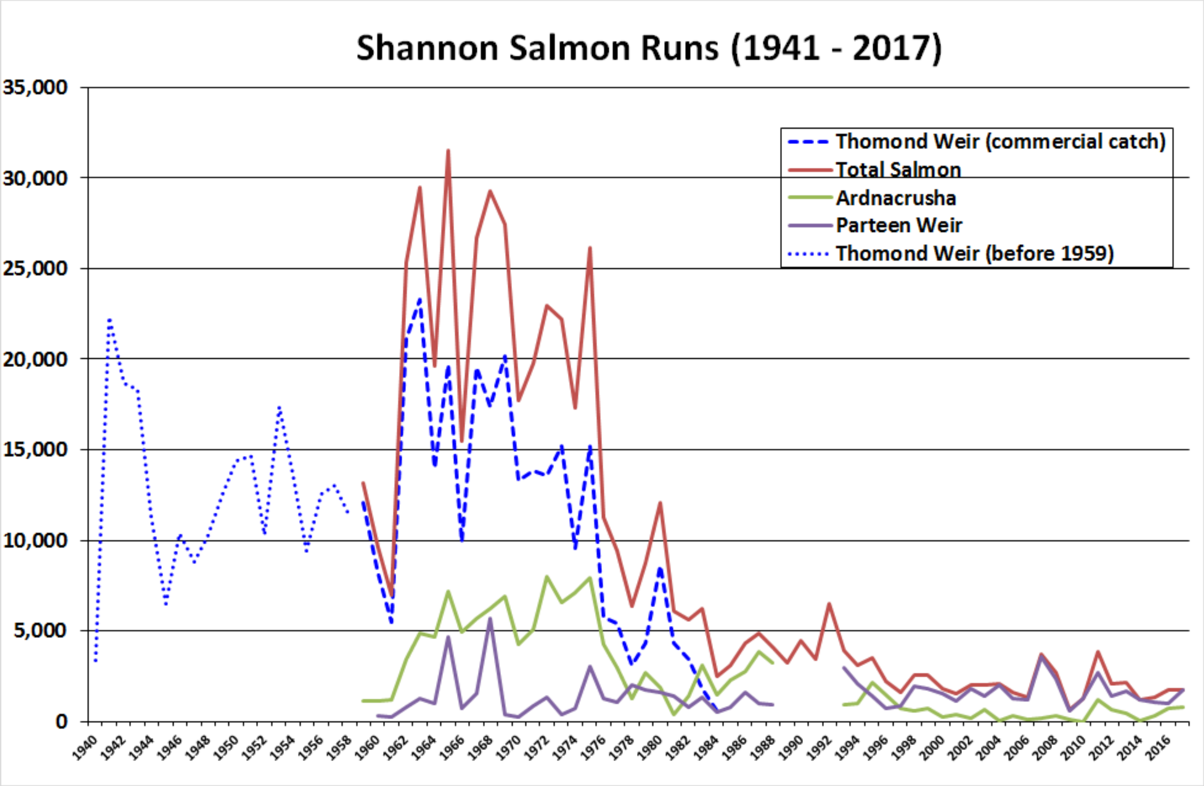


Figure 1 Recent historical trends in returning adult salmon - River Shannon (see text for more details - data from Dr Denis Doherty ESB Fisheries Conservation)

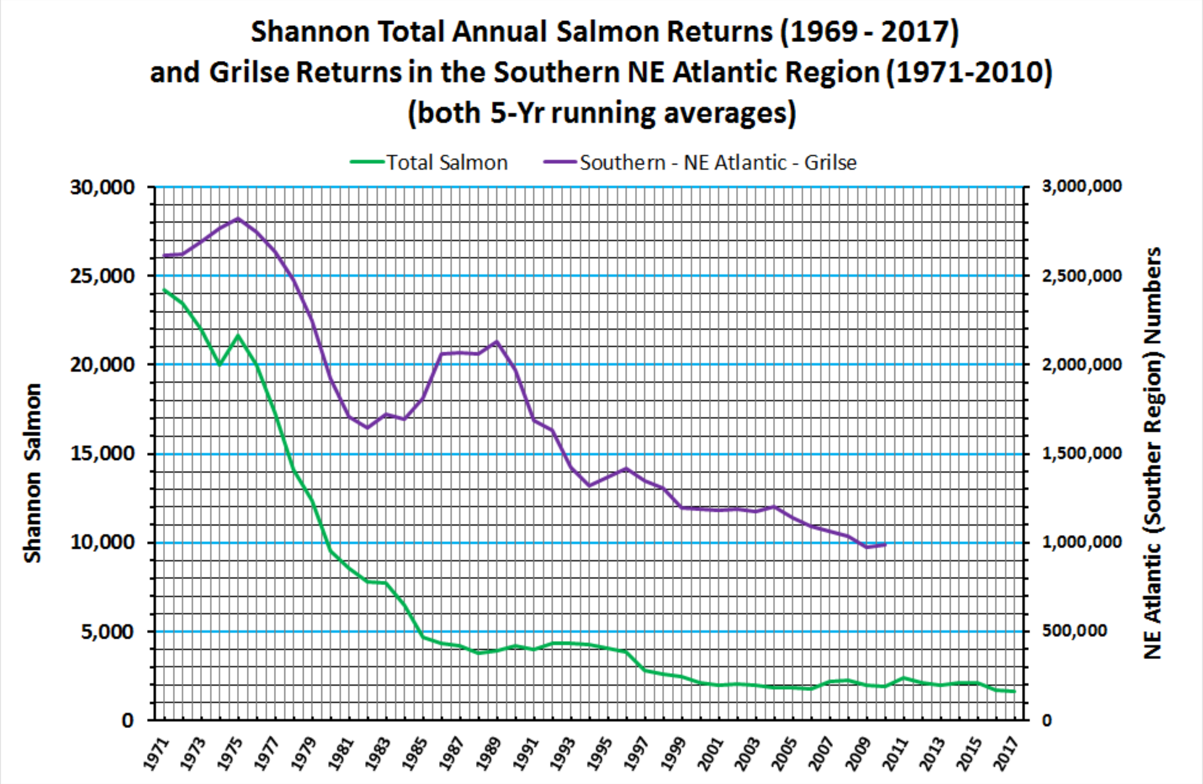


Figure 2 Shannon total salmon numbers compared to regional Atlantic salmon returns (1971-2017)

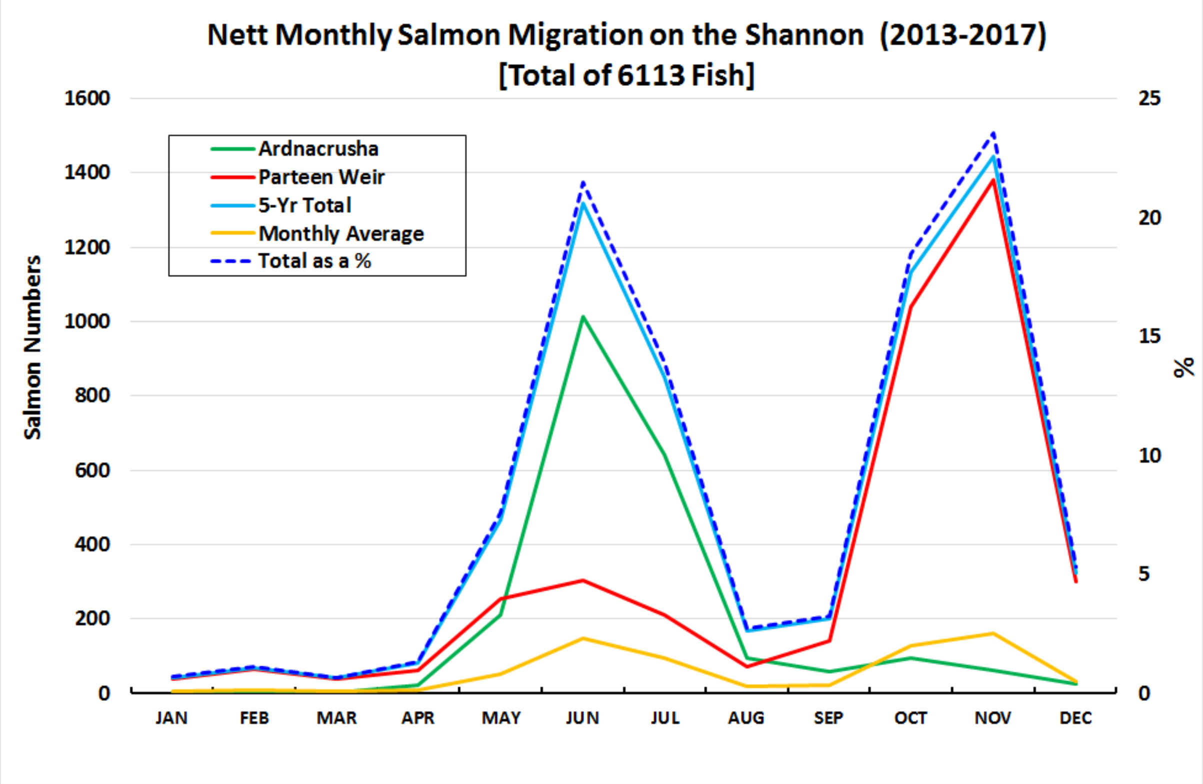
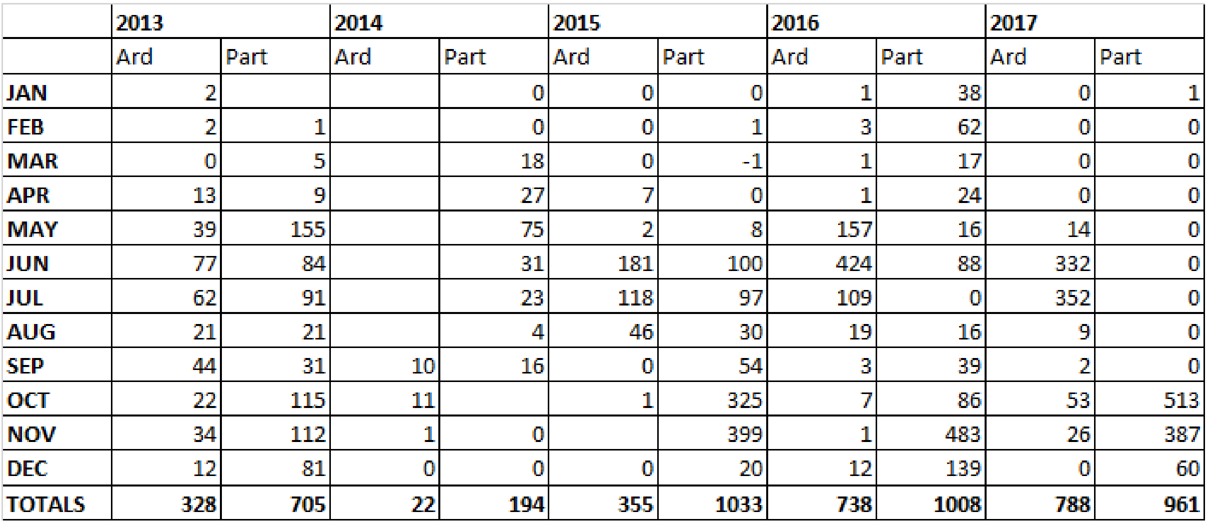
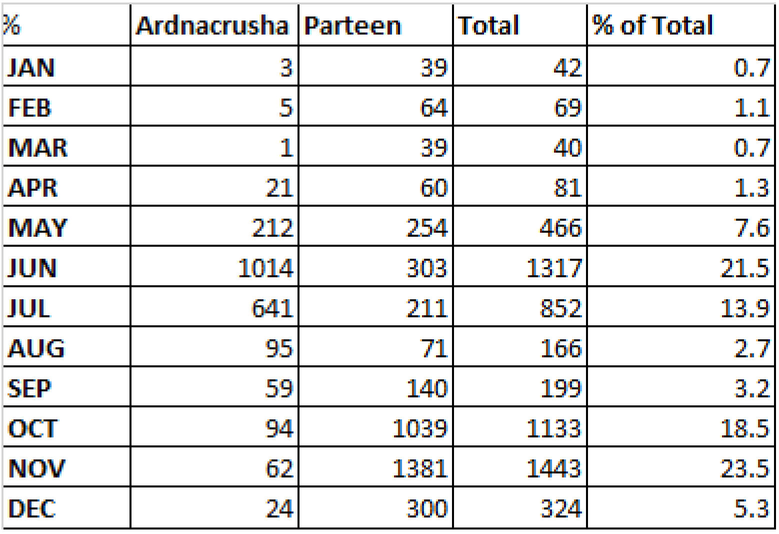


Figure 3 Monthly adult inward migration on the Shannon for the period 2013-2017 (data D. Doherty



	2013		2014		2015		2016		2017	
	Ard	Part	Ard	Part	Ard	Part	Ard	Part	Ard	Part
JAN	2			0	0	0	1	38	0	1
FEB	2	1		0	0	1	3	62	0	0
MAR	0	5		18	0	-1	1	17	0	0
APR	13	9		27	7	0	1	24	0	0
MAY	39	155		75	2	8	157	16	14	0
JUN	77	84		31	181	100	424	88	332	0
JUL	62	91		23	118	97	109	0	352	0
AUG	21	21		4	46	30	19	16	9	0
SEP	44	31	10	16	0	54	3	39	2	0
OCT	22	115	11		1	325	7	86	53	513
NOV	34	112	1	0		399	1	483	26	387
DEC	12	81	0	0	0	20	12	139	0	60
TOTALS	**328**	**705**	**22**	**194**	**355**	**1033**	**738**	**1008**	**788**	**961**

Table 1 Monthly numbers of adult salmon migrating via Ardnacrusha and Parteen Weir (2013-2017)



%	Ardnacrusha	Parteen	Total	% of Total
JAN	3	39	42	0.7
FEB	5	64	69	1.1
MAR	1	39	40	0.7
APR	21	60	81	1.3
MAY	212	254	466	7.6
JUN	1014	303	1317	21.5
JUL	641	211	852	13.9
AUG	95	71	166	2.7
SEP	59	140	199	3.2
OCT	94	1039	1133	18.5
NOV	62	1381	1443	23.5
DEC	24	300	324	5.3

Table 2 Monthly totals of migration salmon (2013-2017) with the % contribution for each month

Temperature Tolerance of Atlantic and Implications for Migration Past LRP

Atlantic salmon is the most tolerant of elevated temperatures of all salmonid fish. Detailed temperature tolerance assessments undertaken by several authors have come up with the following key temperature tolerance figures for juveniles of the species (mainly 0+ and 1+) fish Table3:

Temperature	Temperature Type	Significance
32.81°C (acclimation temperature 15°C or 20°C) Elliot & Elliot (1995)	CT max Critical Temperature (maximum)	The temperature a fish can tolerate for very short periods of exposure (~10minutes) before reaching an end point, i.e. loss of equilibrium followed immediately by death. If returned to cooler (acclimated) temperatures within this period the fish will immediately recover.
27.51°C acclimation temperature (20°C) Elliot & Elliot (1995)	IULT (Incipient Upper Lethal Temperature)	Temperature that can be tolerated by 50% of a population for extended periods of exposure (~7days) during which (toward the latter end of the 7 days) fish (up to 50%) will begin to die if not removed to cooler temperatures).
29.5°C (acclimation temperature 20°C) Elliot 1991		Temperature at which parr can survive for up to 16.5 hours (Elliot 1991)
31.1°C acclimation temperature 20°C) Elliot 1991		Temperature at which parr can survive for up to 1.6 hours (Elliot 1991)

Table 3 Critical maximum temperature limits for Atlantic salmon

Another feature of temperature tolerance in this species is that it has been demonstrated to be independent of the geographical distribution of populations, i.e. it is just as applicable to salmon from northern Norway as it would be for population in France provided both are initially acclimated to the same temperature (see Anttila *et al,* 2014).

The tolerance limits presented in Table 3, were established using fish under laboratory conditions and corroborated by more than one author. However, recent research has shown that Atlantic salmon parr also occur naturally in watercourses where temperatures can not infrequently reach these ranges. Dugdale *et al,* (2016), studying the movement of Atlantic salmon parr in a Canadian river used PIT tags to follow the movements of parr seeking refuge from high temperature main stem sites into cooler tributaries as temperatures rose. The study noted that temperature-related movements in the main stem of the river occurred during a 28-day period in July/August when the average temperature was 23.2°C +/- 3°C and the maximum was 30.5°C. When assessing data for the movement of fish from the main stem into cooler tributaries, the authors found that the best predictors of movement was average main-stem temperatures greater than 22°C for extended periods and temperatures of 28°C for shorter periods. In the case of the lower temperature 50% of movements were predicted to occur after 61 hours exposure and for the higher temperature 50% of movements were predicted to occur after just 1.5hrs of exposure. I have used the results of these field studies, informed also by the temperature tolerance values for Atlantic salmon in Table 4 as a guide to analysing the possible impact of the thermal plumes on adult salmon migration in the Shannon at LRP.

I have made the assumption that salmon encountering temperatures at or lower than 22°C within the zone of influence of the thermal discharge will not be deflected in any way by it. Above this temperature, the likelihood that a salmon might be forced to halt its migration will depend on (i) the temperature involved and (ii) the duration of exposure. In the following table therefore I have analysed all those continuous temperature monitoring reporting periods at Lanesborough from July 2016 to December 2017 where temperatures were found to be at or above 22°C and calculated (i) the full period over which that occurred and (ii) the duration of sub-periods within that whole for each subsequent 1 degree rise in temperature. Furthermore, within this overall body of data, only sites on the western i.e. cooler side of the channel were assessed i.e. temperature logging sites L4 and L6 as it was assumed that salmon would choose to take this cooler route. In addition, it was assumed that within this channel that salmon would travel deeper in the water column where the coolest temperatures were consistently encountered in the continuous logging reports i.e. at 1.5m at L4 and at 1.5 and 3m at Site 6 and therefore only data from these stations were analysed.

The thermal plume survey on July 2014 was carried during the warmest period on the river during the current thermal monitoring efforts. It showed that the plume effectively dispersed to near ambient temperatures (0-0.5°C above ambient) about 400m downstream of the entrance to the 'Cut' from the main body of Lough Ree, from the surface to 2m deep. From that point to a point upstream of L4, where the surface temperature is less than 0.5°C above ambient is 2.1km. Thus a [1]70cm salmon travelling at about 1 body length per second, which has been shown to be an efficient cruising speed for salmon (Quinn, 1988), would take just 63 minutes in to traverse this distance, assuming that about half of it was travelled in zero current and the other in a head current of 0.25m/s.. To put this distance further into perspective it is just under 1.5% of the distance a salmon would have to travel to reach this point from Ardnacrusha if it took the shortest route. Thus in this analysis a migrating adult salmon would be potentially exposed to temperatures at or in excess of 22°C for this very short time. Based on Dugdale *et al*, (2016) at the lower temperature of 22°C salmon would have to be continuously exposed to this temperature for as much as 60 hours before there was a 50% likelihood of their seeking out a cooler refuge. By the time the temperature had reached 28°C, however, that exposure time would have dropped to just 1.5hrs before there was a roughly similar likelihood that the salmon would seek cooler waters. Bearing this in mind, and the fact that the salmon is more than likely homing to an upstream spawning site and therefore motivated to continue upstream, temperatures would need to be at the higher end of this 22 – 28°C range before there would be a significant likelihood that a fish would discontinue its migration to seek a cooler water refuge, given the short time (~63minutes) salmon arriving at LRP would be exposed to in order to traverse the higher temperature stretch in question. In order to use these data in a practical scheme to assess the likelihood of an interruption to migration, I have used a traffic lights colour scheme (Table 4) to interpret the data presented in Table 5 as follows with the assumptions underlying the % of the population at risk deduced from a consideration of the evidence presented above:

---

[1] The average length of Shannon grilse

Colour Code	Presumptive Migration Impact
>22<24°C	No interruption to migration
>24<26°C	<25% of population affected
>26<27°C	>25 <50% affected
>27°C	>50%

Table 4 Temperature categories and putative impacts on salmon migration subject to short exposure times in each temperature interval (see text for explanation)

LRP

July-August 2016				
Jul 12 - Aug 16	**34.7 days**	**No. of 5-min recordings**	**Duration (Hours)**	**% of Period**
L4 (1.5m)	All >22°C	NONE	0	0
L6 (1.5m)	>22 <23°C	55	4.6	0.5
	All >22°C	55	4.6	0.5
Ambient Temp (L1)				
Average	18.3			
Maximum	21.3			

LRP

April - May 2017				
Apr 28 - May 30	**32.9 days**	**No. of 5-min recordings**	**Duration (Hours)**	**% of Period**
L4 (1.5m)	>26 <27°C	21	1.8	0.2
	>25 <26°C	108	9.0	1.2
	>24 <25°C	127	10.6	1.4
	>23 <24°C	138	11.5	1.5
	>22 <23°C	178	14.8	2.0
	All >22°C	572	47.7	6.4
L6 (1.5m)				
	>23<24°C	52	4.3	0.6
	>22 <23°C	163	13.6	1.8
	All >22°C	215	17.9	2.4
S6 (3m)				
	All >22°C	NONE	0	0
Ambient Temp (S1)				
Average	15.7			
Maximum	20.4			

Table 5 Temperature intervals at and above 22°C recorded at L4 and L6 at LRP between July 2016 and December 2017

May - June 2017				
May 31 - Jun 28	**27.9 days**	**No. of 5-min recordings**	**Duration (Hours)**	**% of Period**
L4 (1.5m)	**>27 <28°C**	**5**	**0.4**	**0.1**
	>26 <27°C	15	1.3	0.2
	>25 <26°C	85	7.1	1.1
	>24 <25°C	102	8.5	1.3
	>23 <24°C	382	31.8	4.7
	>22 <23°C	523	43.6	6.5
	All >22°C	1112	92.7	13.8
L6 (1.5m)				
	>24<25°C	2	0.17	0.02
	>23<24°C	56	4.7	0.7
	>22 <23°C	421	35.1	5.2
	All >22°C	479	39.9	6.0
S6 (3m)				
	All >22°C	NONE	0	0
Ambient Temp (S1)	Average = 17.9°C, Maximum =21.6°C			

LRP

June - August 2017				
Jun 28 - Aug 24	**57 days**	**No. of 5-min recordings**	**Duration (Hours)**	**% of Period**
	>28 <29°C	**21**	**2.3**	**0.2**
L4 (1.5m)	**>27 <28°C**	**249**	**20.8**	**1.5**
	>26 <27°C	429	35.8	2.6
	>25 <26°C	963	80.3	5.9
	>24 <25°C	1259	104.9	7.7
	>23 <24°C	1114	92.8	6.8
	>22 <23°C	751	62.6	4.6
	All >22°C	4786	398.8	29.2
L6 (1.5m)				
	>24<25°C	2	0.17	0.02
	>23<24°C	56	4.7	0.7
	>22 <23°C	421	35.1	5.2
	All >22°C	479	39.9	6.0
S6 (3m)				
	>22 <23°C	33	2.75	0.2
	All >22°C	33	2.75	0.2
Ambient Temp (S1)	Average 17.8 °C, Maximum = 20.5°C			

Table 5 contd:

When examining the data in Table 6, it is important to note that the 4th column presenting 'Duration (Hours)' refers to the total time during that recording period for which a particular temperature range lasted, it DOES NOT refer to the exposure time of a migrating salmon to elevated temperatures, which we have earlier estimated to be in the order of just 63 minutes.

Examining the various reporting periods in Table 6 for which temperatures in excess of 22°C were recorded note that during July-August 2016 there would have been no likelihood of an interruption to migration. In the next relevant period (April-May 2017) there would have been less than a day during which a portion of the migrating salmon might have been delayed. Again in the May-June 2017 period the total time during which temperatures were at levels that might result in a delay to some salmon added up to less a day. Only during the June-August period was there a likelihood that a significant proportion of any migrating salmon present on any given day might be delayed. For the bulk of this time i.e. around 7.7 days (i.e. 185 hrs), probably most migrating salmon would have continued to migrate, with perhaps a small portion deciding to drop back to wait for a decrease in temperature. However, for about 2.5 days (i.e. 59 hours) a sizeable proportion of the arriving salmon would be expected to delay. It is notable that these elevated temperatures were concentrated in just over 4 days from the 16th to the 19th of July inclusive but even on these dates the diurnal temperature range experienced ranged from 3.9 to 8°C, so that there were between 1.5 and 4 hours depending on the day, when temperatures were below <24°C when all salmon arriving would likely have continued their upriver migration. During the rest of July there were 18 days when temperatures rose above 24°C (i.e. between 24 - 27°C max) at some time during the day. However during these days there were on average 15 hours each day (range 6 – 23+) when the temperature was <24°C and on average 20 hours (range 16 – 23+) when the temperatures were <25°C, thus providing salmon with a large window each day to migrate. For the remaining days in July the temperatures were below 24°C (mainly below 22°C) and all 24 days of August had maximum temperatures below 19°C.

In order to put these results into perspective, the number of salmon that might be affected by these elevated temperatures in July have been estimated. Based on the average annual adult run for the period 2007-2017 i.e. 2036 fish (which is a conservative figure compared to the average for the past 5 years) as well as the average monthly proportion of the annual run for July i.e. 14.5% (based on data available for the period 2013-2017 - Table 2), an estimated 71 salmon might arrive at LRP in July and 109 in June i.e. 25% of the number entering at Parteen and the dam in during those months. The assumption being made in the latter instance is that the other 75% of these salmon would enter rivers lower in the catchment to spawn i.e. in rivers draining to Lough Derg and Lough Ree and the main stem of the river downstream of LPR, as an examination of ESB Fisheries data would suggest. Thus, were these fish to be evenly spaced across both months, on average 2-3 fish would arrive each day at LRP and the majority of these would likely arrive at times when the temperature would be low enough at L4 (1.5m) to allow for immediate upstream passage. Furthermore, that portion that might be delayed would not likely be delayed for more than a few days before more suitable temperatures for passage would be encountered and would still therefore continue their spawning migration. Clearly, any delay to passage puts an added level of stress on a salmon, and depending on the fish's condition, its remaining energy reserves and its health status, this might have a more or less significant effect on its degree of spawning success and subsequent survival of its progeny. What this exercise demonstrates, however, is that in a year of low average water levels and periodic high temperatures in certain summer months, like 2017, overall, the numbers of salmon potentially at a degree of added stress due to the thermal discharge at LRP is likely to be in the order of less than 5% of the overall migrating population and less than 3.5% in the July example chosen. Given that the Shannon salmon population is no longer self-sustaining (i.e. without the significant annual inputs from the Parteen hatchery), this overall order of risk to the population level can be considered minor and sustainable.

The other life stage that might be affected by the thermal discharges at LRP are seaward migrating smolts. The ESB operate a 'smolt protocol' at the dam at Ardnacrusha between mid-March (i.e. once the river temperature rises to around 8°C to 10°) continuing to around mid-June. This is a power generation procedure using a Kaplan Turbine which is designed to facilitate the movement of smolts down past the dam with minimal mortality rates rather than have them delayed just above it. According to Denis Doherty ESB Fisheries Conservation, the duration of the smolt run varies quite a bit from year to year. Depending on whether the year is cooler or warmer the run might begin later or earlier, be of short and fairly concentrated duration or extended in a stop-start fashion. The latter will also be influenced by discharge which research has shown is probably the most important factor affecting the rate of seaward migration. It usually stops in any case once water temperatures reach 18°C.

Smolts are likely to have the same upper thermal tolerance limits as adult salmon. Under ambient conditions smolts are never exposed to these temperatures at LRP and WOP but in exceptionally warm years, late running smolts i.e. in late May or early June could in theory be exposed to these levels in the plume. Against that, in warmer years one would expect that the bulk if not all the smolts would have already migrated, given the observed cessation of the run at Ardnacrusha observed to generally coincide with a warming to 18°C as cited above. Combining this with the trend for smolts from tributaries farther upstream in a catchment to commence their seaward migration earlier than smolts closer to the sea, as shown by Stewart et *al.,* (2006) for the River Tay in Scotland and supported by evidence from New England showing smolts from sub-catchments farther from the sea developing smolt physiological characteristics as they migrate downstream. (McCormick *et al.,* 1999), would suggest that the likelihood of any significant number of fish being exposed to this temperature level in the discharge plume is relatively remote. However it cannot be ruled out entirely and in this scenario a more significant impact of the discharges however could relate to the rate of passage of smolts in warmer years and how elevated temperatures impair the swimming speed of smolts. In tank-based experiments, Martin *et al.,(*2012) found the optimum swimming speed of Atlantic salmon smolts to be 13°C and that above 17°C this rate was reduced by up to 80%, while at 20°C smolts stopped swimming. This would suggest that smolts appear to be more susceptible to elevated temperature-related impacts on their swimming speed than parr, which have been shown to be active in the wild at temperatures above 22°C or more (Dugdale *et al.,* 2016). According to the 10-year temperature record (2006-2016) for the LRP cooling water intake the maximum ambient temperature in May was 20.29°C whereas the 5%ile temperature was significantly lower at 17.78°C. These temperatures are not encountered in March in the discharge plume and tend to be the exception in April, but occur regularly in May and are the rule in June at LRP (see Tables 2a & 2b and Figures 1a & 1b in ASU, 2016). We know from the 2016 thermal plume surveys undertaken in May 2016 that the plume at LRP was mainly confined to the discharge canal and the eastern side of the main channel, with very little impact on the western side of the channel. This means in effect that smolts could have travelled down past the plume along a parallel western stream where the temperatures were more or less at ambient and where they would have been be unaffected by the thermal discharge. This conclusion however is based on the assumption that the flow in the main channel is sufficiently high to ensure that the thermal plume is forced over toward the eastern side of the channel at both sites. In contrast the May 2017 continuous monitoring was undertaken during lower flows and temperatures in excess of 20°C occurred at L4 (1.5m) for a total of 6.7 days. In these situations, if the swimming impairment noted in laboratory studies translated exactly to the wild then the smolts would drift rather than actively swim. This would in theory at least expose them to a greater risk of predation by pike resident in the affected reaches or to avian predators.

Another risk of elevated temperatures to smolts relates to the physiological changes associated with the process of smoltification which prepare them for entry into a marine environment, where elevated temperatures tend to slow or reverse this process. However, McCormick *et al.,* (1999) have indicated that this is a cumulative effect measured in degree days and the effect may not be significant for such a short passage (~2km) at LRP taken in light of the full course of the migration (135km).

It is clear from the foregoing that in some years, with low flows in May, that a certain portion of the smolt population migrating from tributaries upstream of LRP may be exposed to an increased risk of predation and a small increase in accumulated thermal stress over a 2km stretch of the river downstream of LRP. In the absence of more precise knowledge of the timing of the smolt run in this part of the catchment (which will vary from year to year), nor of the numbers involved, it is difficult to quantify the impact on smolts. However, it is reasonable to assume that the effect is more likely to be minor than moderate because (i) only in certain years would the flows be low enough at that time of the year to see the plume reach to the right (western side) of the channel (ii), the fact that the bulk of smolts may already have started their seaward migration by May, that far upstream in the catchment and (iii) the relatively short distance over which the effect would be felt.

REFERENCES

Anttila, K., Couturier, C.S, Overli, O., Johnsen, A., Marthinsen, G, Nilsson, G.E., and A. P. Farrell (2014) Atlantic salmon show capability for cardiac acclimation to warm temperatures. *Nature Communications* 5, Article 4252 (online publication)

Chaput, G (2012) Overview of the status of Atlantic salmon (Salmo salar) in the North Atlantic and trends in marine mortality. ICES Journal of Marine Science, 69, 1538-1548.

Dugdale, S.J., Franssen, J., Corey, E., Bergeron, N.E., Lapointe, M. and R.A. Cunjak (2016) Main stem movement of Atlantic salmon parr in response to high river temperature. *Ecology of Freshwater Fish*.25, 429-445

Elliott, J.M. (1991) tolerance and resistance to thermal stress in juvenile salmon, *Salmo salar*. *Freshwater Biology* 25, 61-70.

Elliott, J.M and Elliott, J.A. (1995) The effect of the rate of temperature increase on the critical thermal maximum for parr of Atlantic salmon and brown trout. *Journal of Fish Biology* 47, 917-919.

McCormick, S.D, Cunjak, R.A, Bempson, B, O'Dea, M.F and Carey, J. B (1999) Temperature-related loss of smolt characteristics in Atlantic salmon (*Salmo salar*) in the wild. *Canadian Journal of Fisheries and Aquatic Science* 556, 1649-1658.

Martin, P., Rancon, J., Segura, G, Laffont, J. Boeuf, G and Dufour S. (2012) Experimental study of the influence of photoperiod and temperature on the swimming behaviour of hatchery-reared Atlantic salmon (Salmo salar) smolts. *Aquaculture* 362-363, 200-208

Quinn, T. P. Estimated swimming speeds of migrating adult sockeye salmon. *Canadian Journal of Zoology*, 66, 2160-2163.

Stewart, D.J., Middlemas, S.J. and Young A.F. (2006) Population structuring in Atlantic salmon (*Salmo salar*): evidence of genetic influence on the timing of smolt migration in sub-catchment stocks. *Ecology of Freshwater Fish* 15. 552-558.