IFISH

Fish and Habitats: Science and Management

Vol. 3

Fish Kills in Ireland
History, Current Status and Recovery

IFI/2024/1-4706

Iascach Intíre Éireann
Inland Fisheries Ireland

fisheriesireland.ie

IFISH

Fish and Habitats: Science and Management, Vol. 3

Fish Kills in Ireland – History, Current Status and Recovery

Citation: Matson, R. and Kelly, F.L. (2024) Fish Kills in Ireland – History, Current Status and Recovery. IFISH: Fish and Habitats: Science and Management, Volume 3, 73pp. ISSN: 2565-6244 (online). Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24, Ireland.

ISSN: 2565-6244 (online)

Cover photo: Fish mortalities from a fish kill on the River Allow, Co. Cork in June 2024. © Inland Fisheries Ireland 2024

Keywords: fish, temporal, spatial, causes, recovery

ACKNOWLEDGEMENTS

The authors would like to thank all their colleagues in Inland Fisheries Ireland who contributed fish kill reports and data over the years and in particular the team of Fisheries Environmental Officers working within each of the river basin districts. The authors also wish to thank the editor of this volume, Colm Fitzgerald and a guest editor who checked the text and made some useful comments and additions to the text and reference list.

Table of Contents

Executive Summary

- This study gathered and digitised data from 2107 fish kill events in Ireland, spanning more than 50 years from 1969 to 2022. Spatial data was available for 1738 fish kills.
- The number of reported fish kill events has decreased since reporting began in 1969 especially when compared to the high levels of the 1980's.
- Four phases of fish kills occurred in Ireland since 1969. The worst years for reported fish kills were in the 1980s, particularly 1984, 1987 and 1980 respectively with a total of 347 fish kills recorded. Since 1992 there has been a downward trend in reported fish kills.
- The peak in fish kill reports in the 1980s coincided with an intensification of agriculture in Ireland. Despite the downward trend since about 2012, there have been several relatively high numbers recorded, mainly coinciding with the occurrence of heatwaves and droughts.
- Fish kills were more prevalent during the summer months, when warm weather and low water levels exacerbated potential underlying problems within a channel.
- Common causes included agriculture, eutrophication, industry and municipal activities.
- Fish kill events were less frequent in the west and northwest and hotspots were particularly prevalent in the east, south and the north midlands probably coinciding with intensive agricultural activity and large urban centres.
- Fish kills occurred in every county since 1969. Counties Cork and Cavan had the highest proportion of fish kills, while Co. Roscommon and Co. Westmeath had the lowest.
- In the 1970's the highest number of fish kills (where spatial data was available) was reported from Co. Tipperary and in the 1980s from Co. Cork. In the 1990s and 2000s, Co. Cavan had the highest, and in the 2010s it was Co. Cork. Since 2020, the highest number has been recorded in Co. Cavan, followed by Co. Cork.
- Since 1969, the Erne Catchment (*Hydrometric Area 36*) had the highest number of reported fish kills. This was followed by the Lee, Cork Harbour and Youghal Bay (*Hydrometric Area 19*), the Barrow (*Hydrometric Area 14*), Suir (*Hydrometric Area 16*) and Liffey and Dublin Bay (*Hydrometric Area 09*) catchments.
- Across IFI's fishery regions, the Eastern River Basin District (ERBD) had the highest number of fish kill reports during the study period. Two river sub-basin waterbodies in the ERBD (Avoca_020 and Avoca_010) had the highest number of fish kill reports. The Erne_080 (NWRBD), Feale_090 (ShRBD), Barrow_140 (SERBD) and Cavan_010 (NWRBD) were also among the top six sub-basin waterbodies with the highest number of fish kill reports.
- Rivers were the most impacted waterbody followed by lakes.

- Salmonids were the main fish group affected by fish kills between 1969 and 2022 and brown trout followed by salmon were the main species affected.
- Agriculture was the most significant reported cause of fish kills in Ireland from 1969 to 2022, accounting for 23% of known causes. This was followed by eutrophication (13%), a proportion of which may also be associated with agriculture (e.g. runoff from fertiliser) as well as other sources (e.g. release of sewage effluent), industrial (12%), other (9%), municipal (8%), mining (8%) and construction (2%).
- The proportion of fish kills attributed to agriculture, eutrophication, industry, construction and mining (excluding unknowns) was lower in the 2007-2022 period than the 1969-2006 period; however, the proportion of fish kills associated with municipal and other sources increased between both periods. In general, spatial patterns for the four main causes (agriculture, eutrophication, municipal and industrial) did not change between the two timeframes.
    - Overall, Co. Cork had the highest percentage of fish kills, attributed to agriculture between 1969 and 2022. This was followed by counties Monaghan, Limerick, Cavan, Tipperary, Meath and Wexford.
    - Co. Cavan had the highest percentage of reported fish kills due to eutrophication, followed by counties Cork, Monaghan, and Laois. The lowest percentage (0.4%) was recorded in counties Dublin, Kerry, Roscommon and Sligo.
    - The highest percentage of fish kills attributed to municipal sources was recorded in Co. Laois. This was followed by counties Cork, Cavan, Dublin and Tipperary.
    - Co. Cork also had the highest percentage of fish kills associated with industrial sources. This was followed by counties Tipperary, Kerry, Dublin, Monaghan and Cavan.
- Some reported fish kills were assigned a cause due to high temperatures and drought (within the "other" category). However, in Ireland fish kills resulting from high temperatures and drought alone are likely to be rare (coinciding with a complete absence of thermal refugia). Mortalities attributable to this cause probably happened when other pressures also existed, such as nutrient enrichment (eutrophication) and other forms of pollution discharge and it was potentially the increase in water temperature and low water levels that compounded the effect of the underlying water quality problem.
- The recovery of fish populations in the four case study rivers varied from site to site and river to river, but in general, the impact of the fish kills and recovery followed a similar pattern.

- Total fish abundance was often higher in the impacted zone than the unaffected stretch one year after the fish kill occurred. This was caused, in some cases by smaller fish species (e.g. tolerant fish species such as stone loach, minnow and three-spined stickleback) filling the void left after the fish kill.
- Certain age cohorts of brown trout and salmon were absent or present in low densities immediately, or one year after each fish kill.
- Some sites had recovered three years after the fish kill event, as observed by the return of most age cohorts.
- Time of year of the fish kill also affected recovery of fish populations.
- Although there was a perceived recovery of fish populations at many of the case study sites, the fish ecological status on many sites had not improved to the required Water Framework Directive standard of Good status. This requires that all age cohorts of type-specific indicator species be present in expected abundances to achieve this milestone and in many cases, this was not achieved.

1. Introduction

A fish kill occurs in a river when the conditions favourable for fish survival change suddenly due to either natural or anthropogenic causes, leading to multiple deaths (e.g. Boelens and O' Sullivan, 1982; Ochumba, 1990; Kubach *et al*., 2011). This may occur within a localised stretch or over a long distance in a water body. Many causes are possible and can include drought (Magoulick and Kobza, 2003), flooding and rain events (Ochumba, 1990), changes in temperature (thermal and oxygen stress) (e.g. Barica, 1975; Cyrus and McLean, 1996; Till *et al*., 2019), algal blooms (e.g. Swingle, 1966), oxygen depletion (Townsend *et al*., 1992), the release of hazardous chemicals (e.g. Olmsted and Cloutman, 1974 and Napier *et al*., 1998), hydromorphological changes (e.g. McCarthy and Moriarty, 1989) and infectious disease outbreaks (e.g. Marcos-Lopez *et al*., 2010). Death tolls may range from a few individuals to total fish mortality within a waterbody (e.g. Wilton, 2002), but the unexpected death of a single adult fish found in a waterbody may also be reported to and investigated by fishery managers.

Although a pollution event can affect a whole river channel or a small pond or lake, the problem is often short-lived and dissipates quickly as the source of the pollution stops, washes downstream and dilutes, or natural processes neutralise its effects. Due to the dynamic nature of waterbodies and sudden occurrence of fish kills, their cause is often difficult to determine before the source of the damage has dissipated. Therefore, the best chance of identifying the cause is at the time that fish are dying (Boelens and O' Sullivan, 1982).

Besides determining the cause, providing a reliable estimate of mortality can be a challenge. Kennedy *et al*. (2017) found low sampling variance between different surveyors when counting brown trout carcasses for different size cohorts after a simulated fish kill in a small stream in Northern Ireland. Their study also found that the prevalence of different size classes, changed quite quickly with a high proportion of the smaller fish carcasses disappearing after only four hours while the carcasses of larger cohorts remained visible in higher proportions for a much longer period (even two days later). After four days, however, the number of carcasses had reduced significantly and variability between surveyors had increased markedly. According to Ryon *et al*. (2000) flow regime was an important factor determining the dispersal of dead fish in a stream after a fish kill simulation, as well as scavengers, which removed substantial numbers of dead fish afterwards.

Population recovery following fish kills is boosted by fish that can seek out refuge during the disturbance (Sedell *et al*., 1990; Detenbeck *et al*., 2002; Magoulick and Kobza, 2003) as well as the availability of easily accessible sources of recolonisation near the affected area (Roghair and Dolloff, 2005; Kubach *et al*., 2011; Peterson and Bayley, 2011). This stream connectivity, however, can be hindered by anthropogenic alterations and barriers (Poff and Ward, 1990; Detenbeck *et al*., 2002), including weirs and culverts. It is, therefore, logical to assume that natural, heterogenous unmodified habitats will have more potential niches/refugia available to shelter species and their different size/age cohorts, thus improving the resilience of these habitats and their fish populations to negative pollution events.

Research from around the world suggests that fish populations after a fish kill can remain unstable for some time (Rhodes and Hubbs, 1992) and recovery can take between several months (e.g. Yount and Niemi, 1990; Dawson 2002; Walsh *et al*., 2004) to several years (Schneider, 2010). Repopulation tends to start quickly, with young immature fish the main source of the recovery (Olmsted and Cloutman, 1974). One case study on an Irish river suggested that the recovery of 1+ and older brown trout took four to five years (King, 2015). Another study on the Blackwater River in Northern Ireland found salmonid abundance to recover within one year, total salmonid biomass to recover within two years, and population age structure to recover within three years (Kennedy *et al*., 2012). Similarly, a study from Minnesota USA, showed brown trout recovery to start quickly, with the return of spawning adults to an impacted reach one month later, successful spawning activity over the next two years (albeit at a lower rate than in an unimpacted reference reach), and a similar total brown trout population 16 months later. Population age structure, however, had not fully recovered by the end of that study, 29 months later (Schnaser and Mundahl, 2022).

The aim of this study is to digitise all available data on fish kills in Ireland from 1969 to 2022, examine spatial and temporal trends for fish kill events occurring in Ireland and establish a geographical layer to support Water Framework Directive (WFD) (Council of the European Communities (2000)) reporting. A further aim is to provide information on recovery after fish kills in Ireland using four case study examples.

2. Methodology

2.1 Collating fish kill data

In Ireland, data on fish kills have been compiled and reported annually since 1969 to present by the Inland Fisheries Trust (formerly the Central and Regional Fisheries Boards and now Inland Fisheries Ireland) and Marine Institute (formerly Fisheries Research Centre). The authors collated all available data from published annual reports, fish kills reports and internal unpublished IFI reports (Fahy, 1985, 1986; McCarthy, 1988; McCarthy and Moriarty, 1989; Moriarty, 1990, 1991, 1993, 1994, 1996; IFI unpublished data 2010-2022). The data used varied in quality throughout the period with no, or sparse records available during certain periods in the 1970's, 1980's and 1990's (Table 2.1). The authors found references to a small number of fish kills in annual reports, e.g. in 1975 a complete deoxygenation of the water column was reported on Lough Naglack that caused a large fish kill and in 1977 multiple fish kills were reported in the Erne catchment (on the Kinney Pottle River, Dromore River, Finn River and Peters Lake), but spatial coordinates and annual totals weren't available for these years and therefore were excluded from the overall analysis. Furthermore, the same information was not available for every fish kill event; this included gaps or inaccuracies in data relating to location, cause, species impacted and extent of mortality. Dates of fish kills were estimated when only a month was given and when no month was available, the 1st of June was used as a general indicator of a fish kill in that year. Coordinates were assigned based on best estimates (e.g. to the centre of a named river) where general descriptions were provided.

2.2 Geographical information

Spatial data were available in different formats and were standardised to *Irish Transverse Mercator* (ITM) and analysed and presented using ArcGIS Pro (ESRI, 2023).

Maps were created using additional layers including:

- **County:** Irelands county layer (excluding the six counties within Northern Ireland) (see Appendix I).
- **Inland Fisheries Ireland (IFI) Region**: IFI river basin districts (RBDs), broad geographic delineations. These include the Eastern River Basin District (ERBD), Northwestern River Basin District (NWRBD), Shannon River Basin District (ShRBD), Southeastern River Basin District (SERBD), Southwestern River Basin District (SWRBD) and Western River Basin District (WRBD).

- **Water Framework Directive Catchments**: High level river monitoring and water quality layer consisting of 46 river catchments (see Appendix II). The catchments illustrated here, serve as a guide because they are at a relatively high level (mainly hydrometric area) and therefore, administrative in nature. For example, the "*Liffey and Dublin Bay (09)*" includes the main River Liffey catchment itself, but also numerous smaller, unconnected, coastal streams. Furthermore, the River Shannon (*Hydrometric Areas 25* and *26*) has been divided into 11 smaller catchments (Appendix II).

Where a fish kill impacted both a river and a lake, the data was treated as two separate incidents and assigned separate codes, but such instances were rare. Where a fish kill impacted both a tributary and a main channel, the data was treated as one incident.

All reported coordinates were verified via ArcGIS Pro, and where no coordinates were reported, but an accurate description of the location was available, coordinates were assigned using a best guess approach. In addition, data from a small number of fish kill events occurring within cross-border catchments, including the *Foyle* or *Lough Neagh and Lower Bann* regions, were included and attributed to their nearest county within the Republic of Ireland. Fish kills within Northern Ireland are not included in this report because details were submitted to the relevant authorities in Northern Ireland.

2.3 Species impacted and mortality

Information on the species impacted and the number of mortalities was typically reported to the relevant agencies or gathered by those assessing the fish kills in response to these reports. This was among the least reliable data available because it was dependent on how soon a fish kill event is reported, how quickly it could be responded to, and practical considerations upon visiting the site, including accessibility to the waterbody, visibility and conditions on the day, identification skills and the dispersal or removal of dead fish, etc. The data analysed was based on counts, estimates and descriptive comments (attached to the various reports) that were available throughout the years. In some cases, the exact species was reported, while in others it was more general, for example "stickleback", "unidentified marine species" or "salmonid". This data was collated and summarised into four categories, i.e., salmonid, coarse fish, marine and other fish.

2.4 Causes of fish kills

The cause of most fish kill events was recorded at the time of the incident but in many cases, the reason was unreported because the cause was unknown, or suspected but unconfirmed. In addition, many records were described with varying degrees of detail rather than assigned to convenient and discrete categories. In other instances, more than one cause was described. Therefore, it was challenging to collate this information and some reasonable assumptions were necessary to designate a primary cause based on the information available. Where data were available the specific cause was classified into eight broad categories, namely agriculture, construction, eutrophication, industrial, mining, municipal, other and unknown (Table 2.1).

Table 2.1: Cause categories for reported fish kills (1969 to 2022)

Cause	Category description and examples
Agriculture	Discharge or effluent arising from agricultural activities.
Construction	Attributable to civil works or private construction and may be physical (e.g. landslides caused by altered landscapes during construction of wind farms), chemical (e.g. cements, grouts and other chemicals) or biological (e.g. fungicides) in nature.
Eutrophication	Where algal blooms and excessive plant growth depletes dissolved oxygen in the water. Impacts from other disparate sources (that might not be critical on their own) can be exacerbated, especially during times of high temperature, drought and low flow.
Industrial	Discharge and impacts from industry (e.g. chemical spills and water cooling).
Mining	Arising from present day mining operations, including legacy issues from past mining activities (e.g. Avoca, Co. Wicklow).
Municipal	Discharge or effluent from water/wastewater treatment plants (e.g. chlorine discharge and backwashing) or other municipal facilities.
Other	Wide ranging causes unattributable to other listed sources. (e.g. swimming pool and miscellaneous chemical discharges, domestic discharges, siltation, over-abstraction, diseases, parasites, angling discards, poaching, hydroelectric operations, red tides, predation, low temperatures and various natural causes).
Unknown	No evidence of cause, no cause reported, pollution source dissipated by the time of investigation, or the investigation was inconclusive.

2.5 Temporal trends - temperature and rainfall data

Fish kill reports were aggregated by month and compared to average monthly rainfall and temperature data. The *World Meteorological Organization* recommends that 30-year averages be used to minimise variation and smooth out climate trends for parameters including temperature and rainfall (Curley *et al.*, 2023). The mean monthly temperature and rainfall data was gathered from the *Met Éireann 30 Year Averages,* available from www.met.ie. The mean monthly values were then calculated for both parameters by averaging across all available weather stations nationwide during the 1981 to 2010 period (n=7). Only data from this single period was used to avoid potential climate change considerations.

2.6 Recovery of fish populations after a fish kill - case studies

Electrofishing is the method of choice to obtain a representative sample of the fish assemblage in river sites. Standard methods have been developed by Inland Fisheries Ireland in compliance with the European standards for fish stock assessment in wadeable rivers (CEN, 2003 and 2005). Electrofishing data from four rivers were used to assess fish population recovery after fish kill events. Minimum and population density estimates (where relevant) were used, based on a single pass or all three-passes of an area delimited electrofishing survey. *Minimum* density was calculated by dividing the number of fish captured by the surface area (length of site multiplied by wetted width) sampled and *population* density, based on three pass depletion electrofishing, was calculated as per Zippin’s maximum likelihood method (Zippin, 1956).

An ecological classification tool for fish in rivers (Fisheries Classification Scheme 2 (FCS2-Ireland)) (SNIFFER, 2011) was used to assign ecological status to fish in rivers (see section 3.6).

3. Results

3.1 Historical and temporal trends

A total of 2107 fish kills were reported between 1969 and 2022 (Table 3.1). The quality of reported information varied over the period, with some years lacking information (e.g. 1975) and others with totals but no other information available (e.g. 1980 to 1982 and 1996 to 1999).

Table 3.1: Reported fish kills by decade and year (1969 to 2022, N=2107). (Note: records started in 1969, fish kill records for 1975 to 1979 were excluded from this analysis as total number per year was unavailable).

1960s	no.	1970s	no.	1980s	no.	1990s	no.	2000s	no.	2010s	no.	2020s	no.
1969	22	1970	18	1980	30	1990	52	2000	67	2010	35	2020	15
		1971	27	1981	41	1991	60	2001	29	2011	27	2021	43
		1972	26	1982	71	1992	51	2002	55	2012	10	2022	25
		1973	28	1983	87	1993	33	2003	72	2013	52		
		1974	16	1984	114	1994	32	2004	34	2014	22		
				1985	36	1995	88	2005	46	2015	23		
				1986	66	1996	52	2006	27	2016	31		
				1987	121	1997	42	2007	18	2017	14		
				1988	55	1998	43	2008	27	2018	40		
				1989	112	1999	39	2009	13	2019	20		

Three years in the 1980s (1984 (n=114), 1987 (n=121), and 1989 (n=112)) were reported as the worst year for fish kills in Ireland during the study period (Figure 3.1 and Table 3.1). Based on the five-year moving average four phases of fish kills were apparent in Ireland, Phase 1-1969-1974, Phase 2-1980 to 1993, Phase 3 - 1994 to 2009 and Phase 4 - 2010 to present. Since 1992, there has been a downward trend (based on a five-year moving average) in the number of fish kills reported across Ireland (Figure 3.1). From about 2008 the five-year moving average has been relatively stable; however, a small increase is evident after 2012. Despite this positive overall downward trend, there have been several years with relatively high numbers of fish kills during the last decade, e.g. 2013 (n=52), 2018 (n = 40) and 2021 (n=43).

Many peaks in fish kills, e.g. 1989 (n=112), 1995 (n=88), 2013 (n=52) and 2018 (n=40), coincided with heatwave and drought events (Figure 3.1). Official heatwave events (i.e. five consecutive days with a maximum temperature more than 25°C) were recorded in summers of 1976, 1983, 1989, 1995, 2003, 2006, 2013, 2018 and 2022 (e.g. Met Éireann, 2018a). Meteorological droughts (absolute drought, partial drought or dry spell) also occurred during many of these summers (e.g. 1989, 1995 and 2018) (e.g. Met Éireann, 2018b; MacCarthaigh, 1996; Noone *et al*., 2017). In contrast, there was a relatively low number of fish kills (n=10) reported in 2012 when Ireland experienced one of the wettest summers on record (Figure 3.1).

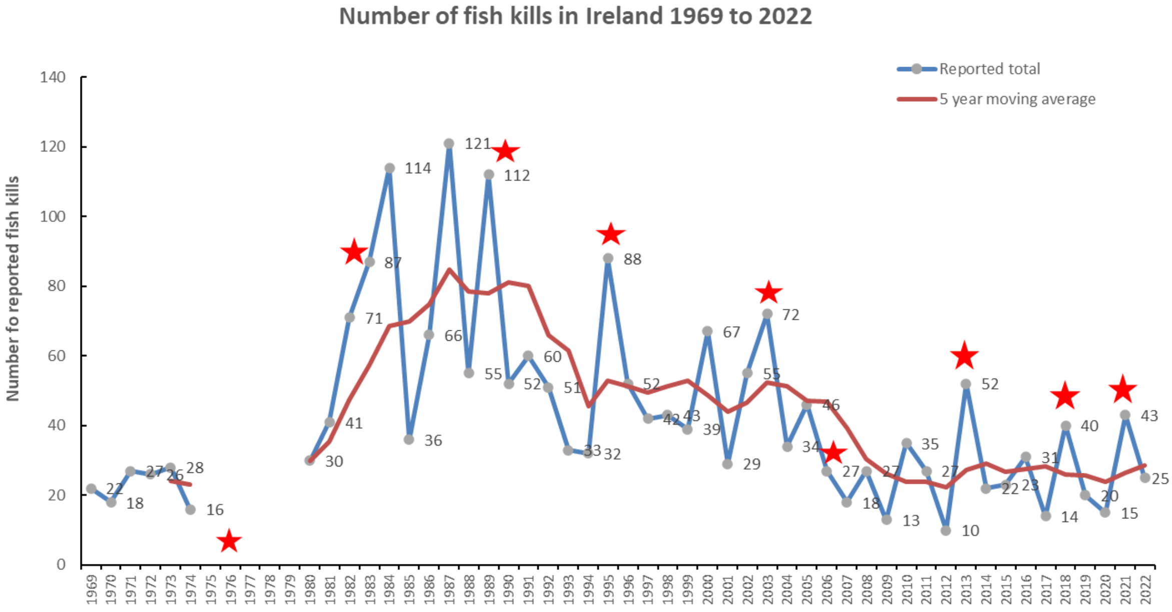


Figure 3.1. Number of reported fish kills in Ireland (1969 to 2022, n=2107). No data is available from 1975 to 1979. A red star denotes an official summer heatwave event (five consecutive days with a maximum temperature in excess of 25°C).

Fish kill events were also most prevalent during the warmest and driest months (May to September), with the lowest instances occurring during the coldest and wettest months (November to February) (Figure 3.2).

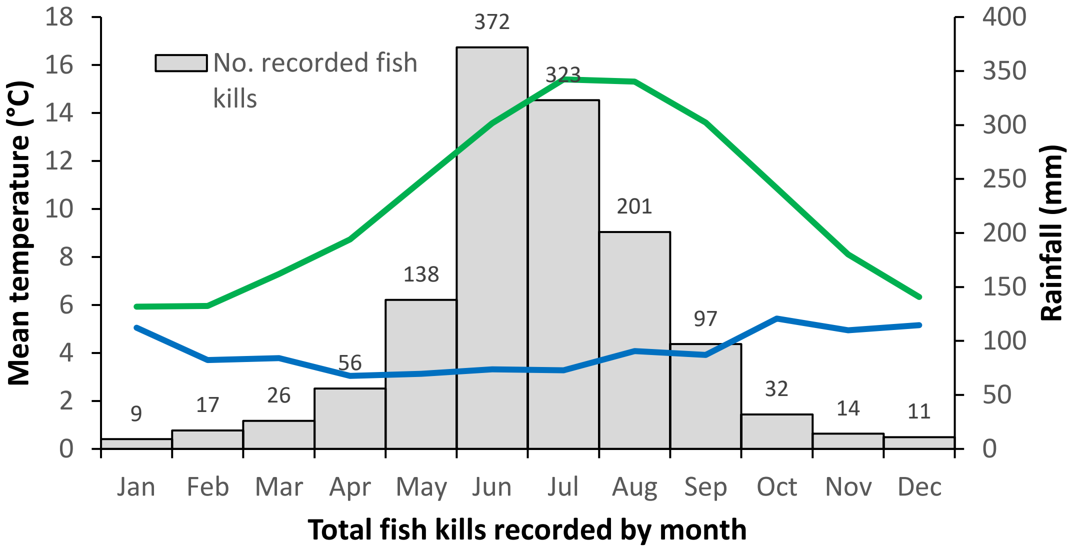


Figure 3.2. Total number of fish kills during each month and 30-year average monthly air temperature (green) and rainfall (blue) values (Met Eireann 1981 to 2010) (n=1296).

3.2 Spatial trends

Spatial data (approximate coordinates) was available for 1738 fish kill events recorded across the entire country from 1969 to 2022 (Figure 3.3). Fish kill events were less frequent in the west and northwest. Other areas were impacted more heavily, with hotspots particularly visible in the east, south and the north midlands (Figure 3.3).

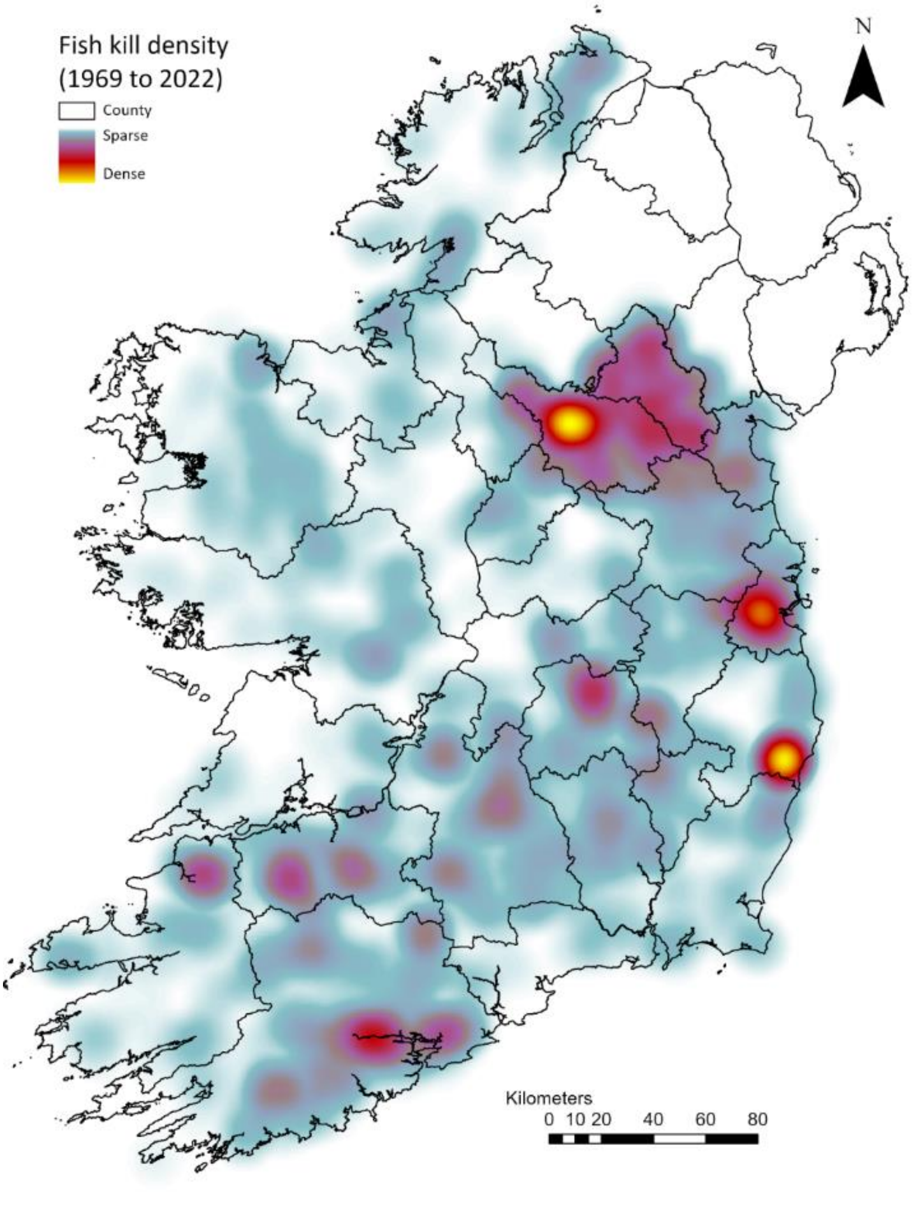


Figure 3.3. Fish kill report density heat map by county from 1969 to 2021. All fish kills events are shown where spatial data was available (n=1738). A higher density indicates more fish kill events occurring within a set distance from each other (radius width set at 25 km). Appendix I shows a map and key to the names of Ireland's counties.

3.2.1 Fish kills by county and decade

Fish kills occurred in every county across the Republic of Ireland between 1969 and 2022 with high concentrations near areas with heavy agricultural activity including (e.g. counties Cork, Cavan, Monaghan) and large urban centres (e.g. Co. Dublin) (Figure 3.6 and Table 3.2). The lowest reported fish kills were recorded in counties Roscommon and Westmeath (Table 3.2).

Table 3.2: Number of fish kills by county and percentage of total (1969 to 2022) (only includes records where spatial data was available (n=1738).

County	No.	%	County	No.	%	County	No.	%
Co. Cork	242	13.9	Co. Galway	64	3.6	Co. Offaly	27	1.6
Co. Cavan	213	12.3	Co. Laois	63	3.6	Co. Leitrim	22	1.3
Co. Monaghan	130	7.6	Co. Donegal	61	3.5	Co. Carlow	21	1.2
Co. Tipperary	125	7.2	Co. Mayo	59	3.4	Co. Clare	20	1.2
Co. Limerick	92	5.3	Co. Kilkenny	56	3.2	Co. Longford	20	1.2
Co. Dublin	83	4.8	Co. Kildare	55	3.2	Co. Waterford	18	1.0
Co. Wicklow	82	4.7	Co. Wexford	47	2.7	Co. Roscommon	13	0.7
Co. Kerry	78	4.5	Co. Louth	38	2.2	Co. Westmeath	13	0.7
Co. Meath	68	3.9	Co. Sligo	28	1.6			

In the 1970s the highest number of fish kills was reported from Co. Tipperary, while in the 1980s this was Co. Cork (Figure 3.6). Co. Cavan followed closely by Co. Cork had the highest reported fish kills in the 1990s. In 2000's Co. Cavan and Co. Wicklow had the highest reported number of incidences, while Co. Cork had the highest reported again in the 2010s (Figure 3.6). Since 2020 (2020 to 2022), the highest reported number have been in Co. Cavan followed closely by Co. Cork (Figure 3.6).

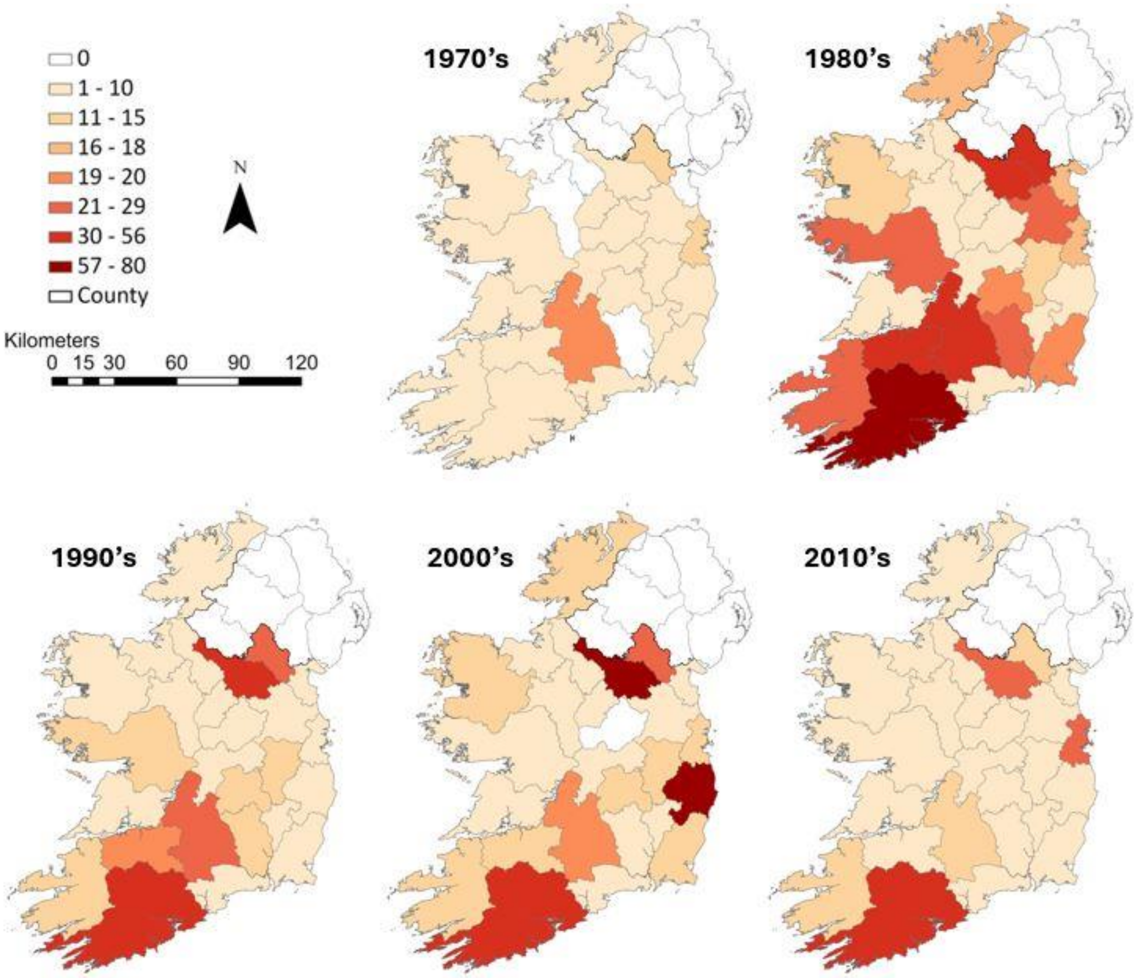


Figure 3.4. Fish kill reports by decade (1970s to 2010s) per county where spatial data was available. (1970s, n=124; 1980s, n=588; 1990s, n=293; 2000s n=382 and 2010s, n=250). A key to the names of Ireland's counties is provided in Appendix 1.

3.2.2 Fish kills by catchment

Since 1969, the highest number of fish kill reports have been reported from the Erne Catchment (*Hydrometric Area 36*) *with a total of* 242 reported fish kills (Figure 3.5). The next highest number came from the Lee, Cork Harbour and Youghal Bay (*Hydrometric Area 19*) (117 reports) and Barrow *(Hydrometric Area 14)* with 106 reports, followed by the Suir (*Hydrometric Area 16*) with 100 reports and the Liffey and Dublin Bay (*Hydrometric Area 09*) with 97 fish kills reported. In general, the least impacted catchments were located towards the west of the country (Figure 3.5).

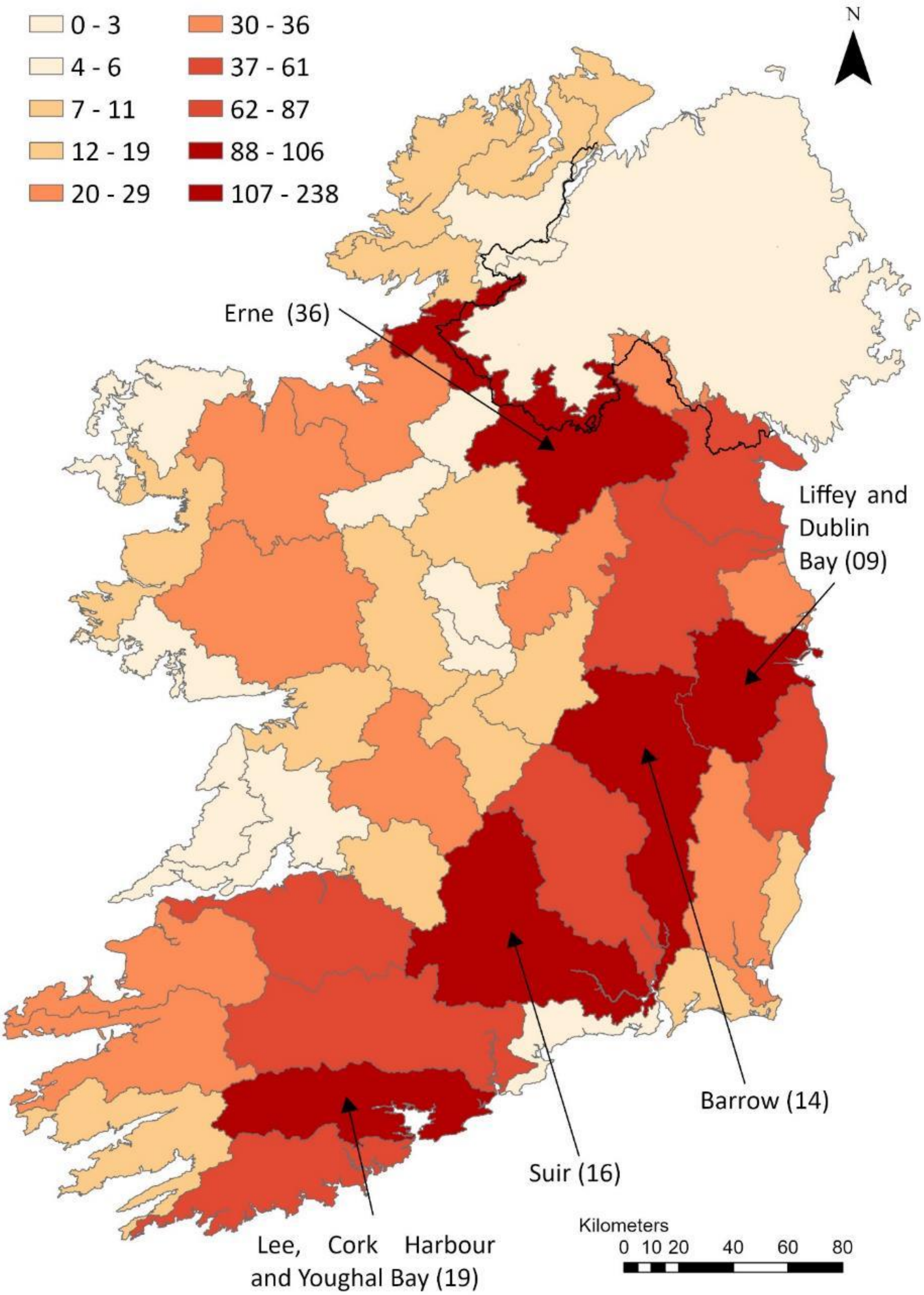


Figure 3.5. Fish kill reports by catchment, 1969 to 2022. A full list of catchment names is provided in Appendix II.

3.2.3 Fish kills by IFI river basin district and river sub-basin

The ERBD had the highest number of fish kill reports (n=401) during the study period. This was followed by SERBD (n=323), NWRBD (n=310), ShRBD (n=287), SWRBD (n=286) and WRBD (n=131).

To investigate where Ireland's historical fish kill hotspots existed within each IFI RBD it was necessary to use a higher resolution map. Each of the six IFI RBDs were divided into their smaller component sub-basin waterbodies (Figures 3.6 to 3.11).

The sub-basin waterbodies experiencing the most fish kills since 1969 were in the ERBD, NWRBD, ShRBD and SERBD (Table 3.3). Two waterbodies in the ERBD (Avoca_020 and Avoca_010) had 55 fish kill reports. The Erne_080, Feale_090, Barrow_140 and Cavan_010 were also among the top six waterbodies with the highest number of fish kill reports (Table 3.3). Some of the most highly impacted waterbodies within each river basin district are highlighted below, showing records of cause and year of impact. Fish kill causes are dealt with in more detail later in Section 3.3.

Table 3.3: River sub-basin waterbodies with the highest number (top six) of fish kill reports 1969 to 2022.

River sub-basin	River	RBD	No.	Year of event(s)
Avoca_020	Avoca	ERBD	38	2002, 2003, 2004, 2005
Erne_080	Erne	NWRBD	38	1973, 1987, 1988, 1990, 1991, 1992, 1993, 1994, 1995, 2000, 2001, 2002, 2004, 2005, 2013
Feale_090	Feale	ShRBD	18	1973, 1984, 1986, 1993
Avoca_010	Avoca	ERBD	17	2003, 2004, 2006, 2007, 2011, 2014
Barrow_140	Barrow	SERBD	14	1985, 1986, 1991, 1992, 2004, 2008, 2010
Cavan_010	Erne	NWRBD	14	1983, 1984, 1986, 1993, 2007, 2008, 2009, 2014, 2018

Eastern River Basin District (ERBD)

Details of 401 fish kills were available from the ERBD during the study period and the number, year and cause of fish kills in waterbodies with high levels of fish kill reporting are summarised in Table 3.4. Two of the most impacted waterbodies within this region (and within any region throughout the country) were the Avoca_010 and Avoca_020, both of which experienced fish kill incidents in the early 2000s due to acid mine drainage from the abandoned mines in the Avoca Catchment, Co. Wicklow (Figure 3.6). Local IFI staff made a concerted effort to document fish kills in these sub-basins during this time (*pers. comm.*, D. Byrne, ERBD). Fish kills around the greater Dublin City area (Liffey_170, Tolka_050 and Dodder_050) were mainly attributed to municipal, construction and industrial activities, whereas agriculture and eutrophication were the assigned causes outside of Dublin (e.g. County_Water_010). The fish kill reports within the Proules_030 waterbody were mainly due to mortalities within small lakes, arising from a range of different causes including eutrophication, municipal and industrial discharge. All reports on the Blackwater (Kells)_080 were due to incidents that took place on Lough Ramor, the latest of which was recorded in 2017.

Table 3.4: Fish kill hotspots by waterbody within the ERBD (1969 to 2022) (note: there may have been multiple incidents occurring on any given year).

River sub-basin name	River	No.	Main causes	Year of event(s)
Avoca_020	Avoca	38	Mining, Municipal, Other	2002, 2003, 2004, 2005
Avoca_010	Avoca	17	Mining, Unknown	2003, 2004, 2006, 2007, 2011, 2014
Dodder_050	Liffey	14	Industrial, Municipal, Eutrophication, Other, Unknown	1970, 1973, 1975, 1987, 1988, 2003, 2009, 2015, 2019, 2022
Proules_030	Glyde	10	Eutrophication, Industrial, Municipal, Other, Unknown	1971, 1975, 1983, 1990, 1993, 1995, 2005, 2013, 2015
Tolka_050	Tolka	9	Construction, Industrial, Other, Unknown	1983, 1989, 1992, 2000, 2010, 2013, 2014
County Water_010	Fane	8	Agriculture, Unknown	1984, 1987, 2000, 2001, 2002, 2003, 2013
Blackwater (Kells)_020	Boyne	7	Industrial, Municipal, Unknown	1984, 1985, 1986, 2001, 2014, 2016
Liffey_170	Liffey	7	Construction, Municipal, Unknown	1972, 1995, 2003, 2007, 2016, 2022
Dee_060	Dee	6	Agriculture, Eutrophication, Unknown	1988, 1995, 2004, 2008, 2012, 2014
Blackwater (Kells)_080	Boyne	5	Unknown, Other	1971, 2008, 2012, 2016, 2017

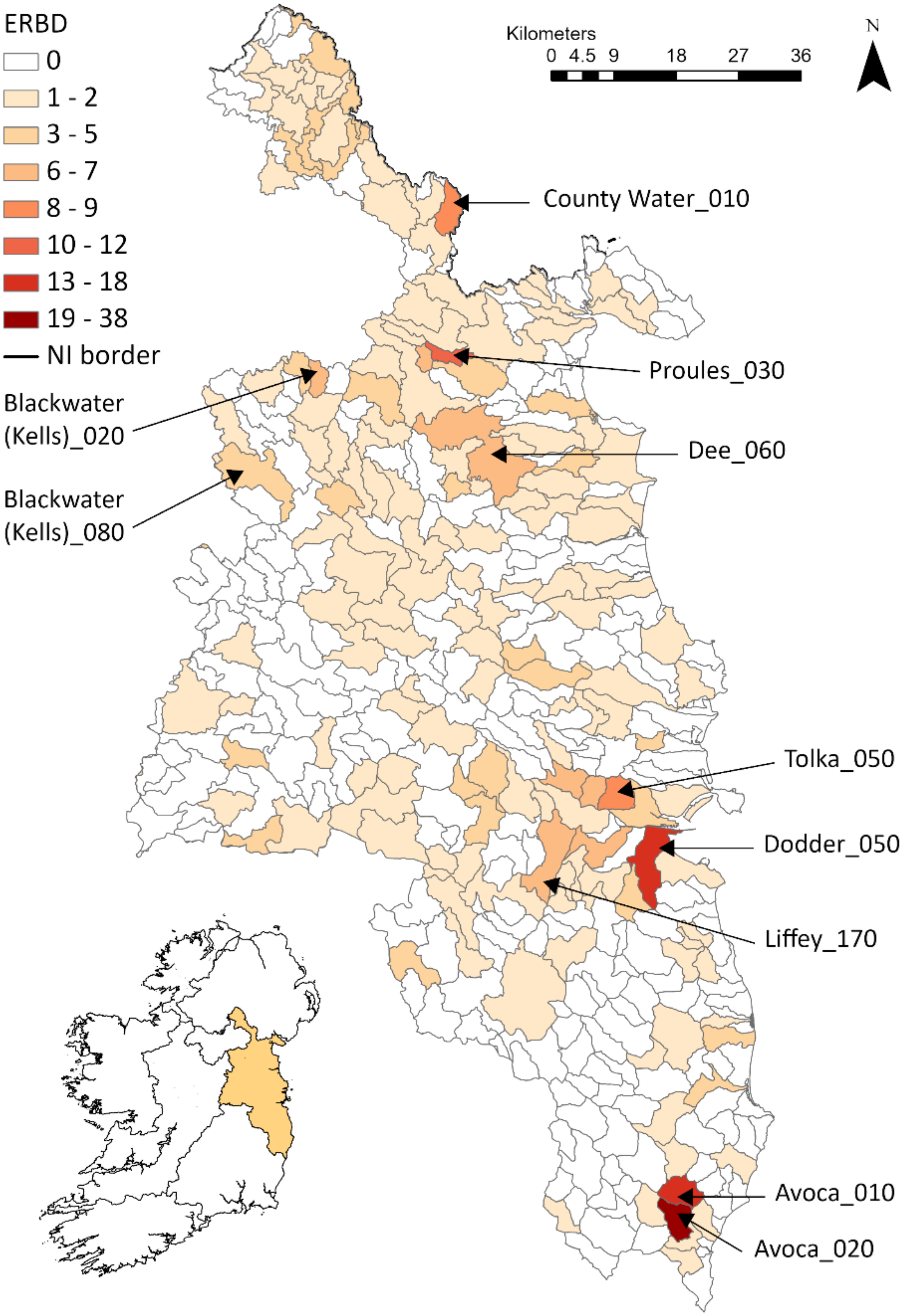


Figure 3.6. Fish kills incidences by river sub-basin waterbody and historical hotspots within the ERBD, 1969 to 2022 (examples of hotspots are highlighted with their sub-basin waterbody names).

Southeastern River Basin District (SERBD)

Spatial data for 323 fish kill incidents was available from waterbodies within the SERBD since 1969 (Table 3.5 and Figure 3.7). Many of the most highly impacted waterbodies were located within the Barrow Catchment (Figure 3.7 and Table 3.5). The Barrow_140 sub-basin followed by the Owenass_020 had the highest number of reported fish kills (Table 3.5).

Most fish kills in the Barrow_170 were reported in the early 1970's and were caused by effluent released from sugar beet factories. The latest fish kill in the same waterbody happened in 2019 after an incident where fertiliser was released into the river. On the northwestern side of the River Barrow catchment, on the Owenass River (Owenass_020), municipal waste discharges (sewage) caused a high number of incidents. Most of these were in the early 1970s, but a few occurred in the 2000s, with the latest incident as recently as 2008. The Duiske River experienced eight fish kills, one of the most recent occurred in 2021 and was caused by silt release from construction works. The Ara River, a tributary of the River Suir, also experienced fish kills due to discharges in the 1980's including creamery effluent on two occasions.

Table 3.5: Fish kill hotspots by river sub-basin waterbody within the SERBD (1969 to 2022) (note: there may have been multiple incidents occurring on any given year).

River sub-basin name	River	No.	Main causes	Year of event(s)
Barrow_140	Barrow	14	Agriculture, Eutrophication, Industrial, Unknown	1985, 1986, 1991, 1992, 2004, 2008, 2010
Owenass_020	Barrow	10	Agriculture, Municipal	1969, 1970, 1971, 1972, 1973, 1974, 1987, 2000, 2006, 2008
Ara_020	Suir	8	Agriculture, Industrial, Municipal, Unknown	1984, 1986, 1987, 1994, 2000, 2007, 2012
Barrow_170	Barrow	8	Industrial, Other, Unknown	1969, 1970, 1971, 1972, 1973, 1974, 1984, 2019
Duiske_020	Barrow	8	Construction, Industrial, Other, Unknown	1984, 1985, 1987, 2000, 2018, 2021

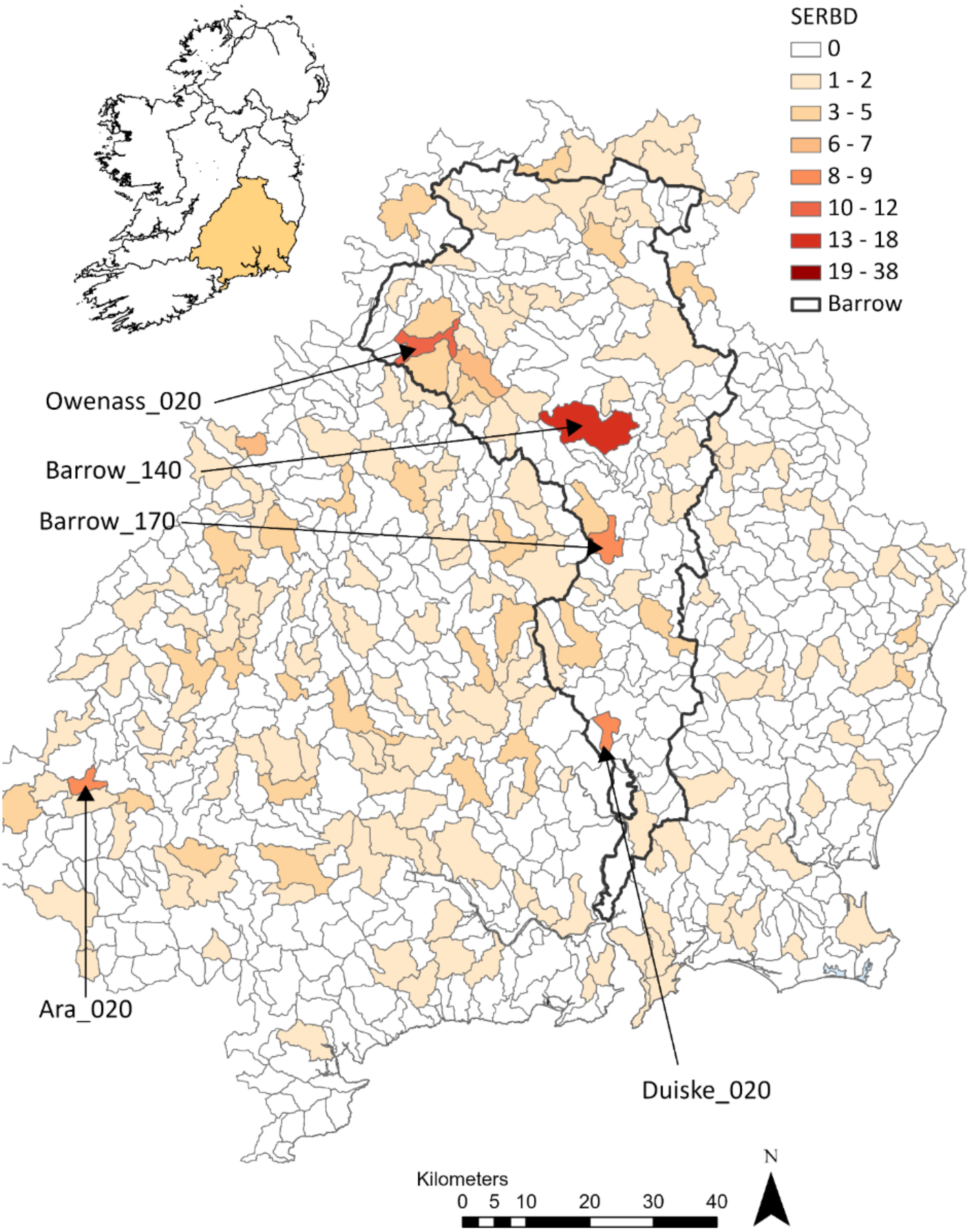


Figure 3.7. Fish kills incidences by sub-catchment and historical hotspots within the SERBD, 1969 to 2022 (examples of hotspots are shown with their waterbody names). The Barrow Catchment is highlighted with a black line.

Northwestern River Basin District (NWRBD)

The NWRBD was the third most impacted region during the reported period with details available for 310 fish kills reported. Although there were numerous fish kill events reported in Donegal, most incidents occurred in counties Cavan and Monaghan (Figure 3.8).

The most heavily impacted river sub-basin waterbody was the Erne_080 with 38 fish kills reported, occurring regularly since the early 1970s, the latest of which was in 2013 (Table 3.6). Many of these were reported from various locations surrounding Lough Oughter and were due to eutrophication.

Just east of this waterbody, municipal activities were the cause of several events in the Cavan_010 waterbody. Other frequently impacted waterbodies included the Annalee_020, Erne_060 and Woodford (Cavan)_010 with eutrophication again the cause of many incidents.

Table 3.6: Fish kill hotspots within the NWRBD (1969 to 2022) (note: there may have been multiple incidents occurring on any given year).

River sub-basin name	River	No.	Main causes	Year of event(s)
Erne_080	Erne	38	Agriculture, Eutrophication, Unknown	1973, 1987, 1988, 1990, 1991, 1992, 1993, 1994, 1995, 2000, 2001, 2002, 2004, 2005, 2013
Cavan_010	Erne	14	Agriculture, Eutrophication, Municipal, Unknown	1983, 1984, 1986, 1993, 2007, 2008, 2009, 2014, 2018
Annalee_020	Erne	12	Eutrophication, Other, Unknown	1986, 1991, 1994, 1995, 2000, 2002, 2006, 2013, 2014, 2015, 2016
Erne_060	Erne	10	Agriculture, Eutrophication, Unknown	1972, 1986, 1989, 1990, 1993, 1995, 2000, 2002
Lackey River_010	Erne	9	Agriculture, Unknown	1984, 1987, 1988, 1991, 2001, 2017, 2019
Woodford (Cavan)_010	Erne	8	Agriculture, Eutrophication, Unknown	1969, 1984, 1987, 1989, 1993, 1994, 2002
Donagh_030	Donagh	7	Agriculture, Eutrophication, Industrial, Other, Unknown	1969, 1970, 1971, 1972, 1973, 1974, 1977, 2000, 2008, 2018, 2020
Major Lough Strean_010	Erne	7	Agriculture, Unknown	1985, 1986, 1987, 1990, 2009, 2013
Eske_020	Eske	6	Agriculture, Eutrophication, Municipal, Other, Unknown	2000, 2004, 2005, 2011, 2017

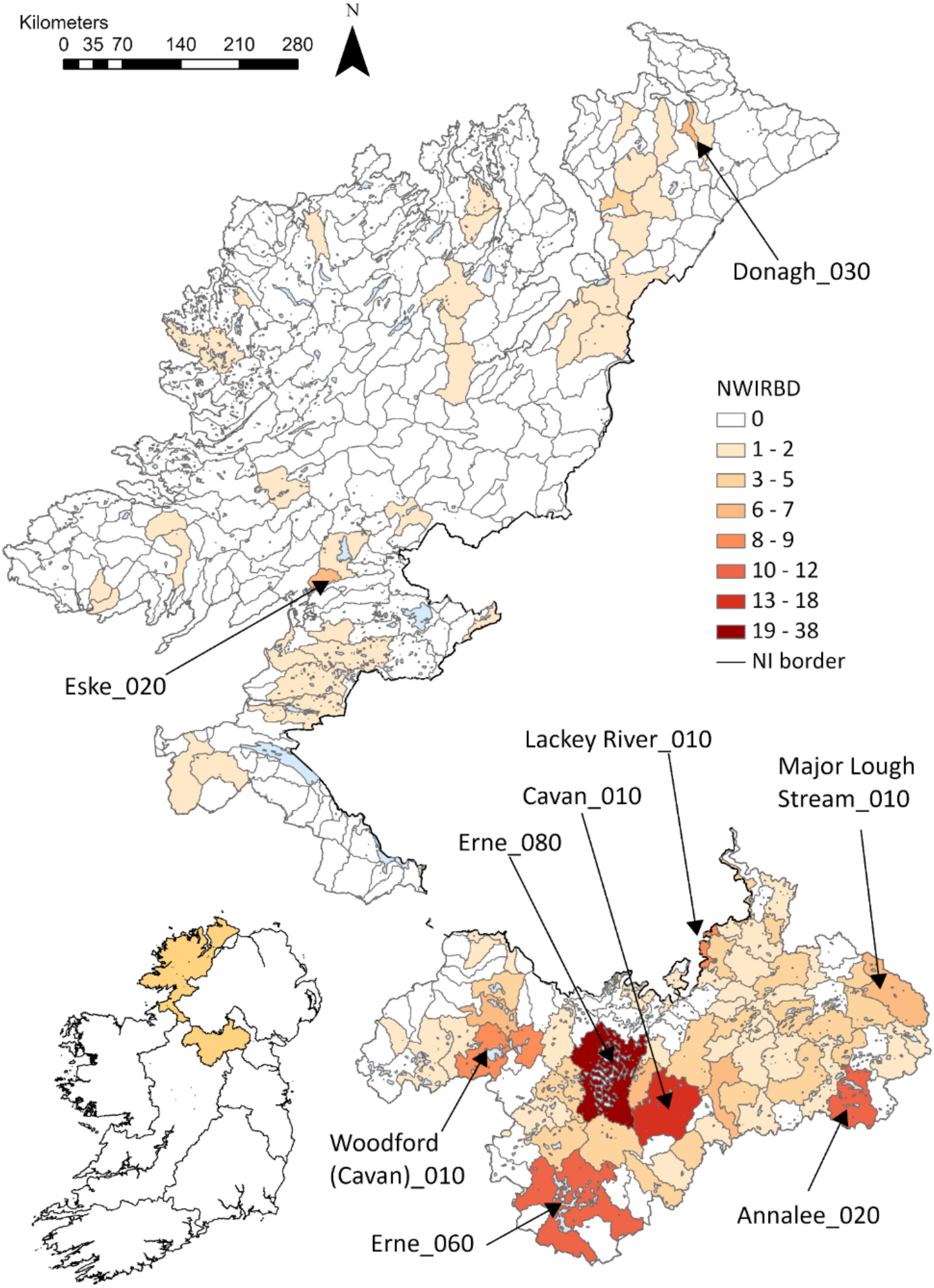


Figure 3.8. Fish kills incidences by sub-catchment and historical hotspots within the NWRBD, 1969 to 2022 (examples of hotspots are shown with their waterbody names).

Shannon River Basin District (ShRBD)

Spatial and other data were available for 287 fish kills in the ShRBD since 1969 (Figure 3.9). There were a few waterbodies within the Shannon River Basin District (ShRBD) where the total number of reported fish kills was relatively high when compared to other RBDs (Table 3.7).

The Feale_090 was the most impacted waterbody within this region, with 18 fish kills; 15 of these were reported in 1986 and were attributed to industrial activities in one location. Creamery effluent was the suspected cause. The Inny_040 experienced eight fish kills, in or close to Lough Sheelin, with the majority of these due to a combination of eutrophication and agriculture. In the 1980's two of these were on the Mountnugent River and were caused by silage effluent and pig slurry. The most recent fish kill in this waterbody was recorded in 2022. The Tullamore_040 waterbody experienced six fish kills, once each year between 1969 and 1974, with industrial activities the cause reported. No fish kills, however, have been reported on that waterbody since then. Fish kills on the Nenagh_060 waterbody also occurred once per year between 1969 and 1974, and again due to industrial activities. Other areas of note included the Deel Newcastlewest_080 (caused by agriculture, eutrophication and industrial sources) and Shannon (Lower)_060 to the northeast of Limerick City, where municipal causes featured quite prominently, while in the Arra_010 agriculture was the predominant source.

Table 3.7: Fish kill hotspots within the ShRBD (1969 to 2022) (note: there may have been multiple incidents occurring on any given year).

River sub-basin name	River	No.	Main causes	Year of event(s)
Feale_090	Feale	18	Industrial, Unknown	1973, 1984, 1986, 1993
Nenagh_060	Shannon	9	Construction, Industrial, Unknown	1969, 1970, 1971, 1972, 1973, 1974, 1984, 1990, 2005
Arra_010	Shannon	8	Agriculture, Eutrophication, Industrial	1986, 1989, 1995, 2000, 2003, 2010
Inny_040	Shannon	8	Agriculture, Eutrophication, Unknown	1972, 1986, 1987, 1988, 1989, 2000, 2022
Deel (Newcastlewest)_080	Shannon	7	Agriculture, Eutrophication, Industrial, Other, Unknown	1983, 1984, 1986, 1987, 1991, 1994
Shannon (Lower)_060	Shannon	7	Industrial, Municipal, Other, Unknown	1984, 1988, 1990, 1994, 2005
Tullamore_040	Shannon	6	Industrial	1969, 1970, 1971, 1972, 1973, 1974
Derrymullan Stream_020	Shannon	4	Industrial, Unknown	1984, 1987

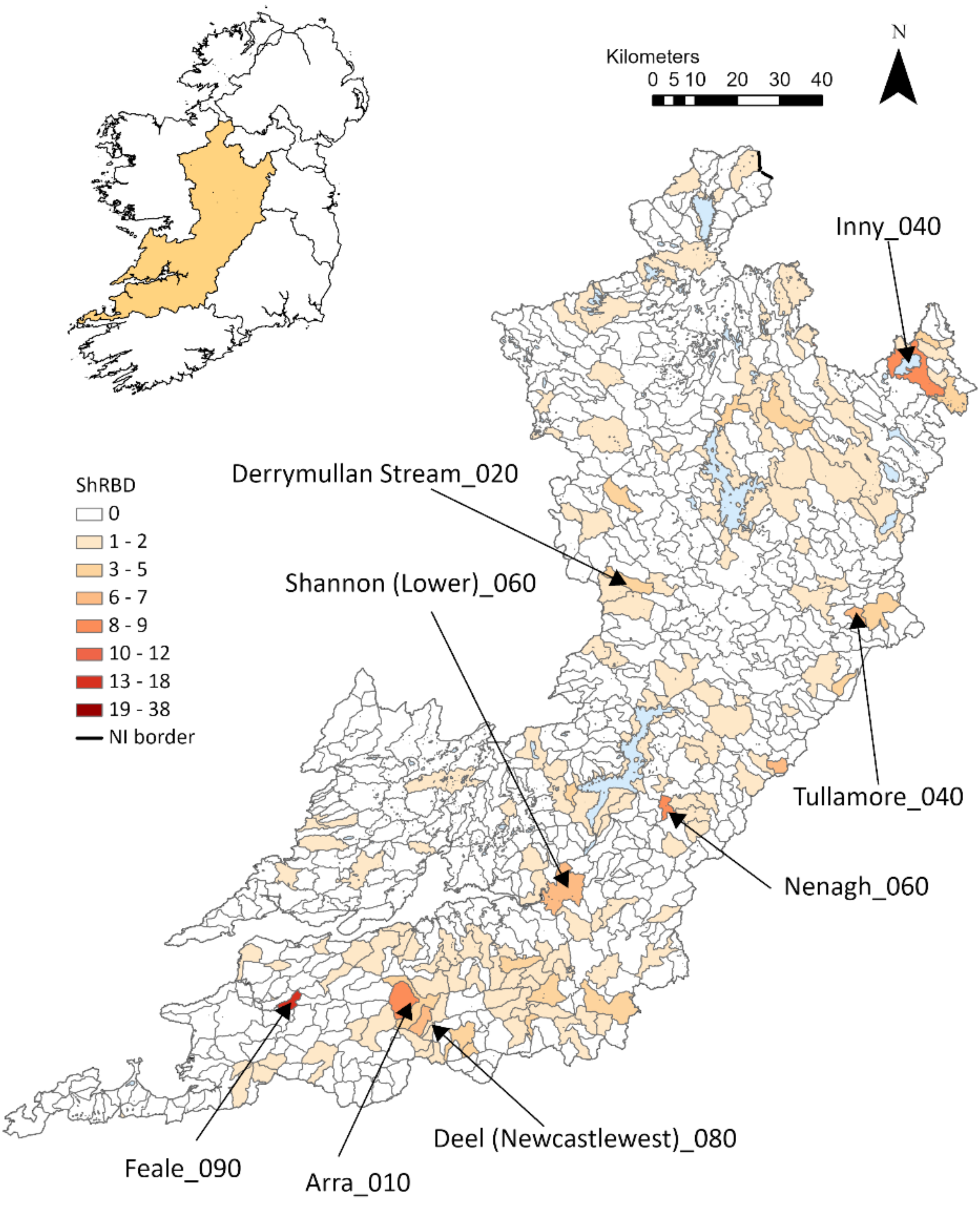


Figure 3.9. Fish kills incidences by river sub-basin waterbody and historical hotspots within the ShRBD, 1969 to 2022 (examples of hotspots are shown with their river sub-basin waterbody names).

Southwestern River Basin District (SWRBD)

Detailed information was available for 286 fish kill incidents reported across the SWRBD, but the south and southeastern portion experienced particularly high numbers (Figure 3.10). Many of these were recorded along the River Lee catchment (Figure 3.10 and Table 3.8). Agriculture was the most reported cause for this region, although there were a lot of unknown cause reports and missing data (Table 3.8).

The Gradoge_010 waterbody on the Munster Blackwater was among the worst impacted waterbodies within this region, with 11 fish kill incidents reported resulting from agriculture, industrial and municipal sources; the latest was recorded in 2021. Closer to Cork City, the Curragheen (Cork City) _010 and Lee (Cork)_80 sub-basins have also been impacted in most decades, mainly due to industrial, municipal and unknown pressures; the latest fish kills being reported in 2021 on both waterbodies. Elsewhere, the Bandon_030 waterbody has had nine reported fish kills with a combination of agriculture, municipal and eutrophication causes contributing to most of the known recorded incidents.

Table 3.8: Fish kill hotspots by river sub-basin waterbody within the SWRBD (1969 to 2022) (note: there may have been multiple incidents occurring on any given year).

River sub-basin name	River	No.	Main causes	Year of event(s)
Gradoge_010	Blackwater (Munster)	11	Agriculture, Industrial, Municipal, Unknown	1987, 1990, 1991, 1995, 2001, 2008, 2005, 2021
Bandon_030	Bandon	9	Agriculture, Eutrophication, Municipal, Other, Unknown	1985, 1989, 1990, 1993, 2003, 2007
Curragheen (Cork City)_010	Curragheen (Cork City)	8	Industrial, Municipal, Other, Unknown	1972, 1984, 1995, 2011, 2016, 2018, 2021
Lee (Cork)_080	Lee (Cork)	7	Eutrophication, Other, Unknown	1984, 1988, 1991, 2010, 2013, 2017, 2022
Milltown (Kerry)_030	Monacappa	6	Industrial, Municipal. Unknown	1992, 1993, 1994, 2007, 2008, 2014
Owenacurra_040	Owenacurra	6	Agriculture, Eutrophication, Unknown	1983, 1984, 1995, 2006,
Womanagh_010	Womanagh	6	Agriculture, Industrial, Unknown	1984, 2000, 2012, 2018
Allow_060	Blackwater (Munster)	4	Agriculture, Industrial	1972, 1991, 1992
Blackwater (Munster)_090	Blackwater (Munster)	3	Agriculture, Eutrophication	1995, 2001, 2008

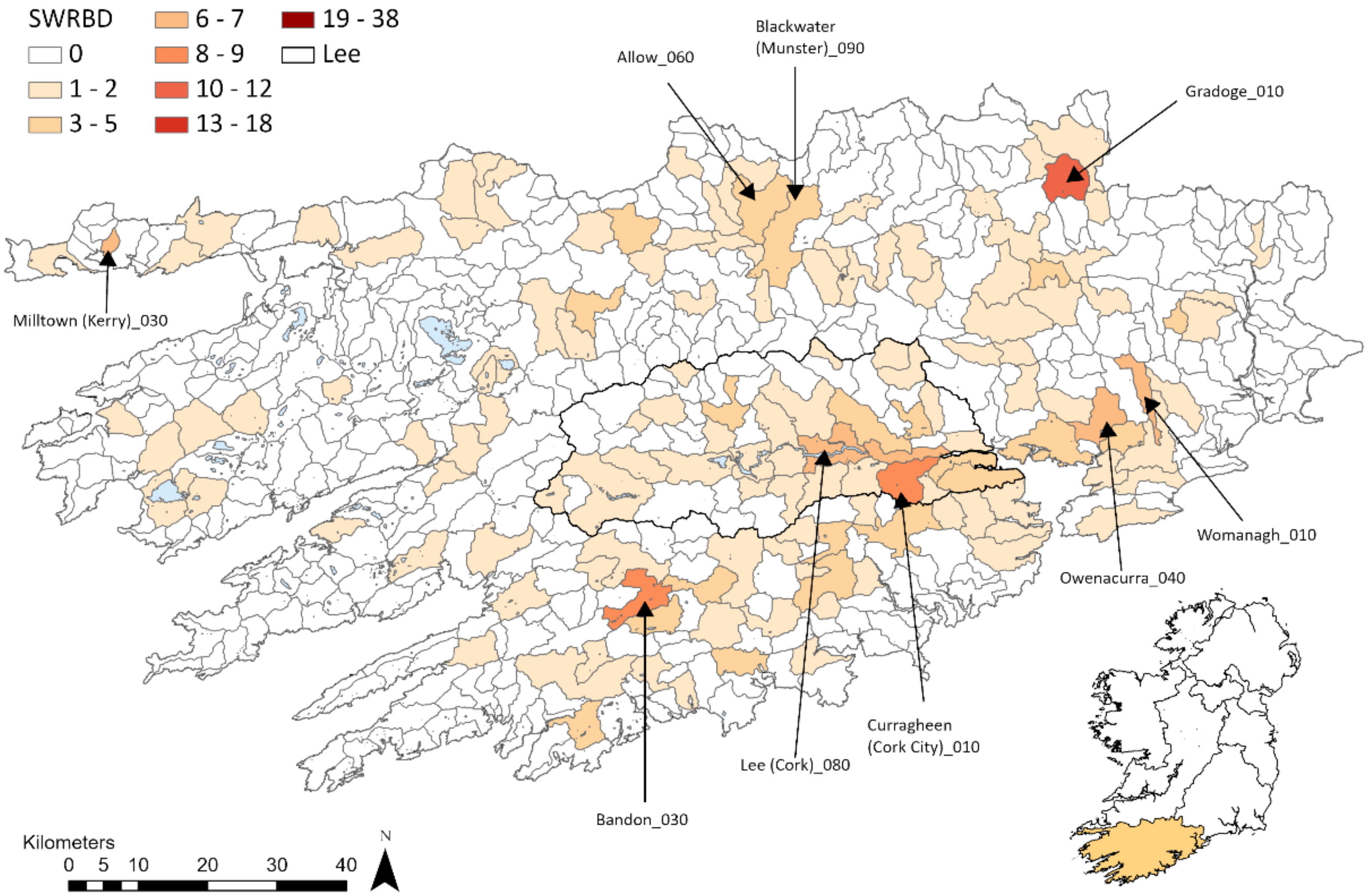


Figure 3.10. Fish kills incidences by sub-catchment and historical hotspots within the SWRBD, 1969 to 2022 (examples of hotspots are shown with their waterbody names). The Lee Catchment is highlighted with a black line.

Western River Basin District (WRBD)

Spatial and other data were available for 131 fish kills events reported across the WRBD (Table 3.9), with most of the more heavily impacted waterbodies on the eastern side of the three major lakes (Loughs Conn, Mask and Corrib) (Figure 3.11).

The most heavily impacted waterbody was the Kilcolgan_010 with a wide range of causes including agriculture, eutrophication and municipal activities recorded. The latest event on this waterbody was in 2021.

Surrounding Lough Carra, the Aghinish_010 waterbody suffered impacts from both eutrophication and agriculture, with the latest occurring again in 2021.

Agricultural activities caused several fish kills in the Clare (Galway)_020, Cloonaghmore_060 and Robe_020 waterbodies, while eutrophication was reported as an issue on the Moy_100 and industrial activities on the Nanny (Tuam)_030.

Table 3.9: Fish kill hotspots within the WRBD (1969 to 2022) (note: there may have been multiple incidents occurring on any given year).

River sub-basin name	River	No.	Main causes	Year of event(s)
Cloonaghmore_060	Cloonaghmore	7	Agriculture, Unknown	1969, 1970, 1971, 1972, 1973, 1974, 2013
Kilcolgan_010	Kilcolgan	6	Agriculture, Eutrophication, Municipal, Other, Unknown	1987, 1992, 1994, 2013, 2016, 2021
Grange (Sligo)_010	Grange (Sligo)	5	Municipal, Other	2006, 2007, 2011, 2019
Clare (Galway)_020	Corrib	4	Agriculture, Unknown	1983, 1984, 2002, 2016
Moy_100	Moy (Mayo)	4	Eutrophication, Unknown	1984, 2003, 2005, 2009
Aghinish_010	Corrib	3	Agriculture, Eutrophication	1993, 2008, 2021
Gweestion_010	Moy (Mayo)	3	Municipal, Other	1987, 1993
Nanny (Tuam)_030	Corrib	3	Industrial, Unknown	1971, 1984, 1992
Robe_020	Corrib	3	Agriculture, Municipal	2018

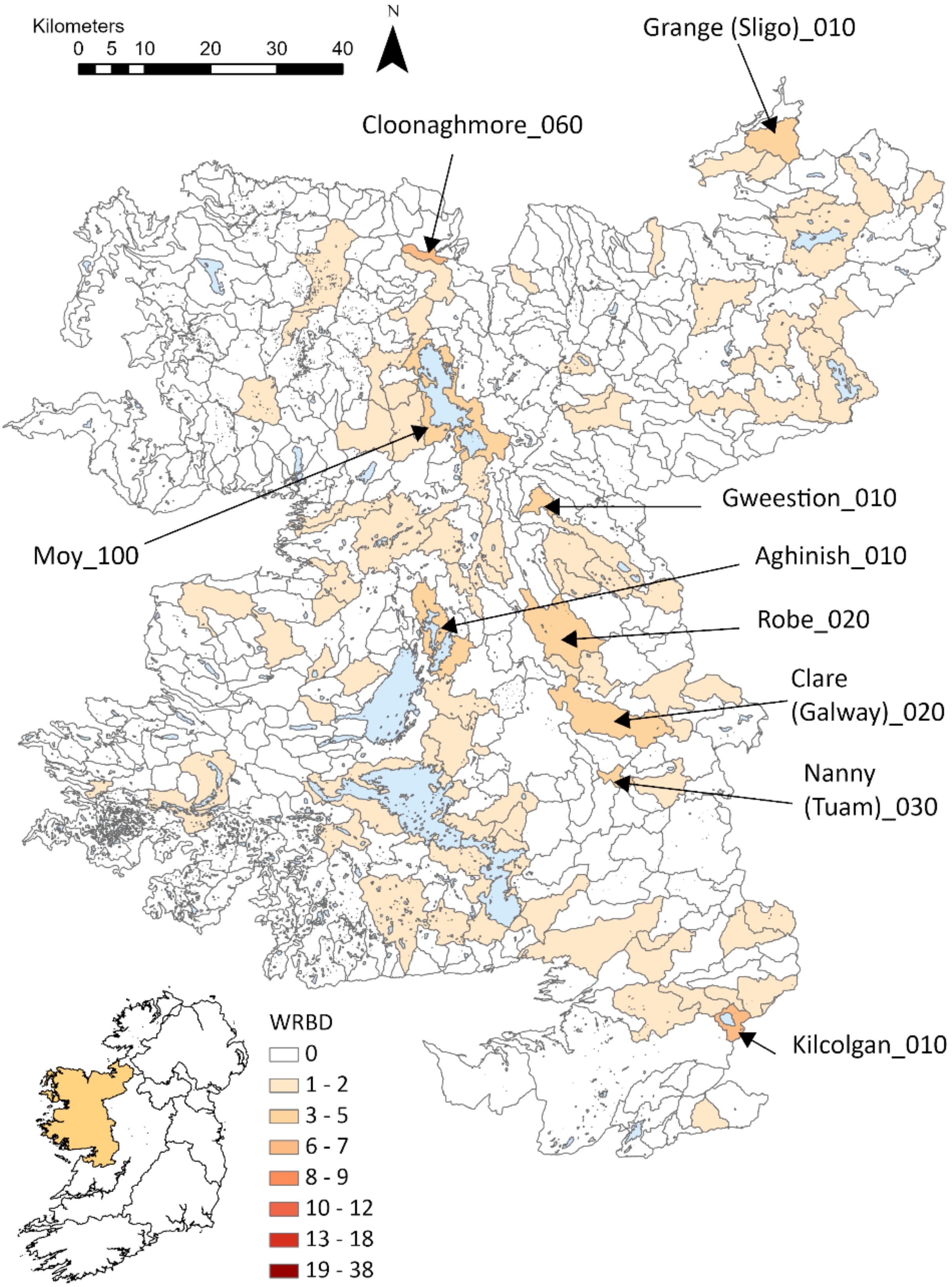


Figure 3.11. Fish kills incidences by sub-catchment and historical hotspots within the WRBD, 1969 to 2022 (examples of hotspots are shown with their waterbody names).

3.3 Fish kills by waterbody type

Information on waterbody type was available for 1,738 fish kill events, comprising five different types, rivers, lakes, artificial waterbodies (e.g. ponds and canals), transitional waterbody (e.g. estuaries and lagoons) and coastal waterbodies (Figure 3.12). Rivers were the most impacted waterbody type (81% of all reports), followed by lakes (12%), artificial waterbodies (5%), transitional waterbodies (1%) and coastal waterbodies (1%). Rivers have consistently been the most impacted waterbody type since the 1960s and the 1980s had the highest number of reported fish kills of any decade (Figure 3.12). The proportion of lakes impacted was highest in the 2000's and the proportion of artificial waterbodies experiencing fish kills was highest in the 2010s (Figure 3.12).

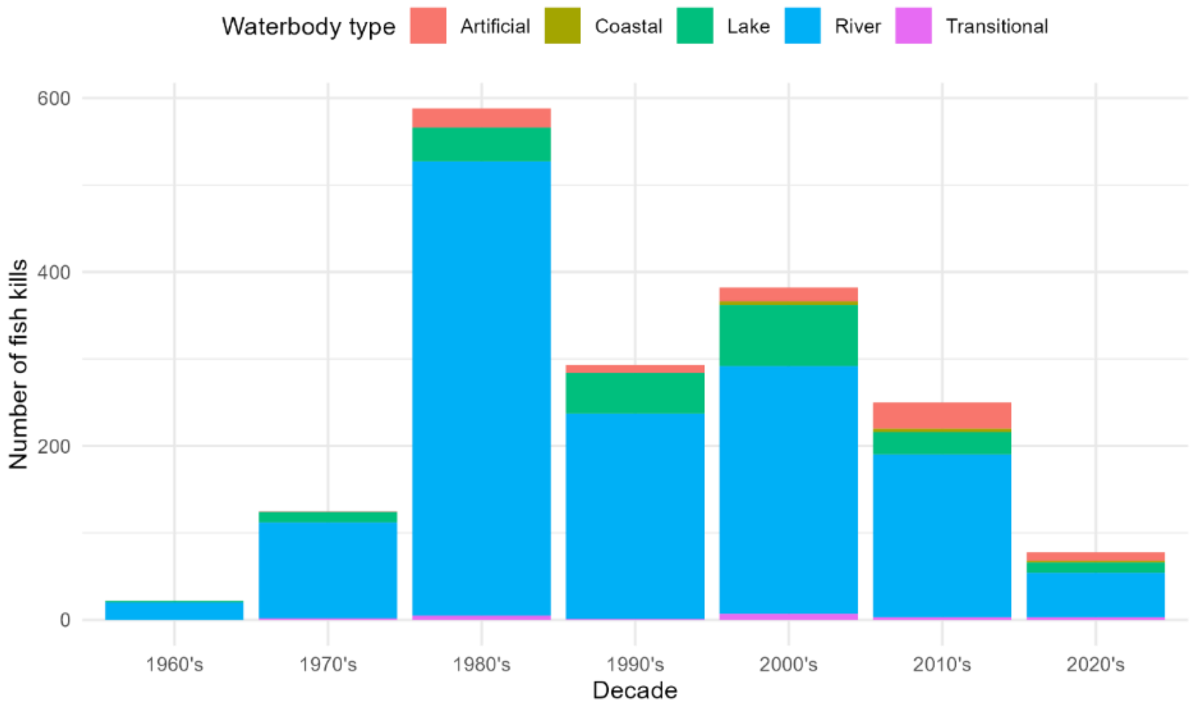


Figure 3.12. Fish kills by waterbody type for each decade (1969-2022) (n=1738) (note: there was only one year of data available for 1960's and three for the 2020's).

3.4 Fish kill causes

The reported causes of fish kills were amalgamated into eight high-level groups, with the percentage of the total fish kill reports attributable to each; 30.8% (536) were attributed to unknown causes. There were 1,202 fish kills remaining when the unknown causes were excluded and these were attributed to agriculture (22.7%), eutrophication (13.3%), industrial (11.7%), other (8.7%), municipal (8.3%), mining (2.9%) and construction (1.6%) (Table 3.10).

Table 3.10: Number of fish kills by cause in Ireland, 1969 to 2022 (n=1738).

Row Labels	1960s	1970s	1980s	1990s	2000s	2010s	2020s	Total	% of Total
Agriculture	3	16	168	84	76	40	7	394	22.7
Eutrophication	0	6	42	81	67	16	20	232	13.3
Industrial	11	60	54	37	21	17	3	203	11.7
other	2	12	16	19	53	27	22	151	8.7
Municipal	5	18	21	20	42	36	2	144	8.3
Mining	0	1	0	0	46	4	0	51	2.9
Construction	0	0	8	4	11	3	1	27	1.6
Unknown	1	12	279	48	66	107	23	536	30.8
TOTAL	**22**	**125**	**588**	**293**	**382**	**250**	**78**	**1738**	**-**

Agriculture was reportedly due to activities including silage effluent leakage, slurry discharge and pesticide use. Industry causes included incidents such as spillages from factories, creameries and processing plants. Municipal sources covered activities such as wastewater treatment and sewerage discharges, as well as leakages from public facilities including a small number of swimming pools. Construction sources often resulted from cement spillages, instream disruption and mechanical damage. A small number of incidents (<1%) were cited as having more than one obvious source and were classified as “mixed”. Those grouped into the “other” sources category included but were not limited to, drought, angling activities, poaching, predation and water abstraction. In general, the number of fish kills attributed to mixed and other sources was low.

3.4.1 Temporal trends

Fish kills relating to agricultural, eutrophication, municipal and industrial sources were consistently recorded over the reporting period. Fish kills due to agriculture peaked in the 1980’s and declined thereafter, while industrial causes peaked in the 1970s and have been decreasing since then (Figure 3.13). Eutrophication was also consistently reported as a cause of fish kills in every decade and peaked in the 1990s, but fish kills associated with this cause have increased slightly in recent times (Figure 3.13). Reports identifying municipal sources have increased in recent decades (Figure 3.13). Reports relating to construction and mining sources were generally low by comparison with other causes. Mining operations accounted for 3% of reports and in all but one of these cases, fish kills were linked to the Avoca River between 2002 and 2011 where there were recurring problems relating to long-recognised acid mine drainage from the abandoned copper and sulphur mines near Avoca, Co. Wicklow. The EPA considered this to be one of the most severely polluted stretches of river in Ireland (Doyle *et al.*, 2003). There were many fish kills reported during the 1980s due to unknown causes, these declined during the following decade, but increased from 2000 to 2020. A report by Fahy (1985) indicated that the dominant sources of fish kills between 1983 and 1985 were agriculture, drought/temperature, local authority and municipal/industrial; however, these cannot be separated out by year.

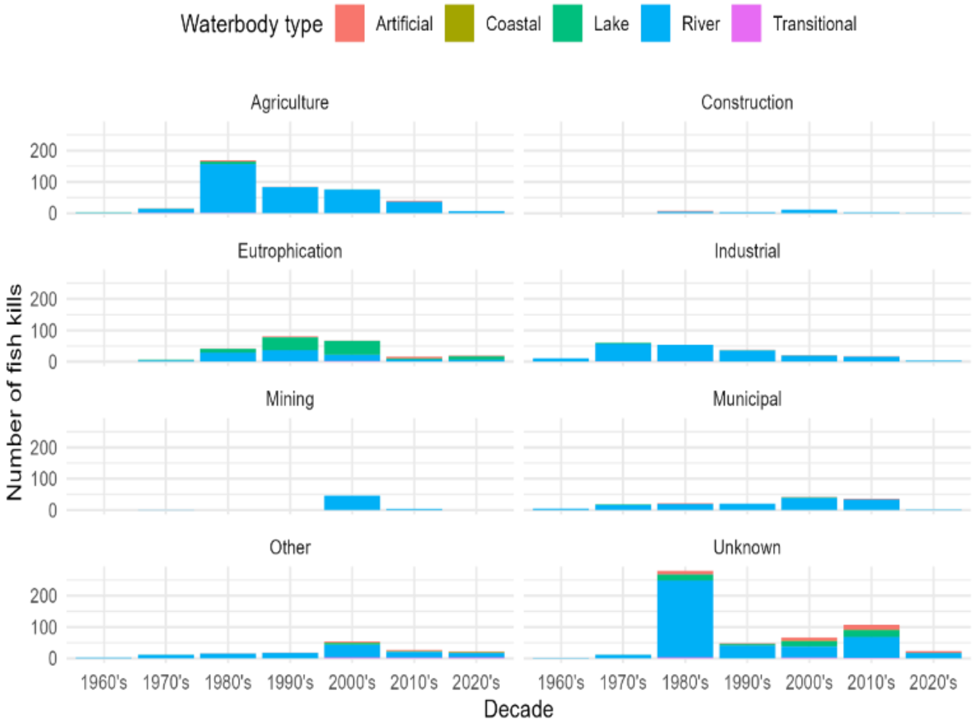


Figure 3.13. Reported fish kills by cause and decade (note: records started in 1969, details were missing from certain years in 1970's and 1980's and 2020's covers 2020 to 2022 only).

The Nitrates Directive, implemented through the Nitrates Action Programme (NAP) and national regulations (e.g. Good Agricultural Practice (GAP) regulations) came into operation in Ireland in 2006. This is the key agricultural measure in Ireland for preventing and reducing water pollution from nutrients (nitrogen and phosphorus) arising from agricultural sources. To investigate if any change has occurred in the spatial distribution of fish kills associated with agriculture, the data set was divided into two periods (1969 to 2006 and 2007 to 2022) pre- and post-NAP introduction. For consistency, these dates were also applied to investigate temporal change due to other causes (i.e. eutrophication, municipal and industrial).

The proportion of fish kills attributed to agriculture, eutrophication, industry, construction and mining (excluding unknowns) was lower in the 2007-2022 period than the 1969-2006 period; however the proportion of fish kills associated with municipal and other sources increased between the two periods (Table 3.11).

Table 3.11: Proportion (%) of fish kills by cause (excluding unknowns) in Ireland (1969-2006 and 2007-2022) (n=1202).

Era	Agriculture	Eutrophication	Industrial	Construction	Mining	Municipal	other
1969-2006	34.8	20.0	18.8	2.3	4.8	9.4	10.0
2006-2022	24.8	16.4	9.2	2.1	2.1	22.3	23.1

3.4.2 Spatial and temporal trends - Agriculture

In total there were 394 fish kills attributed to agriculture reported between 1969 and 2022 (excluding 1976 to 1985 as data wasn't available). The worst year for fish kills caused by agricultural sources was 1987 with 84 reported (Figure 3.14).

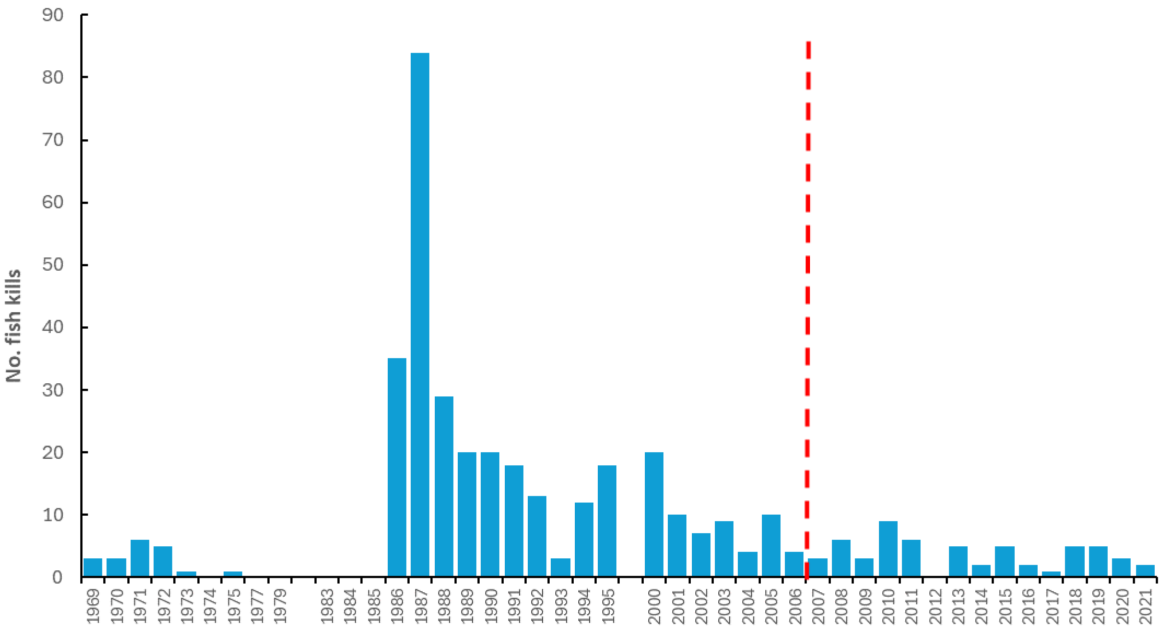


Figure 3.14. Number of fish kills attributed to agriculture 1969 to 2022 (n=394) (note: sparse or no information was available for 1979-1985 and 1996-2000; red dashed line indicates introduction of Good Agricultural Practice (GAP) Regulations).

Spatial trend by county

Overall Co. Cork had the highest percentage (15.7%) of fish kills attributed to agriculture between 1969 and 2022. This was followed by counties Monaghan (10.2%), Limerick (9.6%), Cavan (9.1%), Tipperary (6.9%), Meath (5.3%) and Wexford (5.1%). Counties Longford, Westmeath and Waterford had the lowest percentage of fish kills associated with agriculture.

1969 to 2006: Fish kills associated with agriculture (331) during this period were reported from all 26 counties between 1969 and 2006. The highest percentage was reported from Co. Cork (13.9%), followed by Co. Monaghan (10.9%), Co. Limerick (10%), Co. Cavan (9.1%), Co. Tipperary (7.3%) and Co. Meath (6.3%). The lowest number reported in any county was one each, in Counties Longford and Waterford.

2007 to 2022: Fish kills (63) were reported from 18 counties between 2007 and 2022. Like the early era, Co. Cork (16%) had the highest percentage due to agriculture followed by Co. Cavan (6%), Co. Limerick (5%), Co. Monaghan (4%) and Co. Kerry (4%). The lowest number reported in any county was one each, in Counties Carlow, Longford and Roscommon.

Spatial trend by catchment

Overall, 39 catchments/hydrometric areas had reported fish kills associated with agriculture between 1969 and 2022. Waterbodies within the Erne catchment (*Hydrometric Area 36*) (15.2%) had the highest percentage due to agriculture. This was followed by Shannon Estuary South (*Hydrometric Area 24*) (9.6%), Barrow (*Hydrometric Area 14*) (8.1%), Blackwater (Munster) (*Hydrometric Area 18*) (6.9%), Newry, Fane, Glyde & Dee (*Hydrometric Area 06*) (6.3%), Lee, Cork harbour and Youghal bay (*Hydrometric Area 19*) (5.8%) and Suir (*Hydrometric Area 16*) (5.1%) hydrometric catchments. The lowest percentage (0.3%) were recorded in Upper Shannon (*Hydrometric Areas 26A* and *26B*) and Mal Bay (*Hydrometric Area 28)*.

1969 to 2006: This era was relatively similar to the overall trends, with the highest number of reports in the Erne (15.5%), followed by Shannon Estuary South (9.3%), Barrow (8.4%), Newry, Fane, Glyde and Dee (*Hydrometric Area 06*) (6.6%), Blackwater (Munster) (6%) and Lee (6%). The lowest (0.3%) was again Upper Shannon (26A and 26B), Mal Bay (*Hydrometric Area 28*) and Donagh-Moville (*Hydrometric Area 40*).

2007 to 2022: Like the early era, the Erne catchment (*Hydrometric Area 36*) had the highest percentage (13.6%) of reported fish kills from 2007 to 2022. This was followed by the Blackwater (Munster) (*Hydrometric Area 18*) (11.9%), Shannon Estuary South (*Hydrometric Area 24*) (11.9%) and Barrow (*Hydrometric Area 14*) (6.8%).

3.4.2 Spatial and temporal trends – Eutrophication

Eutrophication is caused by the introduction of nutrients into waterbodies from certain activities, e.g. land-spreading of inorganic and organic fertiliser, sewage, detergents and other nutrient sources.

Phosphates and nitrates are the two main nutrients that cause eutrophication. Overall, there were 232 fish kills attributed to eutrophication across 24 counties and 32 catchments between 1969 and 2022 (Figure 3.15). Eight catchments had only one fish kill each attributed to eutrophication (Colligan-Mahon (*Hydrometric Area 17*), Donegal Bay North (*Hydrometric Area 37)*, Erriff-Clew bay (*Hydrometric Area 17*), Mal Bay (*Hydrometric Area 28*), Nanny-Devlin (*Hydrometric Area 08*), Slaney and Wexford Harbour (*Hydrometric Area 12*), Sligo Bay and Drowse (*Hydrometric Area 35*) and Upper Shannon (*Hydrometric Area 26B*).

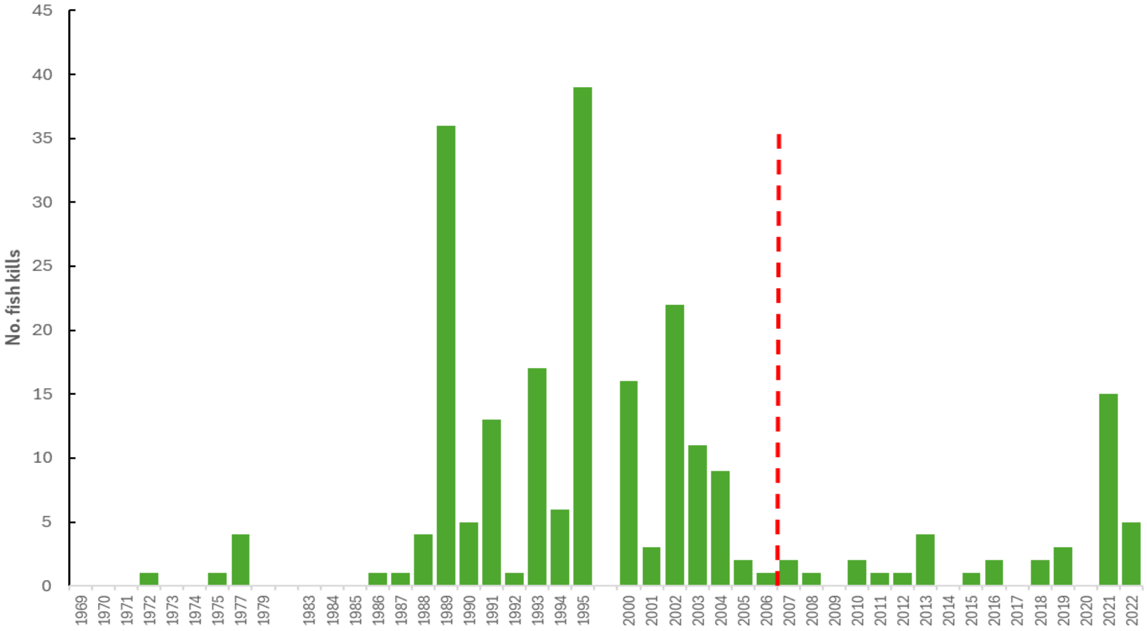


Figure 3.15. Number of fish kills attributed to eutrophication 1969 to 2022 (n=232) (note: sparse or no information was available for 1979-1985 and 1996-2000; red dashed line indicates introduction of Good Agricultural Practice (GAP) Regulations).

Spatial trend by county

Co. Cavan had the highest percentage (34.1%) of fish kills reported, followed by Counties Cork (12.1%), Monaghan (8.6%), Tipperary (6.5%) and Laois (4.7%). The lowest percentage (0.4%) was recorded in counties Dublin, Kerry, Roscommon and Sligo.

1969 to 2006: 193 fish kills were attributed to eutrophication from 1969 to 2006 across 21 counties. Co. Cavan had the highest percentage rate (35.8%) followed by counties Cork (11.4%), Monaghan (9.3%), Tipperary. (6.7%).

2007 to 2022: 39 fish kills were associated with eutrophication across 17 counties between 2007 and 2022. Co. Cavan and Co. Cork had the highest percentage (25.6 and 15.4% respectively).

Spatial trend by catchment

The Erne catchment (*Hydrometric Area 36*) had the highest percentage (37.5%) of fish kills associated with eutrophication from 1969 to 2022. This was followed by the Lee, Cork Harbour and Youghal Bay (*Hydrometric Area 19*) (6.5%), Barrow (*Hydrometric Area 14*) (6.0%), Newry, Fane Glyde and Dee (*Hydrometric Area 06*) (5.2%), Suir (*Hydrometric Area 16*) (5.2%) and Bandon-Ilen (*Hydrometric Area 20*) (4.3%).

1969 to 2006: The spatial trend from 1969 to 2006 was similar to the overall trend with the Erne catchment (*Hydrometric Area 36*) recording the highest percentage (40%). This was followed by the Lee, Cork Harbour and Youghal Bay (*Hydrometric Area 19*) (7%), Barrow (*Hydrometric Area 14*) (6%), Newry, Fane, Glyde and Dee (*Hydrometric Area 06*) (5%) and Suir (*Hydrometric Area 16*) (5%) catchments.

2007 to 2022: The Erne (*Hydrometric Area 36*) also had the highest percentage (25.6%) from 2007 to 2022. This was followed by the Bandon-Ilen (*Hydrometric Area 20*) (10.3%), Barrow (*Hydrometric Area 14*) (7.7%), Newry, Fane, Glyde and Dee (*Hydrometric Area 06*) (7.7%), Suir (*Hydrometric Area 16*) (7.7%) and Upper Shannon (*Hydrometric Area 26C*) (7.7%) catchments.

3.4.3 Spatial and temporal trends - Municipal

There were 144 fish kills recorded between 1969 and 2022 across 24 counties and 35 catchments associated with municipal sources (Figure 3.16). The highest percentage attributed to municipal sources was recorded in Co. Laois (13.2%). This was followed by Cork (10.4%), Cavan (9%), Dublin (9%) and Tipperary (9%). The worst affected catchments/hydrometric areas were Liffey and Dublin Bay (*Hydrometric Area 09*) (13.2%), Barrow (*Hydrometric Area 14)* (10.4%), Erne (*Hydrometric Area 36*) (9.7%) and Suir (*Hydrometric Area 16*) (8.3%). Counties Clare, Kerry, Leitrim and Roscommon had the lowest percentage (0.7%).

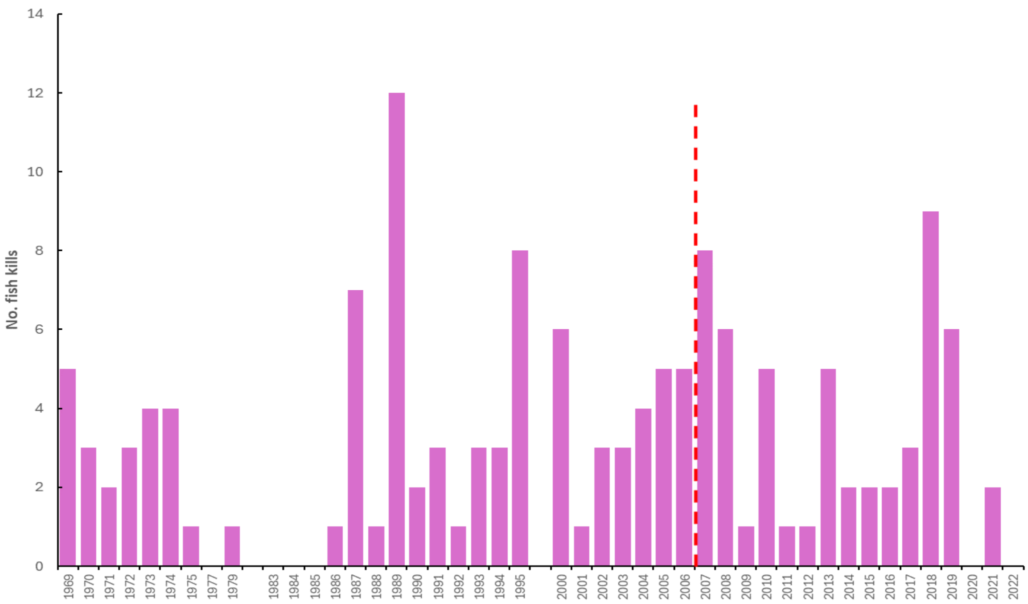


Figure 3.16. Number of fish kills attributed to municipal sources 1969 to 2022 (n=144) (note: sparse or no information was available for 1979-1985 and 1996-2000; red dashed line indicates introduction of Good Agricultural Practice (GAP) Regulations

1969 to 2006: Counties Laois and Cork had the highest percentage of fish kills associated with municipal sources from 1969 to 2006, while the Liffey and Dublin Bay (*Hydrometric Area 09*), Barrow (*Hydrometric Area 14*) and Suir (*Hydrometric Area 16*) were the worst affected catchments/hydrometric areas.

2007 to 2022: From 2007 to 2022 Co. Cavan (17%) followed by counties Cork (9.4%), Dublin (9.4%) and Mayo (9.4%) had the highest percentage of municipal fish kills, while the Erne and Liffey catchments/hydrometric areas were the worst affected.

3.4.4 Spatial and temporal trends – Industrial

There were 203 fish kills attributed to industrial sources from 1969 to 2022, spanning 25 counties and 35 catchments (Figure 3.17). Co. Cork had the highest percentage (17.7%) of fish kills associated with industrial sources. This was followed by counties Tipperary (13.3%), Kerry (12.8%), Dublin (6.9%), Monaghan (6.9%) and Cavan (5.4%). Seven catchments/hydrometric areas accounted for 50% of fish kills associated with industrial sources (Tralee Bay-Feale (*Hydrometric Area 23*) (9.4%), Lee, Cork Harbour and Youghal Bay (Hydrometric Area 19) (8.9%), Blackwater (Munster) (Hydrometric Area 18) (8.4%), Suir (*Hydrometric Area 16*) (7.4%), Liffey and Dublin Bay (*Hydrometric Area 09*) (5.9%), Boyne (5.4%) and Barrow (*Hydrometric Area 14)* (4.9%).

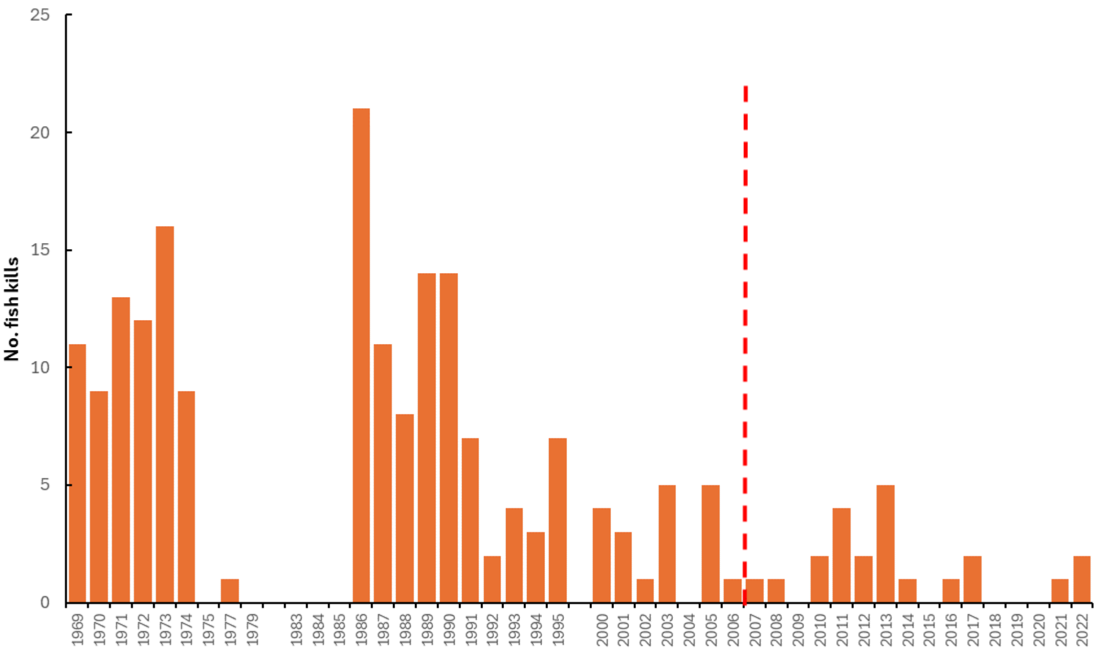


Figure 3.17. Number of fish kills attributed to industrial sources 1969 to 2022 (n=203) (note: sparse or no information was available for 1979-1985 and 1996-2000 red dashed line indicates introduction of Good Agricultural Practice (GAP) Regulations.

1969-2006 – During this period there were 181 fish kills due to industrial sources reported. Co. Cork had the highest percentage (16.0%), followed by Counties Kerry (14.4%), Tipperary (14.4%), Monaghan (7.7%) and Cavan (5.5%).

2007-2022: There were 22 fish kills reported due to industrial sources between 2007 and 2022. The highest percentage was recorded in counties Cork (31.8%) and Dublin (27.3%) and in the Liffey and Dublin Bay (*Hydrometric Area 09*) (22.7%) and Bandon/Ilen (*Hydrometric Area 20*) (13.6%) catchments/hydrometric areas.

3.5 Impact of fish kills on fish species

Salmonids (including salmon, brown trout and sea trout) were the main fish group listed in fish kill reports (62.5%) between 1969 and 2022 where data was available (Table 3.12). Coarse fish (including bream, carp, dace, roach, rudd, and roach or cyprinid hybrids) accounted for 29.5% of reports, the other fish group (eel and lamprey) were recorded in 9.8% of incidents and marine fish species for 2.5% (Table 3.12).

Brown trout (n=909) was the most common fish species reported, followed by salmon (n=262), roach (n=150), European eel (n=112), perch (n=109) (Table 3.10). Stickleback (potentially nine or three-spined stickleback) (n=108) were also frequently reported (Table 3.12). In transitional and coastal areas, flounder was the most frequently reported species (n=21) but other fish species including mullet, herring and bass were also noted.

Table 3.12: Summary of number and percentage of each fish group and fish species (common name) listed as affected in fish kill reports, 1969-2022. (Note: in most cases more than one species was recorded. Lamprey and stickleback were not identified to species in most cases).

Fish group	No. of fish kills	% of fish kills
Salmonid	1086	62.5
Coarse fish	513	29.5
Other fish	170	9.8
Marine fish	44	2.5
Common name	**No. of fish kills**	**% of fish kills**
Brown trout	909	52.3
Salmon	262	15.1
Roach	150	8.6
Eel	112	6.4
Perch	109	6.3
Stickleback	108	6.2
Minnow	96	5.5
Sea trout	81	4.7
Pike	76	4.4
Lamprey	74	4.3
Stone loach	67	3.9
Three-spined stickleback	48	2.8
Flounder	21	1.2
Gudgeon	15	0.9
Mullet	11	0.6
Tench	10	0.6
Carp	6	0.3
Bass	2	0.1

3.6 Impact and recovery of fish populations from fish kills

There is a paucity of published literature available detailing the recovery of fish populations after fish kills in Ireland. As part of the long-term national fish monitoring programme for the WFD opportunistic investigative monitoring was undertaken to assess the recovery of fish species in four rivers; Dodder (Co. Dublin), Kiltha (Co. Cork), Vartry (Co. Wicklow) and White (Co. Louth) after fish kills that occurred in 2012, 2013 and 2017 (Table 3.13 and 3.14). The length of channel and fish casualties impacted varied by river (Table 3.13 and Figure 3.18). Single or multiple electrofishing surveys were undertaken for at least two years after each fish kill within the impacted zone on each river (Table 3.14). Data was available from upstream and downstream (control sites) of the impacted zone on the Dodder, Kiltha and White rivers. No upstream data was available for the River Vartry (Table 3.14).

Table 3.13: Summary details for fish kills on four rivers, 2012 to 2017.

River (impact zone)	Date of incident	Cause	Estimated length of river impacted (km)	Estimated number of fish mortalities
Dodder, Co. Dublin	1/03/2013	Discharge of chlorinated water from a municipal water supply line	2.5	>3,000
Kiltha, Co. Cork (Mogeely Village to Womanagh River Confluence)	11/08/2012	Discharge of insecticide	5.25	>7,000
Vartry, Co. Wicklow (d/s Vartry Reservoir at roundwood to Ashford)	28/06/2012	Unidentified	9	1,000s
Vartry, Co. Wicklow (d/s Vartry Reservoir)	21/02/2017	Lime spill from water treatment plant	0.5	>100
White, Co. Louth (Dunleer to Dee River Confluence)	03/08/2012	Suspected chemical discharge (not identified)	4.0	1000

Table 3.14: List of selected electrofishing survey sites on four rivers experiencing fish kills between 2012 and 2017. The negative values for distance from source of fish kill indicate that a site was upstream of the source and, therefore not impacted by the event (*indicates survey site closest to the original source of impact).

Site	River	Name	Distance from source of fish kill (km)	Year of electrofishing surveys
A	Dodder, River	Footbr. Beaver Row	11.58	2008, 2011, 2013, 2015, 2022
B	Dodder, River	Mount Carmel Hospital	8.12	2011, 2013, 2014, 2015, 2016, 2018, 2019
C	Dodder, River	Bushy Park	6.3	2013, 2014, 2015, 2016, 2018, 2019
D	Dodder, River	Knocklyon	2.21	2013, 2014, 2015, 2016, 2018
E	Dodder, River	Firhouse	1.4	2013, 2014, 2015, 2016, 2018
F	Dodder, River	**Oldbawn***	0	2013, 2014, 2015, 2016, 2017, 2018, 2019
G	Dodder, River	Bohernabreena	-2.53	2011, 2013, 2014, 2015, 2016, 2017, 2018, 2019
A	Kiltha River	Grange (Castlemartyr)	3	2013, 2014
B	Kiltha River	**Killamucky (South Mogeely) ***	2	2012, 2013, 2014
C	Kiltha River	Garryoughtragh (North Mogeely)	-1	2012, 2013, 2014
A	Vartry River	Newrath Br.	11.99	2008, 2013, 2014, 2015, 2017, 2018, 2019
B	Vartry River	Ashford Br.	9.79	2013, 2014, 2015, 2017, 2018, 2022
C	Vartry River	Nun’s Cross Br.	7.77	2013, 2014, 2015, 2017, 2018
D	Vartry River	**Annagolan Br.***	3.42	2013, 2014, 2015, 2017, 2018, 2019, 2022
A	Dee, River	Br. at Drumcar	4.94	2013, 2014, 2015, 2021
B	White River	Coneyburrow Br.	1.84	2013, 2014, 2015, 2016, 2017, 2021
C	White River	**Dunleer***	0.5	2013, 2014, 2015, 2016
D	White River	Athclare	-3.03	2013, 2014, 2015, 2016
E	White River	Gibber’s Br.	-6.18	2013, 2014, 2015, 2016
F	White River	Martinstown Br.	-9.48	2013, 2014, 2015, 2016

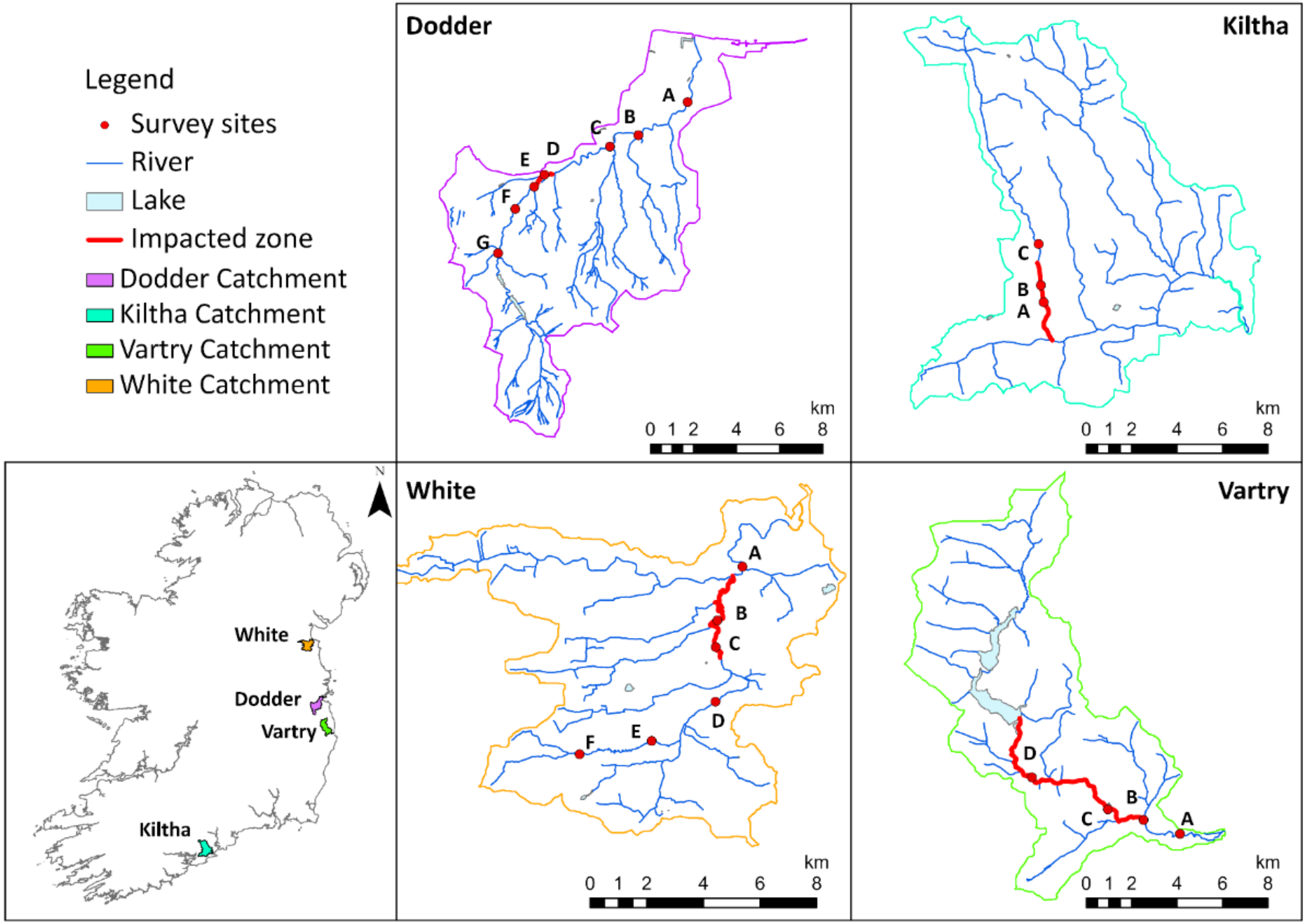
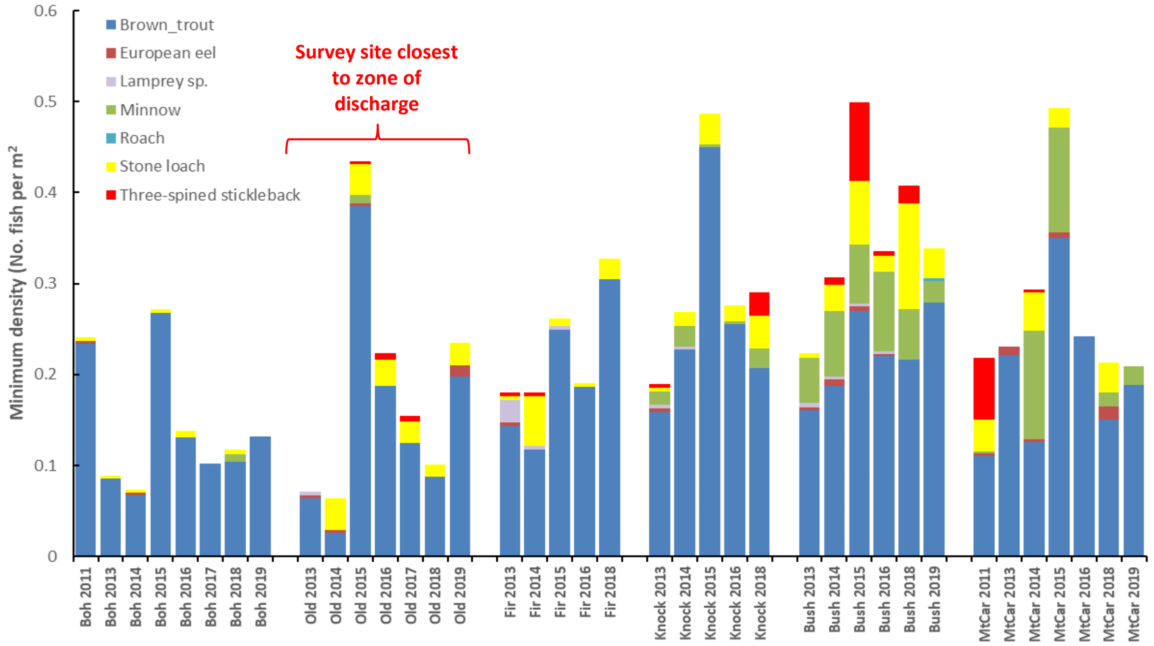


Figure 3.18. Location maps of the Dodder, Kiltha, White and Vartry rivers highlighting the estimated fish kill impact zones (red line) and electrofishing survey sites (red dots).

3.6.1 Recovery of fish population in the River Dodder

The fish kill on the River Dodder was reported on the 1st of March 2013 below the Boherboy supply pipeline near Oldbawn, Co. Dublin and impacted approximately 2.5 km of channel (Figure 3.18). It was estimated that approximately 3,000 fish were killed, including brown trout, lamprey and stone loach due to a discharge of chlorinated water during commissioning of a new water supply pipeline. Six sites were surveyed to assess the status of fish stocks on the River Dodder in July 2013 and regularly up to 2019 (Table 3.14).

Total minimum density (all species) was lowest in 2013 (126 days after the fish kill) and 2014 Oldbawn (Site F), the site closest to the discharge, but increased to levels like other sites from 2015 (Figure 3.19). Species richness was also lower at the Oldbawn site in 2013 than the following years (Figure 3.19). Total minimum brown trout density was lower at Oldbawn and Firhouse in 2015 than subsequent years (Figure 3.21). Minimum density of stone loach was also higher at many sites in the year following the discharge (2014) (Figure 3.19).



Survey site closest to zone of discharge

Figure 3.19. Trends in total (minimum) fish density (number of fish per m^2) River Dodder, 2011 to 2019 (note: the fish kill occurred in March 2013; sites are arranged from upstream to downstream). For comparison purposes minimum densities were calculated from the first fishing pass only. (Boh=Site G-Bohernabreena; Old=Site F-Oldbawn; Fir=Site E-Firhouse; Knock=Site D-Knocklyon; Bush=Site C-Bushy Park; MtCar=Site B-Mount Carmel).

Relatively poor densities of brown trout fry were recorded at Oldbawn (Site F) in July 2013 (126 days after the fish kill) and none were recorded in 2014, two years after the fish kill (Figure 3.20). Site E

(Firhouse) located approximately 1.4km from the source of the discharge, had a relatively high density of brown trout fry (0+) when compared to the other sites in 2013 (126 days after the fish kill) but had no other age groups present, except for a single 1+ individual (Figure 3.23 and 3.24). There was a large increase in density of 0+ brown trout fry in 2015 at all sites surveyed. However densities reduced significantly again in 2016 and 2017 (Figure 3.20).

The Knocklyon site was located at the lower end of the impacted zone and was the most diverse site in terms of the number of brown trout age classes present in 2013 (Figure 3.22). This suggests any inhibiting factors experienced close to the site of the effluent discharge (e.g. Firhouse) may have dissipated at this distance downstream (1.4km from discharge) or fish moved downstream to cleaner waters. This may also account for the relatively high density of 1+ and older brown trout at the Bushy Park site in 2023 and 2014 (Figure 3.21).

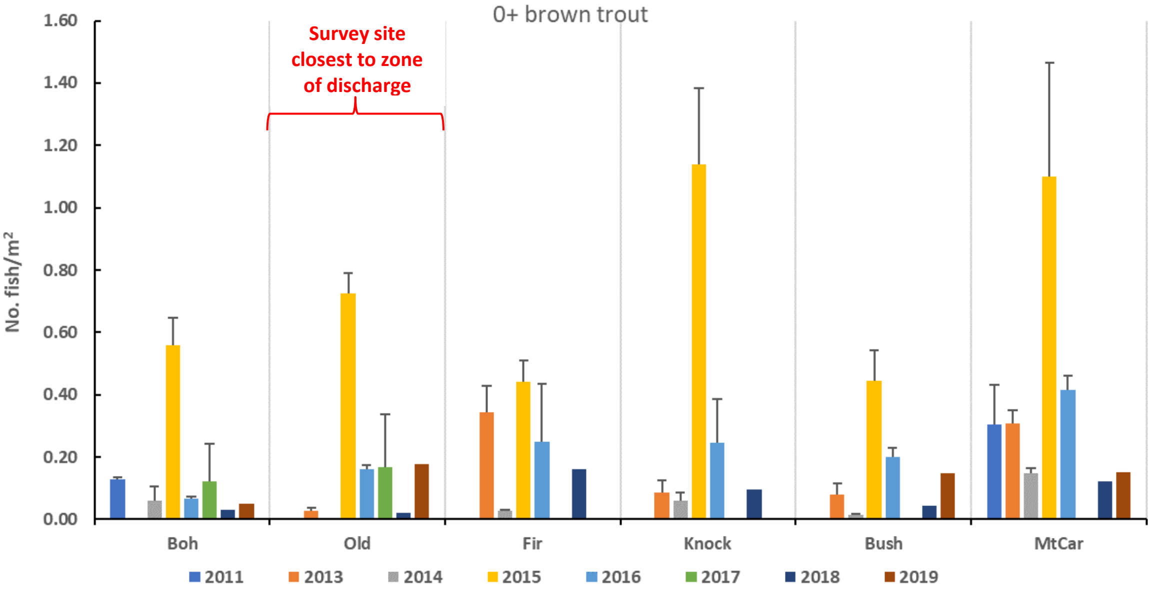


Figure 3.20. Trends in brown trout fry (0+) population density (number of fish per m^2) at six sites on the River Dodder, 2011 to 2019. 95% confidence intervals are shown where available (note: the fish kill occurred in March 2013; Firhouse, Knocklyon and Bushy Park sites were not surveyed in 2017) (Boh=Site G-Bohernabreena; Old=Site F-Oldbawn; Fir=Site E-Firhouse; Knock=Site D-Knocklyon; Bush=Site C-Bushy Park; MtCar=Site B-Mount Carmel).

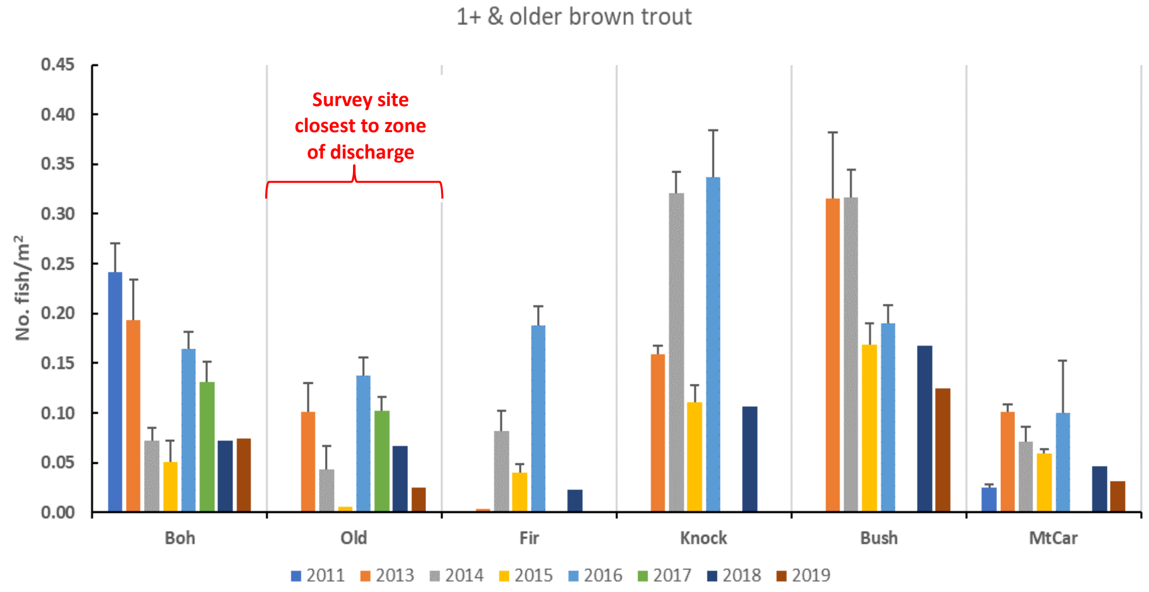


Figure 3.21. Brown trout (1+ and older) population density per m^2 at six sites on the River Dodder, 2011 to 2019. 95% confidence intervals are shown where available (note: the fish kill occurred in March 2013; Firhouse, Knocklyon and Bushy Park sites were not surveyed in 2017) (Boh=Site G-Bohernabreena; Old=Site F-Oldbawn; Fir=Site E-Firhouse; Knock=Site D-Knocklyon; Bush=Site C-Bushy Park; MtCar=Site B-Mount Carmel).

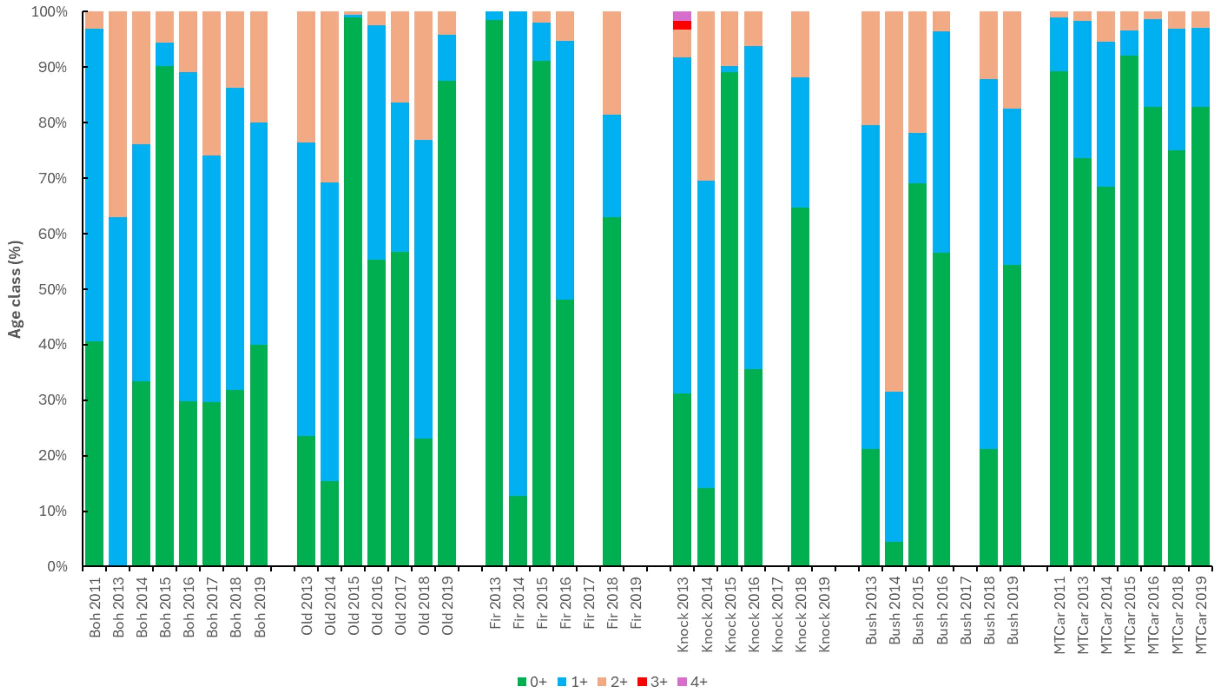


Figure 3.22. Age class profile (%) of brown trout at various sites on the River Dodder, 2011 to 2019 (Fish kill occurred in March 2013) (note Firhouse, Knocklyon and Bushy Park sites were not surveyed in 2017) (Boh=Site G-Bohernabreena; Old=Site F-Oldbawn; Fir=Site E-Firhouse; Knock=Site D-Knocklyon; Bush=Site C-Bushy Park; MtCar=Site B-Mount Carmel).

Using the FCS2-Ireland fish classification tool, each site surveyed on the River Dodder was assigned a fish classification status (Table 3.15). Fish ecological status at Oldbawn and Firhouse has been at Moderate since the fish kill in 2012 with a deterioration observed at Oldbawn in 2018. Fish ecological status at Knocklyon and Bushy Park was Good from 2013 to 2015 but deteriorated to Moderate in the following years. The most recent EPA Q-value status on this stretch of river ranges from Poor to Moderate (EPA, 2024). Where failures in fish ecological status occurred, they were mainly due to lower-than-expected abundance of brown trout fry or 1+ and older brown trout, and salmon of all age classes.

Table 3.15: Fish ecological status for selected sites on the River Dodder, 2008 to 2022 (Sites are arranged from upstream to downstream; Blue=High status, Green=Good status; Yellow=Moderate status; Orange=Poor status and Red=Bad status; * indicates closest site to source of discharge and ** indicates sites within impact zone).

Fish ecological status												
Site	**Site name**	**2008**	**2011**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2022**	**Reason for failure**
G	Bohernabreena	-	Good	Mod	Mod	Mod	Mod	Mod	Mod	Mod		Lower than expected brown trout fry or parr and salmon (all ages)
F	**Oldbawn***	-		Mod	Mod	Mod	Mod	Mod	Poor	Mod		
E	Firhouse**			Mod		Mod	Mod		Mod			
D	Knocklyon**	-		Good	Good	Good	Mod		Mod			
C	Bushy Park**			Good	Good	Good	Mod		Mod	Mod		
B	Mount Carmel		Mod	Mod	Mod	Mod	Poor		Mod	Mod		
A	Beaver Row	Good	High	Good	-	Mod	-		-		High	N/A

3.6.2 Recovery of fish population in the Vartry River

The fish kill on the Vartry River occurred on the 28th of June 2012 with an estimated 9.0 km zone of river impacted from downstream of the Vartry Reservoir to Ashford, Co. Wicklow (Figure 3.18). A second fish kill occurred on the river on 21st February 2017 in the same area; however this was more localised. It was estimated that approximately 8,000 fish were killed during the 2012 fish kill event and 500 during the 2017 incident. The 2017 fish kill was caused by a lime spill at the Vartry Water Treatment Plant. It was not possible to confirm a source for the 2012 fish kill. Four sites were surveyed annually on the Vartry River between 2013 and 2019 (excluding 2016) and in 2022 (IFI, 2020).

The Annagolan Br. site was located within the fish kill impact zone on both occasions and total fish density was highest there in 2013, almost one year after the fish kill; however, the fish stock was dominated by tolerant fish species such as minnow and three-spined stickleback. The opposite was observed at the three remaining survey sites, where salmonids dominated (Figure 3.23).

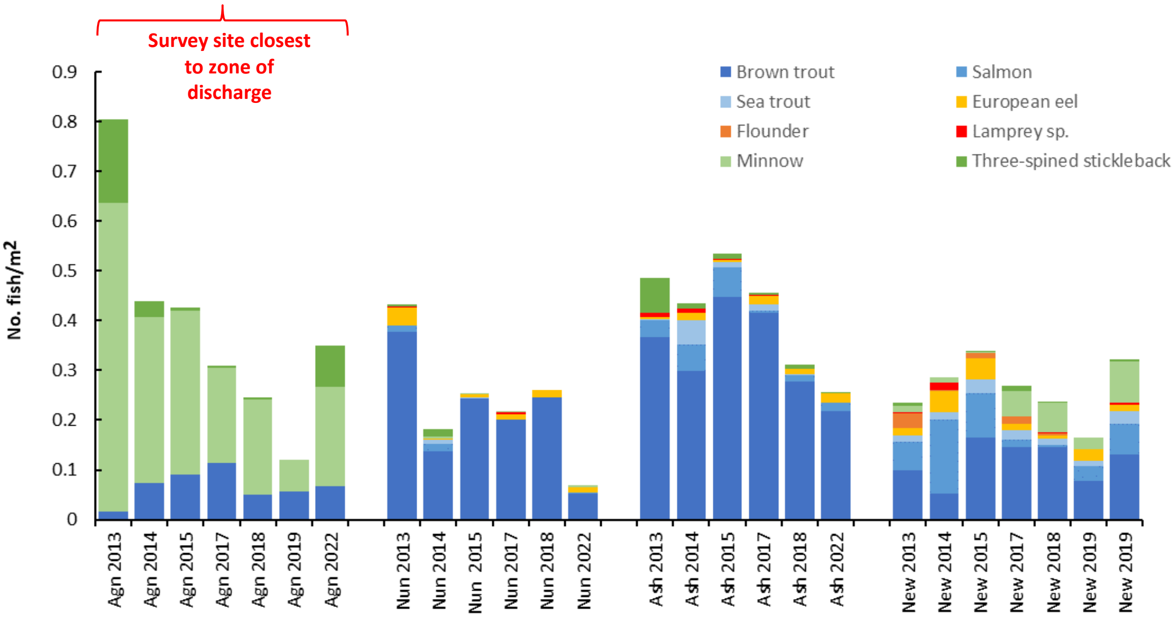


Figure 3.23. Trends in total (minimum) fish density (no. fish/m^2) on the Vartry River, 2013 to 2022 (note: fish kills occurred June 2012 and February 2017; sites are arranged from upstream to downstream). For comparison purposes minimum densities were calculated from the first fishing only (Agn=Site D-Annagolan Br.; Nun=Site C-Nun's Cross, Ash=Site B-Ashford Br.; New=Site A-Newrath Br.).

Population density of brown trout fry (0+) and older (1+ & older) were relatively low at Annagolan Br. in 2013 (one year after the fish kill) (Figure 3.24). Brown trout fry increased over the next three years but reduced again in 2018 (one year after the 2017 fish kill). There were no 1+ and older brown trout present at Annagolan Br. in 2013, one year after the fish kill (Figure 3.25 and 3.26) but were present in relative low numbers in the three following years (Figure 3.25).

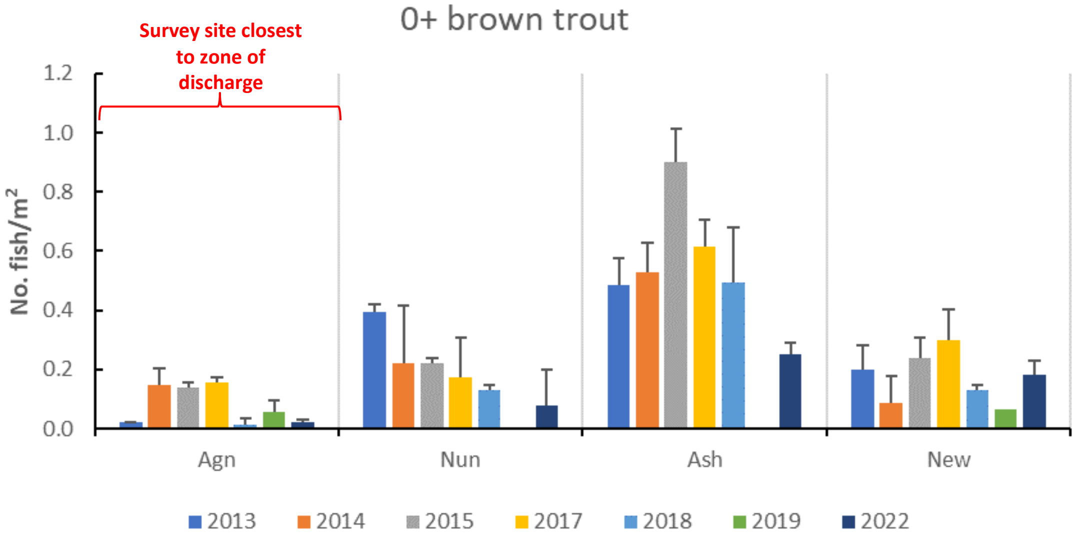


Figure 3.24. Trends in population density (number of fish/m^2) of 0+ brown trout, including 95% confidence intervals (where available), at four sites on the Vartry River 2013 to 2022 (note: only one fishing was carried out on Newrath Br. in 2019). (Agn=Site D-Annagolan Br.; Nun=Site C-Nun's Cross; Ash=Site B-Ashford Br.; New=Site A-Newrath Br.)

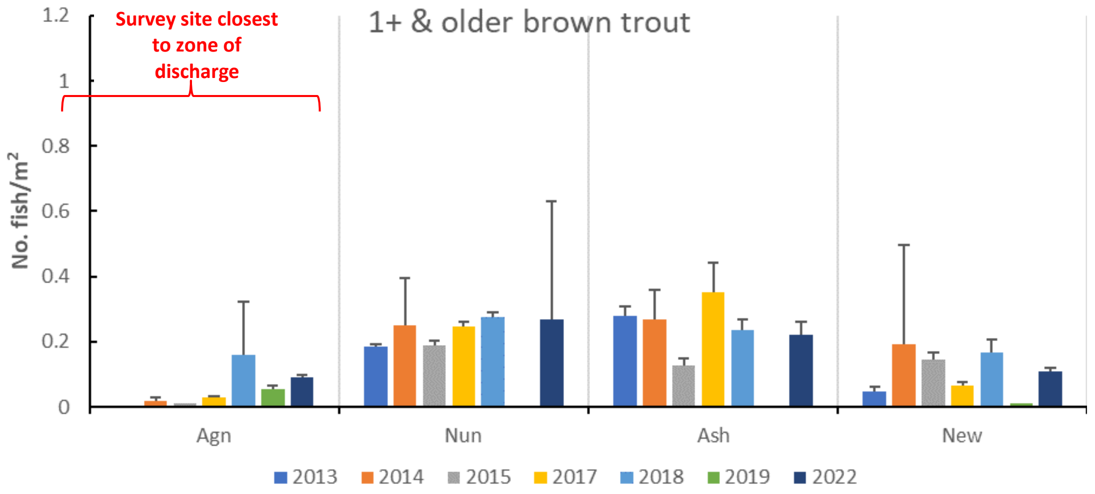


Figure 3.25. Trend in population density of 1+ & older brown trout (number of fish/m^2), including 95% confidence intervals (where available) at four sites on the Vartry River 2013 to 2022 (note: only one fishing was carried out on Newrath Br. in 2019) (Agn=Site D-Annagolan Br.; Nun=Site C-Nun's Cross; Ash=Site B-Ashford Br.; New=Site A-Newrath Br.).

Four brown trout age classes were recorded at the four sites surveyed on the Vartry River, 0+, 1+, 2+ and 3+ (Figure 3.26). The 0+ age class was the most abundant and dominant age cohort at most sites and sampling occasions; however, in 2018, after the second fish kill, 1+ were the dominant age cohort at Annagolan Br. Brown trout aged 2+ were also absent from Annagolan Br. and Nuns Cross in the years following the 2012 fish kill but were present in 2017 at both sites and 2018 at Nuns Cross.

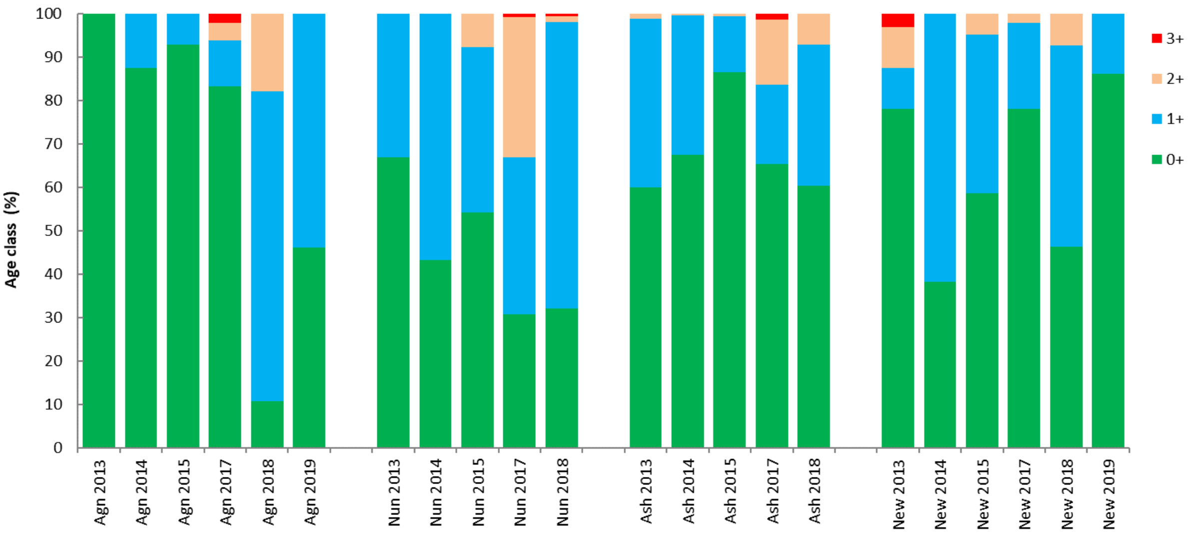


Figure 3.26. Age class profile (%) of brown trout at four survey sites on the Vartry River, 2013 to 2019 (fish kills occurred June 2012 and October 2017) (note: only one fishing was carried out on Newrath Br. in 2019) (Agn=Site D-Annagolan Br.; Nun=Site C-Nun's Cross; Ash=Site B-Ashford Br.; New=Site A-Newrath Br.).

Using the FCS2-Ireland fish classification tool, each site surveyed on the Vartry River was assigned a fish classification status (Table 3.18). Fish ecological status was Poor at Annagolan Br. in 2013, one year after the fish kill. This improved to Moderate in 2014 and has remained at Moderate since then (Table 3.16). All other sites were assigned a fish ecological status of Good in 2013. Nun's Cross deteriorated to Moderate in 2015 and two sites improved to High status in 2014 and 2015 but deteriorated to Good in 2017 (Table 3.16). Where failure in fish ecological status occurred, it was mainly due to lower-than-expected abundance of brown trout fry or 1+ and older brown trout and a relatively high abundance of tolerant fish species.

Table 3.16: Fish ecological status for selected sites on the Vartry River, 2008 to 2022b (Blue=High status, Green=Good; Yellow=Moderate; Orange=Poor and Red=Bad; * indicates closest site to source of discharge).

Fish ecological status										
Site	**Site name**	**2008**	**2013**	**2014**	**2015**	**2017**	**2018**	**2019**	**2022**	**Reason for failure**
D	**Annagolan Br.***	-	Poor	Mod	Mod	Mod	Mod	Mod	Mod	Lower than expected brown trout (all ages)
C	Nun's Cross	-	Good	Good	Mod	Mod	Mod	Mod	Mod	

B	Ashford Br.	-	Good	High	High	Good	Good	_	Good	N/A
A	Newrath Br.	Good	Good	High	High	Good	Good	-	Good	N/A

3.6.3 Recovery of fish population in the White River

The fish kill on the White River was reported on the 3rd of August 2012. An estimated 4.0km stretch of river was impacted from Dunleer Village, Co. Louth to the confluence with the River Dee (Figure 3.18). An estimated 1000 fish were killed, including juvenile and adult salmon and trout, eels, minnow and stone loach. It was not possible to identify the cause of the fish kill.

Dunleer was the closest survey site to the fish kill incident. Total fish (minimum) density was highest at Dunleer in 2013 and the population had a large proportion of tolerant fish species (i.e. minnow, stone loach and three-spined stickleback) (Figure 3.27). Total minimum density increased from 2012 (before the fish kill) to 2013 (one year after the fish kill) at the Coneyburrow site (1.84km d/s of discharge). The species composition also changed at this site one year after the fish kill to one dominated by tolerant fish species (minnow, stone loach and three-spined stickleback) (Figure 3.27).

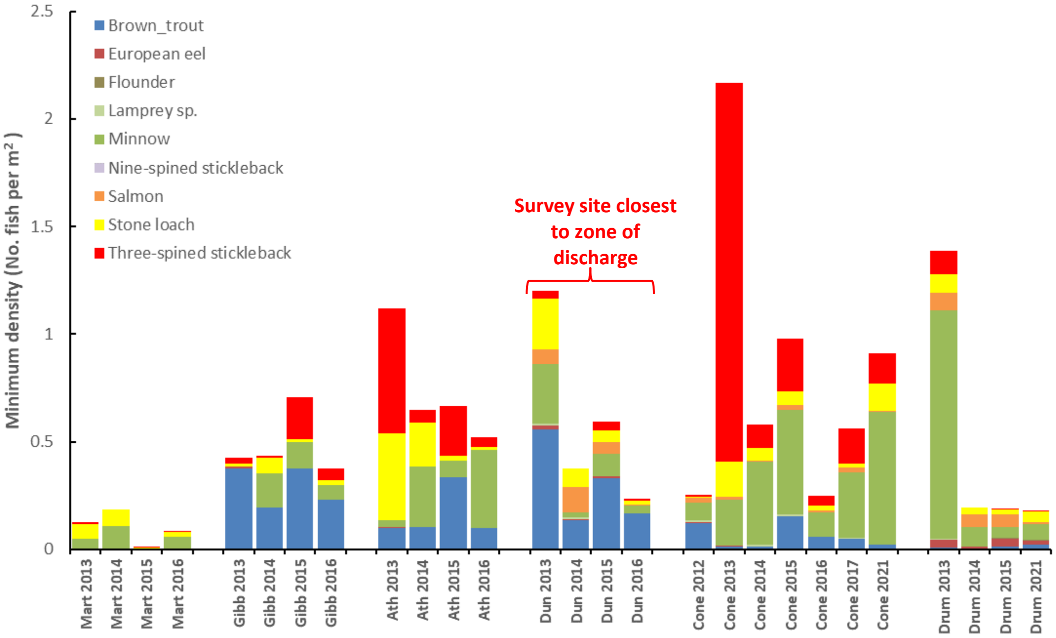


Figure 3.27. Trends in total (minimum) fish density (number of fish per m^2) in sites on the White River and River Dee, 2012 to 2021 (note: the fish kill occurred in August 2012; sites are arranged from upstream to downstream; for comparison purposes, minimum densities were calculated from the first fishing only) (Mart=Site F-Martinstown Br.; Gibb=Site E-Gibber's Br.; Ath=Site D-Athclare; Dun=Site C-Dunleer; Cone=Site B-Coneyburrow Br.; Drum=Site A-Br. at Drumcar).

Population density of brown trout fry (0+) was relatively high in 2013 at the Dunleer site, reducing significantly in 2014 (Figure 3.28). This was followed by another sharp increase in 2015, and reduction in 2016. Brown trout 1+ and older population density fluctuated across all surveys at the Dunleer site between 2013 and 2016 but was lower in 2014 than 2013 (Figure 3.29). Brown trout population density was also lower in 2013 than surveys prior to the fish kill (Figure 3.29).

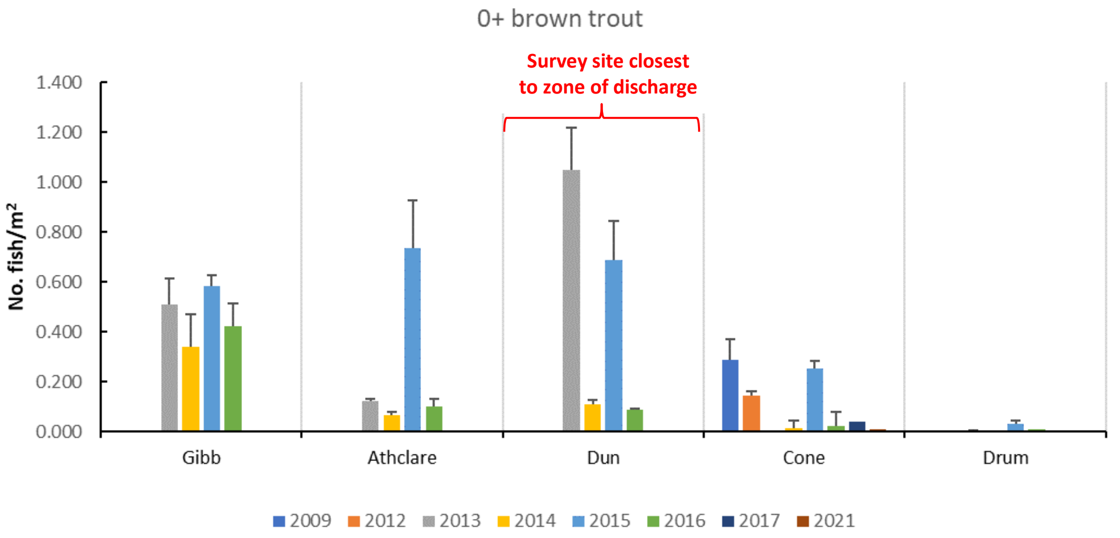


Figure 3.28. Brown trout fry (0+) population density (number of fish per m²) at various sites on the White River and River Dee, July 2012, August 2014 and August 2014. 95% confidence intervals are shown where available (the fish kill occurred August 2012) (Mart=Site F-Martinstown Br.; Gibb=Site E-Gibber's Br.; Ath=Site D-Athclare; Dun=Site C-Dunleer; Cone=Site B-Coneyburrow Br.; Drum=Site A-Br. at Drumcar).

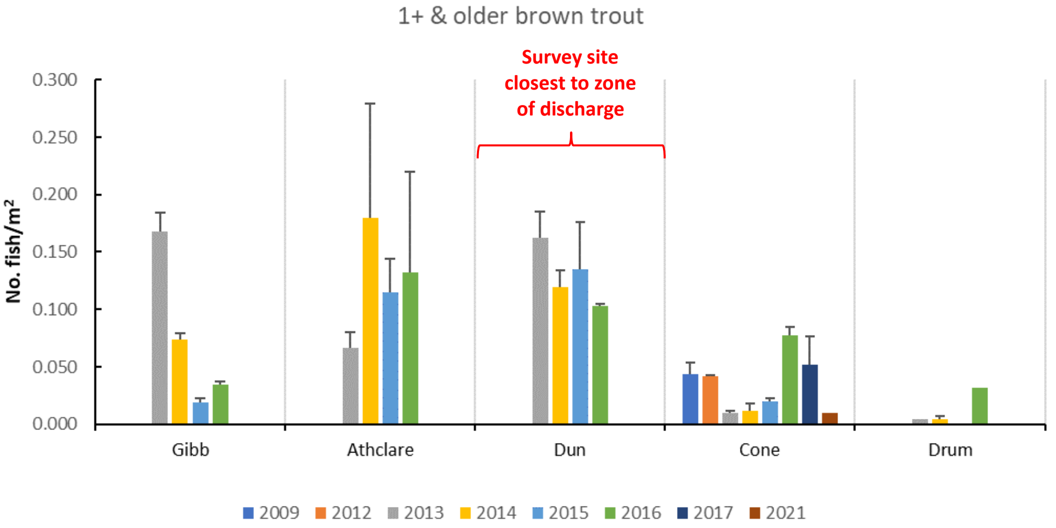


Figure 3.29. Brown trout 1+ & older population density (number of fish per m²) at various sites on the White River and River Dee, 2012 to 2021. 95% confidence intervals are shown where available.

(Fish kill, August 2012) (Mart=Site F-Martinstown Br.; Gibb=Site E-Gibber's Br.; Ath=Site D-Athclare; Dun=Site C-Dunleer; Cone=Site B-Coneyburrow Br.; Drum=Site A-Br. at Drumcar).

Four age classes were recorded at the Coneyburrow site in 2009, three were present in 2012 and only two in 2013. Age classes began to recover consistently in 2016 (Figure 3.30).

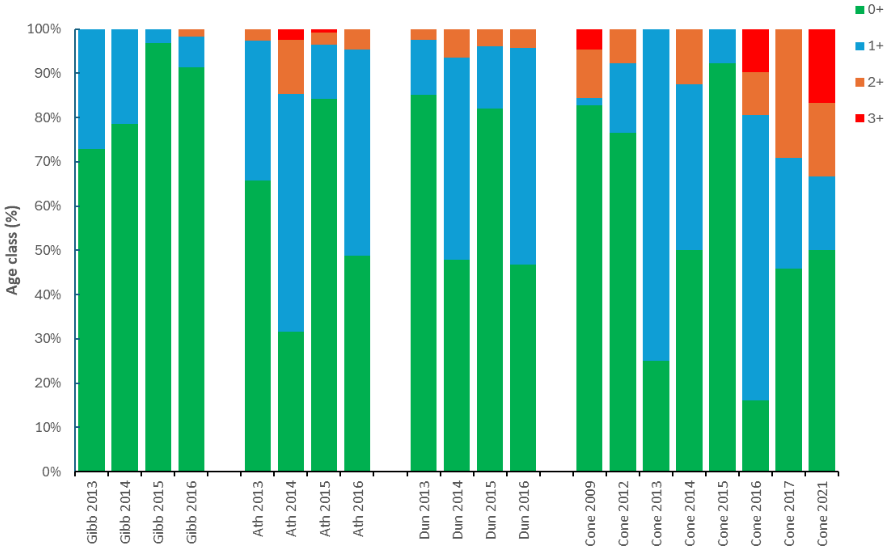


Figure 3.30. Age class profile (%) of brown trout at four sites on the White (Louth) River, 2009 to 2021 (note: the fish kill occurred in August 2012) (Mart=Site F-Martinstown Br.; Gibb=Site E-Gibber's Br.; Ath=Site D-Athclare; Dun=Site C-Dunleer; Cone=Site B-Coneyburrow Br.; Drum=Site A-Br. at Drumcar).

Population density of salmon fry was lower after the fish kill at Coneyburrow (2013 and 2014) in comparison to the two surveys prior to the incident (2009 and 2012) (Figure 3.33). Salmon fry density was higher in 2014 than in 2013 at the Dunleer site and was significantly lower in 2015 and 2016 (Figure 3.31). A similar pattern was observed for 1+ and older salmon at these two sites (Figure 3.32).

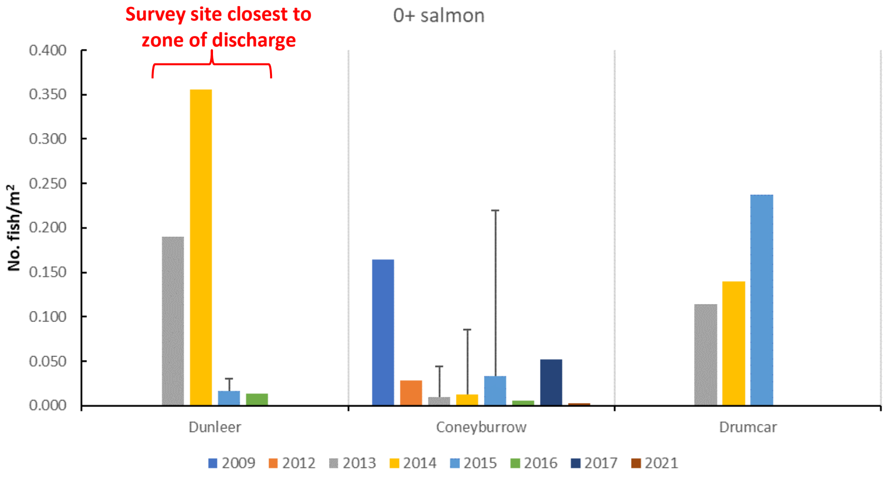


Figure 3.31. Salmon fry (0+) population density (number of fish per m^2) at various sites on the White River and River Dee, 2012 to 2021. 95% confidence intervals are shown where available (note: the fish kill occurred in August 2012) (Mart=Site F-Martinstown Br.; Gibb=Site E-Gibber's Br.; Ath=Site D-Athclare; Dun=Site C-Dunleer; Cone=Site B-Coneyburrow Br.; Drum=Site A-Br. at Drumcar).

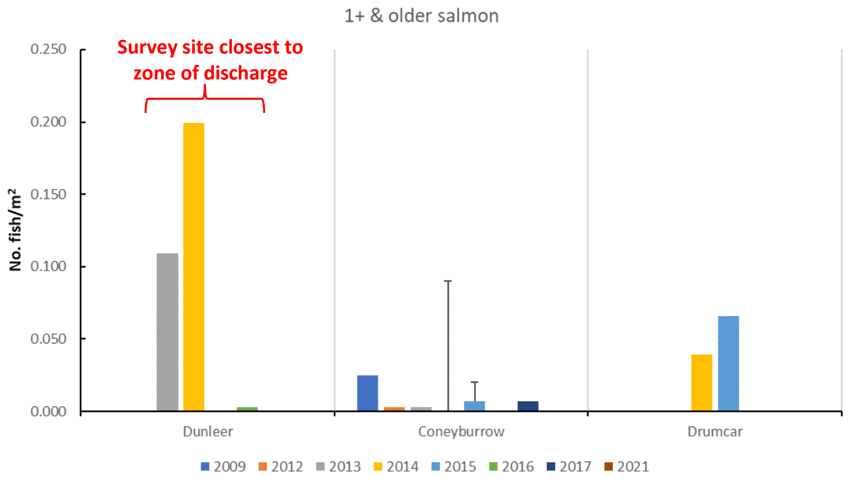


Figure 3.32. Salmon 1+ & older population density (number of fish per m^2) at various sites on the White River and River Dee, 2012 to 2021. 95% confidence intervals are shown where available (note: the fish kill occurred in August 2012) (Mart=Martinstown Br.; Gibb=Gibber's Br.; Ath=Athclare; Dun=Dunleer; Cone=Coneyburrow Br.; Drum=Br. at Drumcar).

Using the FCS2-Ireland fish classification tool, each site surveyed on the White River was assigned a fish classification status (Table 3.17). Fish ecological status was at Moderate at three sites on the White River in 2013 and this trend continued up to 2016. Prior to the fish kill in August 2012, the Coneyburrow site was assigned Moderate status; however, this deteriorated to Poor in 2013 and 2014 and improved to Moderate in 2015 (Table 3.17). Where failure in fish ecological status occurred, it was mainly due to lower-than-expected abundance of brown trout and salmon (all ages) and a relatively high abundance of tolerant fish species.

Table 3.17: Fish ecological status for selected sites on the White River, 2008 to 2022 (Blue =High status, Green=Good status; Yellow=Moderate status; Orange=Poor status and Red=Bad status; * indicates closest site to source of discharge, **indicates sites within impacted zone).

Fish ecological status										
Site	Site name	2009	2012	2013	2014	2015	2016	2017	2020/21	Reason for failure
F	Martinstown Br	-	-	Poor	Poor	Poor	Poor	-	Bad	Lower than expected abundance of brown trout and
E	Gibber's Br.	-	-	Mod	Mod	Mod	Mod	-	-	
D	Athclare	-	-	Mod	Mod	Mod	Mod	-	-	

C	**Dunleer***	-	-	Mod	Mod	Mod	Mod	-	-	salmon (all ages)
B	Coneyburrow Br.**	Mod	Mod	Poor	Poor	Mod	Mod	Mod	Poor	
A	Drumcar Br.	-	-	Mod	Mod	Mod	-	-	Mod	

3.6.4 Recovery of fish population in the Kiltha River

The fish kill on the Kiltha River occurred on the 11th of August 2012 impacting an estimated 5.25km of river channel between Mogeely Village, downstream to the Womanagh River confluence near Castlemartyr, Co. Cork (Figure 3.18). It was estimated that at least 7,000 fish, including brown trout, juvenile salmon, stone loach, eels, lamprey and three-spined stickleback were killed because of a discharge of insecticide from a grain depot. Two sites, North Mogeely and South Mogeely were surveyed 25 and 53 days respectively after the fish kill in 2012 and again in 2013 and 2014 (after just over one and two years respectively). A third site, Castlemartyr, located approximately 2.6km downstream of the discharge was included in the 2013 and 2014 surveys. North Mogeely (a control site) was located upstream of the discharge, while South Mogeely (closest site to the discharge) and Castlemartyr were located within the fish kill zone (Tables 3.13 and 3.14).

Total fish density was lower at the two sites in the impacted zone, than at the upstream site during all surveys (Figure 3.33). In 2012 the fish population at South Mogeely was dominated by tolerant fish species (mainly stone loach), while upstream of the impacted zone, the population was dominated by brown trout and salmon (Figure 3.33). Approximately one year after the fish kill, total fish density and total trout density had increased at South Mogeely (Figure 3.33). In 2014, two years after the fish kill, the fish populations at Castlemartyr were dominated by tolerant fish species (Figure 3.33).

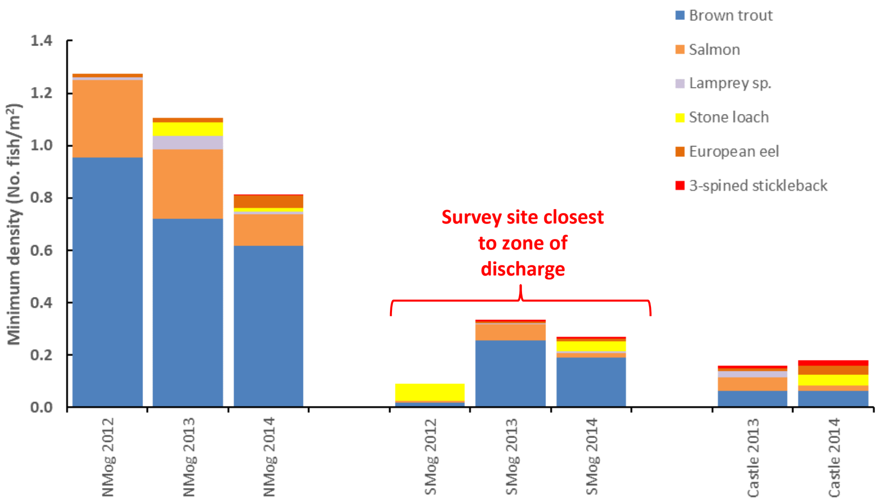


Figure 3.33. Trends in total (minimum) fish density (number of fish per m²) on the Kiltha River from 2012 to 2014 (note: the fish kill occurred in August 2012; sites are arranged from upstream to downstream)(*Note: for comparison purposes, minimum densities were calculated from the first fishing only) (NMog=Site C-North Mogeely (Garryoughtragh); SMog=Site B-South Mogeely (Killamucky); Castle=Site A-Castlemartyr (Grange)).

Brown trout fry (0+) and older population densities at South Mogeely were lower in 2012 after the fish kill, with 1+ and older especially lower when compared with the following two years (Figure 3.34). Salmon fry (0+) was not recorded in 2012 but were present in 2013 and 2014 (Figure 3.35). Salmon parr (1+ and older) were recorded in low numbers in both 2012 and 2013 at South Mogeely but were not encountered during the 2014 survey (Figure 3.35).

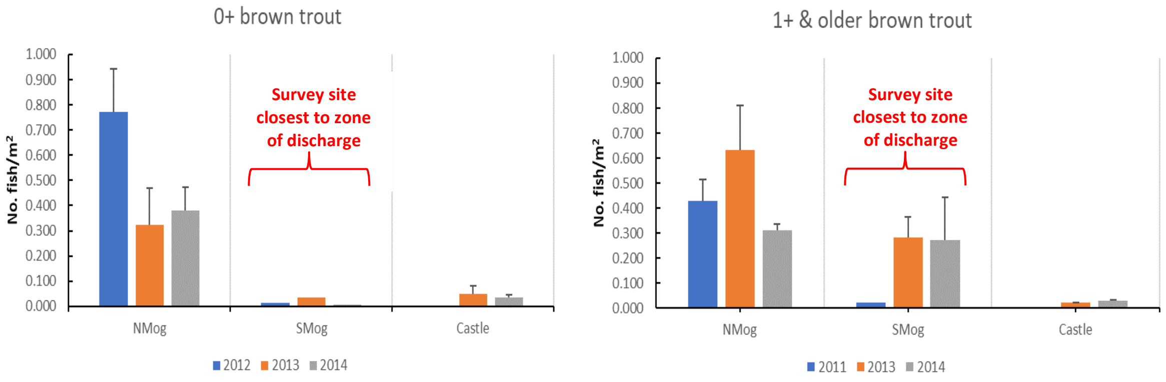


Figure 3.34. Trends in brown trout (0+ and 1+ & older) population density (number of fish per m²) at three sites on the Kiltha River, 2012 to 2014. 95% confidence intervals are shown where available (NMog=Site C-North Mogeely (Garryoughtragh); SMog=Site B-South Mogeely (Killamucky); Castle=Site A-Castlemartyr (Grange)).

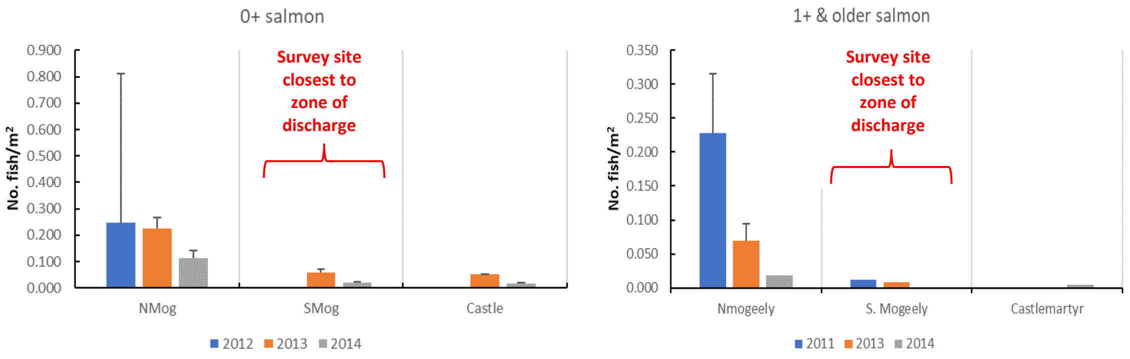


Figure 3.35. Trends in juvenile salmon (0+ and 1+ and older) population density (number of fish per m²) at three sites on the Kiltha River, 2012 to 2014 (NMog=Site C-North Mogeely (Garryoughtragh); SMog=Site B-South Mogeely (Killamucky); Castle=Site A-Castlemartyr (Grange)).

Three to four age classes of brown trout were present at the North Mogeely site (upstream of the fish kill) between 2012 and 2014. Only two age classes were present at South Mogeely approximately 25 days after the fish kill, this increased to three in 2013 and remained at three in 2014. Three age classes were also present at the Castlemartyr site in 2013 and 2014 (Figure 3.36).

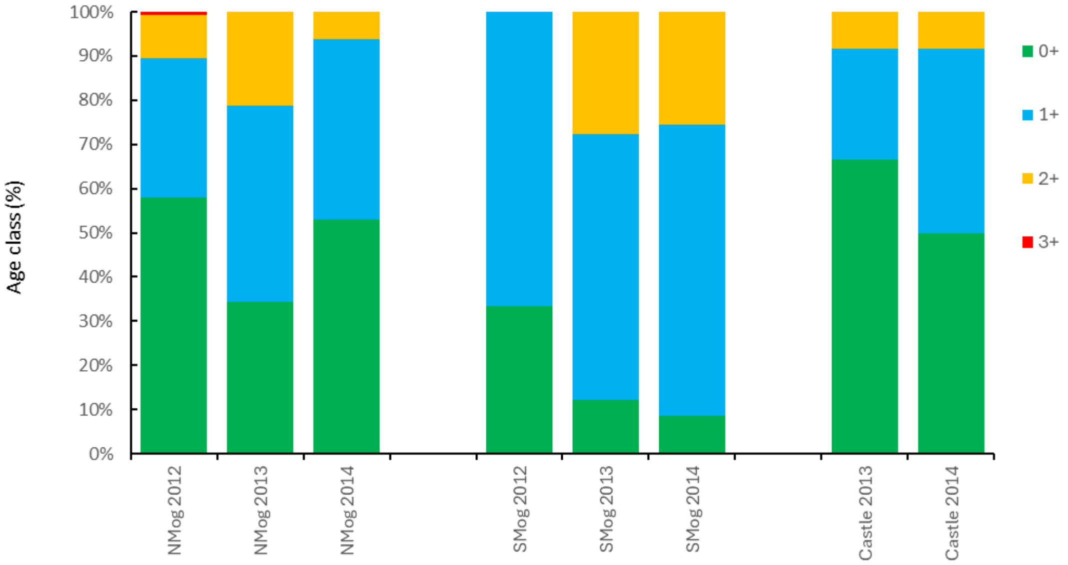


Figure 3.36. Age class profile (%) of brown trout at various sites on the River Kiltha, 2012 to 2014 (note: the fish kill occurred in August 2012) (NMog=Site C-North Mogeely (Garryoughtragh); SMog=Site B-South Mogeely (Killamucky); Castle=Site A-Castlemartyr (Grange)).

Using the FCS2-Ireland fish classification tool, each site surveyed on the Kiltha River was assigned a fish classification status (Table 3.18). The North Mogeely site, upstream of the fish kill zone, was classed as Good on all three survey occasions whereas the two sites located within the impacted zone, were assigned a fish status of Poor in 2012 and 2013 and Moderate in 2014. The South Mogeely site failed due to lower than expected abundance of brown trout fry and salmon parr and the Castlemartyr site was downgraded due to lower than expected abundance of both brown trout and salmon (all age classes).

Table 3.18. Fish ecological status and fish kill history for sites surveyed on the Kiltha River 2012, 2013 and 2014. The ecological quality class and associated confidence in class are shown (Blue =High status, Green=Good; Yellow=Moderate; Orange=Poor and Red=Bad; * indicates within and closest site to source of discharge, ** indicates site within fish kill zone).

			Ecological status		
Site	**Site name**	**2012**	**2013**	**2014**	**Reason for failure**
C	North Mogeely	Good	Good	Good	N/A

B	**South Mogeely***	**Poor**	**Poor**	**Mod**	Lower than expected brown trout fry and salmon parr
A	Castlemartyr**	**Poor**	**Poor**	**Mod**	Lower than expected abundance of brown trout and salmon

4. Discussion

4.1 Spatial and temporal trends

Available information for a total of 2107 fish kills reported from 1969 to 2022 was collated and reviewed. Four phases of fish kills occurred in Ireland since 1969. The number of reported fish kill events has decreased since the 1980s. The worst years for reported fish kills were in the 1980s, particularly 1984, 1987 and 1980 with a total of 347 fish kills recorded. Since 1992, there has been a downward trend in reported fish kills. The peak in fish kill reports in the 1980s coincided with an intensification of agriculture. In response to this situation, a nationwide public information campaign was launched, and an enforcement strategy was put in place by the Regional Fisheries Boards and Local Authorities. Despite the downward trend since about 2012, there have been some relatively high numbers recorded in some years, mainly coinciding with heatwaves and droughts.

Most fish kills occurred during summer months, when temperatures were higher and rainfall lower, with the associated low water levels leaving streams with less capacity to dilute pollution. Warmer water has less capacity for dissolved oxygen and, therefore, deoxygenation occurs more frequently in summer. In winter, water levels are higher and effluents can be diluted more effectively; colder water holds more dissolved oxygen, thereby rendering the same amount of discharged effluent potentially less damaging than in summer. Warm weather causes bacteria involved in the natural decomposition process in waterbodies to multiply faster which can also lead to an increase in deoxygenation. Respiration of fish and other aquatic organisms is also higher in summer as their metabolic rate increases due to warmer temperatures; therefore, their need for oxygen is normally higher in summer (IFT, 1974).

Spatial data was available for 1738 fish kills. Fish kills occurred in every county since 1969. Fish kill events were less frequent in the west and northwest and hotspots were particularly prevalent in the east, south and the north midlands coinciding with intensive agricultural activity and large urban centres. Counties Cork and Cavan had the highest proportion of fish kills, while Co. Roscommon and Co. Westmeath had the lowest. IFI have been assessing the ecological status of fish stocks in waterbodies in Ireland since 2007 and this has shown that waterbodies assigned High and Good fish ecological status are more prevalent in the waterbodies along the Atlantic seaboard than in the midlands, east and south (e.g. Corcoran *et al.*, 2023). The Environmental Protection Agency has observed a similar spatial pattern (e.g. EPA, 2024).

In the 1970s the highest number of fish kills (where spatial data was available) was reported from Co. Tipperary and in the 1980's this was Co. Cork. In the 1990s and 2000s, Co. Cavan had the highest and in the 2010s it was Co. Cork. Since 2020, the highest number has been recorded in Co. Cavan followed by Co. Cork. Spatial data from recent agricultural censuses (1991, 2002, 2010 and 2021) shows that counties Cork and Tipperary have consistently had the highest total cattle populations but are also two of Ireland's largest counties by area. The highest populations of pigs by county in 2020 were recorded in Counties Cavan, Cork, Offaly and Tipperary (e.g. CSO, 2020).

Since 1969 the Erne Catchment (*Hydrometric Area 36*) has had the highest number of reported fish kills. This was followed by the Lee, Cork Harbour and Youghal Bay catchment (*Hydrometric Area 19*), the Barrow (*Hydrometric Area 14*), Suir (*Hydrometric Area 16*) and Liffey and Dublin Bay (*Hydrometric Area 09*). The Eastern River Basin District (fishery region) had the highest number of fish kill reports during the study period. Two river sub-basin waterbodies in the ERBD (Avoca_020 and Avoca_010) had the highest number 55 fish kill reports. The Erne_080, Feale_090, Barrow_140 and Cavan_010 were also among the top six waterbodies with the highest number of fish kill reports.

Rivers were the most impacted waterbody type followed by lakes. Salmonids were the main fish group affected by fish kills and brown trout followed by salmon were the main species affected. Fish vary considerably in their tolerance of poorly oxygenated conditions. Salmonids (e.g. brown trout and salmon) need the most oxygen and will not survive for long when dissolved oxygen concentration is less than 50% saturation and will often move out of reaches where the concentration is less than 70% saturation (IFT, 1974). Other species, such as perch and pike do not need as much oxygen as salmonids (>50%), while tench, carp and eels can tolerate even lower oxygen conditions (as low as 20% D.O. saturation).

4.2 Causes

Agriculture was the most frequently reported cause of fish kills in Ireland from 1969 to 2022, accounting for 23% of known causes. This was followed by eutrophication (13%), a proportion of which may also be from agriculture (e.g. runoff from fertiliser) as well as other sources (e.g. release of sewage effluent into waterbodies), industrial (12%), other (9%), municipal (8%), mining (8%) and construction (2%).

The proportion of fish kills attributed to agriculture, eutrophication, industry, construction and mining (excluding unknowns) was lower in the 2006-2022 period than the 1969-2006 period; however, the proportion of fish kills associated with municipal and other sources increased from 9.4% to 22.3%

between the two periods. The decrease in the number of fish kills due to agriculture, eutrophication, industry and construction may be due to the introduction of the GAP Regulations in 2006, the EPA Act 1992 (e.g. introducing stricter licensing controls on certain activities) and other Regulations. However the spatial patterns for the four main causes have not changed between the two eras.

Overall Co. Cork had the highest percentage (15.7%) of fish kills attributed to agriculture between 1969 and 2022. This was followed by counties Monaghan (10.2%), Limerick (9.6%), Cavan (9.1%), Tipperary (6.9%), Meath (5.3%) and Wexford (5.1%). Co. Cavan had the highest percentage (34.1%) reported due to eutrophication, followed by counties Cork (12.1%), Monaghan (8.6%), Tipperary (6.5%) and Laois (4.7%). The lowest percentage (0.4%) was recorded in counties Dublin, Kerry, Roscommon and Sligo. The highest percentage attributed to municipal sources was recorded in Co. Laois (13.2%). This was followed by Co. Cork (10.4%), Co. Cavan (9%), Co. Dublin (9%) and Co. Tipperary (9%). Co. Cork had the highest percentage (17.7%) of fish kills associated with industrial sources. This was followed by Counties Tipperary (13.3%), Kerry (12.8%), Dublin (6.9%), Monaghan (6.9%) and Cavan (5.4%).

Point sources of pollution can cause dramatic and sudden fish kill events causing thousands of deaths (e.g. the discharge of chlorinated water from a municipal water supply line on the River Dodder in 2013 caused the death of an estimated 3,000 fish). However non-point (diffuse) sources can cause chronic pollution over time leading to small intermittent fish kills and poor habitat conditions for fish or large fish kills depending on the intensity of the deleterious inputs. Fish kills are a common occurrence in eutrophic shallow lakes (Sayer *et al*., 2016). Eutrophication (i.e. the over enrichment of rivers and lakes by nutrients entering waterbodies) can lead to excess plant and algal growth, decrease water clarity, algal blooms and deoxygenation. Eutrophication can affect fish in many ways, including causing a change in community structure (e.g. from salmonid (pollution intolerant) dominated, to cyprinid (pollution tolerant) dominated), clogging of gills, poisoning by toxic secretions, localised anoxia, loss of food sources (due to changes in benthic community structure in rivers or changes in phytoplankton structure in lakes), reduction in growth, increase in fish disease, and may also cause a sustained elimination of fish from a waterbody (e.g. Dorgahm, 2014, Kies, 2023; Sandström and Karås, 2002).

Many pollutants can be deoxygenating or toxic to certain fish species. Fish and aquatic invertebrates require dissolved oxygen to survive. If large amounts of organic wastes are discharged into a water body, they serve as a food source for bacteria (decomposition), which then proliferate and deplete the dissolved oxygen reserves present. This may lower the oxygen content of a waterbody to critical levels, where fish and other organisms die (IFT, 1974). Substantial amounts of toxic ammonia can also be produced during this process. Common organic wastes that can cause major pollution events include silage effluents and milk wastes. Other common organic pollutants are domestic sewage, farmyard run-off, manure or slurry from piggeries, cattle sheds, poultry houses and marts, abattoir wastes, wastes from breweries, etc. (e.g. IFT, 1974). The effect of organic wastes varies depending on the volume of the discharge, size of the waterbody and water temperature (IFT, 1974). Other pollutants such as suspended solids can increase turbidity and may smother the stream bed preventing water from passing through gravels in which trout and salmon lay their eggs and, in some cases, may suffocate fish by clogging their gills. Mining wastes can contaminate rivers with certain metals, some of which can be toxic to fish in certain concentrations and can persist for decades in sediments (e.g. Gray, 1997). Many pesticides and other chemicals are also toxic to fish. For example, minute levels of cypermethrin, a chemical that was used in agriculture (e.g. sheep dips) and forestry (e.g. pine weevil treatment) can be extremely toxic to fish, with minute concentrations in water producing stress or even resulting in death at 0.4-2.2 µg/l (Stephenson, 1982).

The impact of agriculture on aquatic ecosystems is well documented and recognised as the source of both diffuse (i.e. eutrophication (enrichment of water by nutrients by runoff from land) and point sources (e.g. a direct discharge of slurry into a waterbody) (e.g. Zia *et al*., 2013, EPA, 2021). Pollutants from agriculture includes pesticides, nitrogen compounds, phosphates, livestock waste and particulates/sediment through soil erosion (Carpenter *et al*., 1998; Skinner *et al*., 1997). Point sources are more likely to be a direct cause of a sudden fish kill whereas diffuse agricultural pollution is one of several possible factors causing eutrophication. Often, poor agricultural practices are a source of pollution and critical element when a fish kill occurs. Slurry and silage effluents are common agricultural pollutants in Ireland, often exacerbated by the spreading of slurry and fertilisers before or during periods of rainfall. The benefits of vegetative riparian buffer zones in reducing pollution run-off are known (Bingham *et al*., 1980) and play an important role in filtering sediments and nutrients from cropland runoff (Dillaha, 1989). Often, such exclusionary riparian margins are too narrow or non-existent. European policy measures exist to mitigate this problem, with agri-environment schemes such as the Agri Climate Rural Environment Scheme (ACRES) requiring its participants to take environmental improvement measures, in return for grant aid.

Cattle are agents of geomorphological change and heavy grazing leads to soil compaction which limits the soil’s infiltration capacity and increases runoff (Trimble and Mendel, 1995). Cattle drinks or troughs located near watercourses may help funnel surface water more quickly into watercourses (e.g. O’ Callaghan, 2018) thus bypassing the land’s natural nutrient filtration capabilities. In a review by O’ Callaghan (2018), the impacts arising from cattle access to a river included a loss of riparian vegetation, a reduction in depth and increase in channel width, reduced bank stability, increased sedimentation and the simplification of in-stream habitats including impacts to the hyporheic zone through the clogging of interstitial spaces.

While such processes are chronic in nature and might lead to reduced fish populations in general, they are unlikely to result in a sudden fish kill event. Instead, they can help create the underlying conditions necessary for a fish kill event to occur when some other sudden factor arises, such as an intense bout of warm weather combined with a drought, or an effluent spillage. In addition, the reduction in habitat quality and variety will reduce the refugia available to fish and their different age/size cohorts, increasing the chances of a sudden impact becoming something more catastrophic.

Cattle access represents a potentially significant localised impact on freshwater systems (Conroy *et al.,* 2016); however this might not be true at reach level, unless there is intense grazing and access along a significant portion of the channel. Instead, significant localised impacts are more likely a combination of other processes, yet still related to livestock intensity in the area. These include farmyard run-off, fertiliser spreading, slurry and effluent spillages. Throughout the literature, negative impacts from cattle access commonly relate to hydromorphology and sedimentation (O'Callaghan *et al*., 2018; Rice *et al*., 2021) and microbial load including disease-causing bacteria and viruses (Nagels and Davies-Colley, 2002; O'Callaghan *et al*., 2018; Vidon *et al*., 2008).

Indirectly, agricultural runoff (from animal wastes and fertilizers draining fields) can cause harmful algal blooms and deoxygenation in waterbodies, when rainwater washes nutrients off the land, into streams and rivers causing excess plant growth and ultimately deoxygenation (i.e. eutrophication). This (eutrophication) can also be caused by other non-point sources of nutrients such as lawn fertilisation, application of pesticides, forestry, road construction or building construction, urban runoff and nutrient runoff in storm water overflows.

Non-point sources of phosphorus and nitrogen are difficult to measure due to the dispersed nature of activities that contribute them to a system (Carpenter *et al*., 1998). Nutrient enrichment, due to nitrates and phosphates causes eutrophication depleting the oxygen available for fish, an effect exacerbated during the night, when net photosynthesis shifts to net respiration (Neal *et al*., 1998). The effects of low dissolved oxygen on fish include impacts to fish behaviour, metabolic rate, egg and larval development and sensitivity to toxic stress (e.g. Davis, 1975; Hamor and Garside, 1976; McKim, 1977). Dissolved oxygen concentrations are influenced by a range of factors which include temperature, photosynthesis, respiration, salinity and atmospheric exchange (Davis, 1975). Such effects are intensified, when temperatures increase, water levels decrease and channels experience droughts, especially during the summer (Neal *et al*., 1998).

Sources of pollution from industry include effluents and waste originating from factories and processing plants. In Ireland, this is often due to industries supporting local agricultural services, including creameries and abattoirs. On other occasions, pollution comes from chemical waste, petrochemical spillages (see below) and the release of detergents and other toxic substances.

Sources of pollution resulting from the activities of local authorities and municipal services include sewage from wastewater treatment plants, releases of washings and chlorinated water (see below) from water supply facilities and leachate from local landfills. Construction has contributed to several fish kills in Ireland and tends to result from excessive silt and sediment entering the channel during works or cement spillages.

Chlorination is used in the disinfection and treatment of drinking, bathing and wastewater (e.g. Bellanca, 1977; Brungs, 1973). Chlorine is highly toxic to fish and causes a reaction in the blood preventing oxygen use, which results in fish death due to anoxia (Grothe and Eaton, 1975). Chlorine can also cause gill tissue necrosis in fish leading to respiratory problems (e.g. Mahjoor and Loh, 2008). Effluents containing chlorine originating from water treatment plants and swimming pools have caused several fish kills in Ireland over the past fifty years, most notably, in the Dodder River in 2013, when a water supply pipeline discharged high levels of chlorine into the river.

Several fish kills involving oil and hydrocarbon spillages have occurred in Irish rivers over the past number of decades. Oil spills impact flowing water to a lesser degree than standing water, due to the current's ability to flush pollutants out more quickly (e.g. Yount and Neimi, 1990). The impact, however, can be severe. In open water, oil can be toxic to fish; at the bottom, it may get trapped in the sediment, harming benthic organisms; along the margins, it can coat plant material, reducing its potential as a food source and means of shelter for other aquatic organisms (USEPA, 2018). Fish exposed to hydrocarbons may also suffer from a variety of dysfunctions, including neoplasia (growth defects), reduced reproductive success and immunotoxicity (Collier *et al*., 2013). Oil spills behave differently in freshwater than in the sea. Due to its salt content, sea water is more dense than freshwater and allows lighter, less dense oils, including unleaded petrol (<0.78 g/cc) (CEN, 2008) and diesel (<0.85 g/cc) (CEN, 2009) to rise above it, within the water column (NOAA, 2018). Heavier oils (>1.01 g/cc), that would normally float in sea water, may sink to the bottom of a river (NOAA, 2018), contaminating the sediment (Wilson *et al*., 2005). Hydrocarbons can persist for years in sediments (e.g. Blumer and Sass, 1972; Burns *et al*., 1994; Reddy *et al*., 2002) but depending on their composition, state and concentration, can eventually be decomposed by bacteria and fungi (Leahy and Colwell, 1990).

Pollution originating from mining is relatively uncommon in Ireland but is known in a few areas, most notably, the Avoca catchment in Co. Wicklow. Mining activity accounted for many fish kill reports in Co. Wicklow in 2003. From the 17th century up until 1982, mines adjacent to the Avoca River produced iron, lead and copper. Subsequent flooding and acid mine leachate has resulted in serious pollution problem along a significant length of the Avoca channel (Yau and Gray, 2005). Heavy metals may be present in both surface water and sediment but do not all share the same level of mobility (Islam *et al*., 2015). A relationship exists between the concentration of metals in both sediment and water and those present in fish tissue (Bervoets and Blust, 2003). High metal concentrations impact physiological processes in fish (e.g. Hansen *et al*., 2002) and higher concentrations of specific metals accumulate more in specific organs, with one study for example showing copper to accumulate to higher levels in the liver (Rashed, 2001).

Some reported fish kills were assigned a cause due to high temperatures and drought (in the “other” category). However, in Ireland fish kills resulting from high temperatures and drought alone are rare (coinciding with a complete absence of thermal and spatial refugia available for fish). Based on the evidence of this study, mortalities attributable to this cause often happened when other pressures also existed, such as nutrient enrichment (eutrophication) and other forms of pollution discharge and it was potentially the increase in water temperature that compounded the effect of the underlying water quality problem. Certain cold water fish species, e.g. brown trout and salmon feed and grow optimally in cooler water temperatures usually at or below 16°C and where dissolved oxygen levels are close to 100% saturation and above 70% saturation (Swift, 1961; Allen, 1985; Forseth and Johnsson, 1994). The scientific literature suggests that the lethal water temperature threshold for brown trout and salmon ranges from 22 to 26°C depending on age cohort (Forseth and Johnsson, 1994 Elliott, 2010) while sustained values exceeding 20°C are believed to induce significant physiological stress and increase mortality risk. Recent IFI studies have shown that maximum water temperatures reached or exceeded these figures during recent heat wave events since 2018 (e.g. Barry *et al*., 2024); therefore certain catchments and certain areas of catchments will be more at risk to fish kills during heatwaves and droughts in the coming years as climate change is predicted to cause increases in air temperature, heatwaves, dry periods/droughts and heavy precipitation events (Nolan and Flanagan, 2020).

4.3 Recovery after a fish kill

The recovery of fish populations in the four case study rivers varied from site to site and river to river, but in general the impact and recovery was similar.

Total fish abundance was often higher one year after the fish kill occurred in the impacted zone than the unaffected stretch. This was caused, in some cases (e.g. Vartry and White River) by an increase in tolerant fish species (e.g. stone loach, minnow and three-spined stickleback) at sites closest to the discharge. Often another species of small fish (or age class) will fill a void left after a fish kill in a river segment, resulting in abundance levels higher than those of unaffected segments (Anon, 2003). Nordwall *et al*. (2001) found that, when brown trout belonging to the 1+ and older cohort were removed from several streams in Sweden, an increase in the 0+ and 1+ cohorts was observed the following year. In this case, less competition from larger, older cohorts may have facilitated alevin survival upon hatching.

Certain age cohorts of brown trout and salmon were absent or present in low densities immediately or one year after each fish kill. Many sites had recovered three years after the fish kill event, as observed by the return of most age cohorts. This is similar to other published studies. A study on the Blackwater River in Northern Ireland found salmonid abundance to recover within one year, total salmonid biomass to recover within two years, and population age structure to recover within three years (Kennedy, 2012). Similarly, a study from Minnesota USA, showed brown trout recovery to start quickly, with the return of spawning adults to an impacted reach one month later, successful spawning activity over the next two years (albeit at a lower rate than in an unimpacted reference reach), and a similar total brown trout population 16 months later. Population age structure, however, had not fully recovered by the end of that study, twenty-nine months later (Schnaser and Mundahl, 2022). However, one longer term case study on an Irish river suggested that the recovery of 1+ and older brown trout took four to five years (King, 2015).

Timing of the fish kill also affected recovery of fish populations. For example, the fish kill on the River Dodder occurred in March 2013. Brown trout fry were present at all monitored sites downstream of the discharge point 126 days after the fish kill. Therefore, it is most likely that the eggs located in the redds in spring 2013 survived the fish kill event (discharge of chlorine), while older age classes may have been eradicated or moved downstream to cleaner waters. Upon hatching, the void left by older trout may have enabled the brown trout fry to flourish, particularly at the Firhouse site.

Although there was a perceived recovery (e.g. pre-fish kill conditions at unimpacted sites) of fish populations at many of the case study sites, the fish ecological status on many sites had not reached the required Water Framework Directive standard of Good status. This requires that all age cohorts of type specific indicator species be present in expected abundances to achieve this milestone and in many cases, this was not achieved. A variety of factors can help or hinder the recovery process including removing the source of the problem (Niemi *et al*., 1990). Due to lags associated with fish recolonisation and recovery of food webs following a fish kill, effects on an ecosystem may last for several decades depending on the habitat type (Sayer et al., 2016). The water quality in the wider catchment is an important factor as sources of re-colonisation provided by refugia are an important element in the recovery of fish populations but this can also depend on the level of habitat diversity present at the site (Aarts *et al*., 2004; Yount and Niemi, 1990). The physical state of the impacted site is important and where the physical state of the river is poor, recovery may take longer (Niemi *et al*., 1990) or may never achieve the same level as unmodified sites (e.g. Kiltha River in this study). Habitat heterogeneity is important for mitigating pollution effects. For example, research by Elliot (2000) highlighted the importance of pools during drought conditions. Although colder water has a greater capacity to hold dissolved oxygen (Harvey *et al*., 2011), deeper, cooler water on the bottom of a pool may be preferable to warmer water higher up, even if oxygen concentrations are greater at shallower depths (Elliot, 2000). In addition, site connectivity must remain unsuppressed to allow fish to move freely and recolonise impacted reaches (Kubach *et al*., 2011; Niemi *et al*., 1990).

If waterbodies are to recover after fish kills it is essential that nutrient and other deleterious inputs to Irelands waterways are reduced and best practice is followed in all activities in and adjacent to the waterways.

4.4 Management considerations

Attributing the cause of a fish kill has implications for managers, policymakers, scientists and the public. Often, there are multiple causal factors that act in concert (Burkholder *et al*., 1999). Using a historical fish kill database to show trends can be problematic due to patchy and incomplete data, data often collected from multiple, disparate sources. Furthermore, inaccurate spatial information may have been reported or was absent.

The assignment of clearly defined causal categories, like those presented in this study has its risks and ignores combined sources. This is clear in the case of agriculture. Agriculture may be obviously and directly responsible for causing a fish kill where chemical and effluent discharges are concerned but could also be blamed for eutrophication and de-oxygenation during high temperatures and drought. However, eutrophication could also be caused by municipal and other sources.

Assigning accurate spatial data is important for future reporting. As part of this study, a new spatial data collection application is being developed using ArcGIS Survey 123. This application aims to standardise and enhance the quality of data recorded for future fish kills in Ireland by ensuring that, at the very minimum, each record includes a date, location coordinates and cause. It is not limited to that basic information, however and allows for the collection of numerous other parameters.

4.5 Future work

As discussed above, fish kill events occur more frequently during the summer months when temperatures rise and rainfall decreases. Both, however, may only be compounding the effects of other underlying factors, such as eutrophication. Further work should consider modelling, to evaluate the potential risk of fish kills in catchments based on their land use, underlying geology and water quality. Temperature and rainfall data and climate change predictions should be incorporated into the model and this would be useful for future work-force planning and climate adaptation measures. The work of IFI's climate change research projects will support this work by providing high resolution water temperature data.

5. References

Aarts, B. G., Van Den Brink, F. W. and Nienhuis, P. H. 2004 Habitat loss as the main cause of the slow recovery of fish faunas of regulated large rivers in Europe: the transversal floodplain gradient. *River Research and Applications*, **20 (1)**, 3-23.

Allen, K.R. 1985 Comparison of the growth rate of brown trout (*Salmo trutta*) in a New Zealand stream with experimental fish in Britain. *Journal of Animal Ecology*, 487-495.

Barica, J. 1975 Summer kill risk in prairies ponds and the possibilities of prediction. Journal of the Fisheries Research Board of Canada, **32**, 1283-1288.

Barry, J., Coyne, J., Brennan, A., Walsh, A. and Kelly, F.L. 2024 *Climate Change Mitigation Research Programme (CCMRP) and Office of Public Works Climate Resilience Project (WOPCRP) – Joint Annual Report*. National Research Survey Programme, Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24.

Bellanca, M.A. and Bailey, D.S. 1977 Effects of chlorinated effluents on aquatic ecosystem in the lower James River. *Journal of Water Pollution Control Federation*, **49 (4)**, 639-645.

Bingham, S.C., Westerman, P.W. and Overcash, M.R. 1980 Effect of grass buffer zone length in reducing the pollution from land application areas. *Transactions of the American Society of Agricultural Engineers*, **23 (2)**, 330-0335.

Blumer, M. and Sass, J. 1972 Oil pollution: persistence and degradation of spilled fuel oil. *Science*, **176 (4039)**, 1120-1122.

Boelens, R.G. and O 'Sullivan, C.M. 1982 *A Guide to the Investigation of Fish Kills*. Institute for Industrial Research and Standards, Dublin.

Bervoets, L. and Blust, R. 2003 Metal concentrations in water, sediment and gudgeon (*Gobio gobio*) from a pollution gradient: relationship with fish condition factor. *Environmental pollution*, **126 (1)**, 9-19.

Brungs, William A. 1973 Effects of residual chlorine on aquatic life. *Journal of Water Pollution Control Federation*, **45 (10)**, 2180-2193.

Burkholder, J.M., Mallin, M.A. and Glasgow, H.B. 1999 Fish kills, bottom-water hypoxia, and the toxic Pfiesteria complex in the Neuse River and Estuary. *Marine Ecology Progress Series*, **179**, 301-310.

Burns, K.A., Garrity, S.D., Jorissen, D., MacPherson, J., Stoelting, M., Tierney, J. and Yelle-Simmons, L. 1994 The Galeta oil spill. II. Unexpected persistence of oil trapped in mangrove sediments. *Estuarine, Coastal and Shelf Science*, **38 (4)**, 349-364.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N. and Smith, V.H. 1998 Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, **8(3)**, 559-568.

CEN 2003 *Water Quality — Sampling of Fish with Electricity*. CEN EN 14011:2000.

CEN 2005 *Water Quality - Guidance on the scope and selection of fish sampling methods*. CEN EN 14962

CEN 2008 *Automotive fuels – Unleaded Petrol – Requirements and Test Methods*. European Standard. Ref. No. EN 228:2008

CEN 2009 *Automotive fuels – Diesel – Requirements and Test Methods*. European Standard. Ref. No. EN 590:2009

Collier, T.K., Bernadita, F.A., Arkoosh, M.R., Dietrich, J.P., Incardona, J.P., Johnson, L.L., Ylitalo, G.M. and Myers, M.S. 2013 Effects on fish of polycyclic aromatic hydrocarbons (PAHs) and naphthenic acid exposures. *Fish Physiology*, **33**, 195-255.

Conroy, E., Turner, J. N., Rymszewicz, A., O' Sullivan, J.J., Bruen, M., Lawler, D., ... and Kelly-Quinn, M. 2016 The impact of cattle access on ecological water quality in streams: Examples from agricultural catchments within Ireland. *Science of the Total Environment*, **547**, 17-29.

Corcoran, W., Matson, R., McLoone, P., Bateman, A., Cierpial, D., Gordon, P., McCarthy, E., Kelly, K., Robson, S., Wightman, G., Twomey, C., Roche, W. and Kelly, F.L. 2023 *Sampling Fish for the Water Framework Directive - Summary Report 2022*. National Research Survey Programme, Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24

Council of the European Communities 2000 Establishing a framework for Community action in the field of water policy. Directive of the European Parliament and of the Council establishing a framework for community action in the field of water policy (2000/60/EC). *Official Journal of the European Communities*, **43**, 1-73.

CSO 2020 https://www.cso.ie/en/releasesandpublications/ep/p-coa/censusofagriculture2020-preliminaryresults/livestock/

Curley, M., Coonan, B., Ruth, C.E. and Ryan, C. 2023 *Ireland's Climate Averages 1991-2000*. Climatological Note No. 22. Met Éireann, Ireland.

Cyrus, D.P. and McLean, S. 1996 Water temperature and the 1987 fish kill at Lake St Lucia on the southeastern coast of Africa. *Southern African Journal of Aquatic Sciences*, **22 (1-2)**, 105-110.

Davis, J. C. 1975 Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. *Journal of the Fisheries Board of Canada*, **32 (12)**, 2295-2332.

Dawson, K. 2002 Fish kill events and habitat losses of the Richmond River, NSW Australia: An Overview. *Journal of Coastal Research Special Issue*, **36**, 216-221

Davies-Colley, R. J. and Nagels, J. W. 2002 Effects of dairying on water quality of lowland streams in Westland and Waikato. *Proceedings of the New Zealand Grassland Association*, **64**, 107-114.

Detenbeck, N.E., DeVore, P.W., Niemi, G.J. and Lima, A. 2002 Recovery of temperate-stream fish communities from disturbance: A review of case studies and synthesis of theory. *Environmental Management*, **16(1)**, 33-53.

Dillaha, T.A., Reneau, R.B., Mostaghimi, S. and Lee, D. 1989 Vegetative filter strips for agricultural nonpoint source pollution control. Transactions of the American Society of Agricultural Engineers, **32(2)**, 513-0519.

Dorgham, M.M. 2014 Effects of Eutrophication. In. Anar, A.A., and Singh Gill, S. (Eds) *Eutrophication: Causes, Consequences and Control,* Volume 2. pp. 29-44. Springer Publications.

Doyle, A., Younger, P. L., Gandy, C.J. and Coulton, R. 2003 *Restoring the Avoca River: an Integrated Social/Technical Scoping Study of Acid Mine Drainage Remediation Options*. Report to the Eastern Regional Fisheries Board, Dublin.

Elliott, J.M. 2000 Pools as refugia for brown trout during two summer droughts: trout responses to thermal and oxygen stress. *Journal of Fish Biology*, **56 (4)**, 938-948.

Elliott, J. and Elliott, J.A. 2010 Temperature requirements of Atlantic salmon *Salmo salar*, brown trout *Salmo trutt*a and Arctic charr *Salvelinus alpinus*: predicting the effects of climate change. *Journal of Fish Biology*, **77 (8)**, 1793-1817.

EPA 2024 *Water Quality in 2023: An Indicators Report*. Environmental Protection Agency.

ESRI 2023 https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview.

Fahy, E. 1985 *Fish Kills in Ireland in 1983 and 1984*. Fishery Leaflet 128, Irish Fisheries Leaflets, Department of Fisheries and Forestry.

Fahy, E. 1986 *Fish Kills in Ireland in 1985*. Fishery Leaflet 132, Irish Fisheries Leaflets, Department of Tourism, Fisheries and Forestry.

Forseth, T. and Jonsson, B. 1994 The growth and food ration of piscivorous brown trout (*Salmo trutta*). *Functional Ecology*, **8 (2)**, 171-177.

Gray, N. 1997 Environmental impact and remediation of acid mine drainage: A management problem. *Environmental Geology*, **30 (1)**, 62-71.

Grothe, D.R. and Eaton, J.W. 1975 Chlorine-induced mortality in fish. *Transactions of the American Fisheries Society*, **104 (4)**, 800-802.

Hamor, T. and Garside, E. T. 1976 Developmental rates of embryos of Atlantic salmon, *Salmo salar* L., in response to various levels of temperature, dissolved oxygen, and water exchange. *Canadian Journal of Zoology*, **54 (11)**, 1912-1917.

Harvey, R., Lye, L., Khan, A. and Paterson, R. 2011 The Influence of air temperature on water temperature and the concentration of dissolved oxygen in Newfoundland Rivers. *Canadian Water Resources Journal*, **36 (2)**, 171-192.

Hansen, J.A. 2003 The effects of long-term cadmium exposure on the growth and survival of juvenile bull trout (*Salvelinus confluentus*). *Aquatic toxicology*, **58 (3-4)**, 165-174.

IFI 2020 *The Status of Fish Stocks in the Vartry River Catchment, Co. Wicklow, 2013 to 2019*. Inland Fisheries Ireland, 3044 Lake Drive, Citywest Business Campus, Dublin 24, D24 Y265.

IFT 1974 *Pollution and Eutrophication*. Supplement to the Annual Report 1973/1974. The Inland Fisheries Trust Incorporated. 36pp.

Islam, M.S., Ahmed, M.K., Raknuzzaman, M., Habibullah-Al-Mamun, M. and Islam, M.K. 2015 Heavy metal pollution in surface water and sediment: a preliminary assessment of an urban river in a developing country. *Ecological Indicators*, **48**, 282-291.

Kennedy, R.J., Rosell, R. and Hayes, J. 2012 Recovery patterns of salmonid populations following a fish kill event on the River Blackwater, Northern Ireland. *Fisheries Management and Ecology*, **19 (3)**, 214-223.

Kennedy, R.J., Allen, M., Rosell, R. and Reid, A. 2017 An assessment of carcass counting surveys with increasing time lapse following a simulated fish kill on a small upland stream. *Fisheries Management and Ecology*, **24 (6)**, 446-451.

Kies, F. 2024 Impact of eutrophication on lake fish diseases. International Journal of Veterinary Research, **4 (1)**, 1-9.

King, J.J. 2015 Ecology and economics of fish kills; Mortality and recovery of Brown trout (*Salmo trutta* L.) and Atlantic salmon (*Salmo salar* L.) in an Irish river. *Biology and Environment – Proceedings of the Royal Irish Academy*, **115B (3)**, 157-170.

Kubach K.M., Scott M.C. and Bulak J.S. 2011 Recovery of a temperate riverine fish assemblage from a major diesel oil spill. *Freshwater Biology*, **56**, 503-518.

Leahy, J.G. and Colwell, R.R. 1990 Microbial degradation of hydrocarbons in the environment. *Microbiological Reviews*, **54 (3)**, 305-315.

MacCarthaigh, M. 1996 *An Assessment of the 1995 Drought. Including a Comparison with Other Known Drought Years*. Environmental Protection Agency Report.

Magoulick, D.D. and Kobza, R.M. 2003 The role of refugia for fishes during drought: a review and synthesis. *Freshwater Biology*, **48 (7)**, 1186-1198.

Mahjoor, A.A. and Loh, R. 2008 Some histopathological aspects of chlorine toxicity in rainbow trout (Oncorhynchus mykiss). *Asian Journal of Animal and Veterinary Advances*, **3 (5)**, 303-306.

Marcos-Lopez, M., Gale, P., Oldtmann, B.C. and Peeler, E.J. 2010 Assessing the impact of climate change on disease emergence in freshwater fish in the United Kingdom. *Transboundary and Emerging Diseases*, **57 (6)**, 293-304.

McCarthy, D. 1988 *Fish Kills 1969 – 1987*. Fishery Leaflet 141, Irish Fisheries Leaflets, Department of the Marine.

McCarthy, D. and Moriarty, C. 1989 *Fish Kills in Ireland in 1988*. Fishery Leaflet 143, Department of the Marine.

McKim, J. M. 1977 Evaluation of tests with early life stages of fish for predicting long-term toxicity. *Journal of the Fisheries Board of Canada*, **34 (8)**, 1148-1154.

Met Éireann 2018a Exceptional Weather Events. Retrieved from: https://www.met.ie/cms/assets/uploads/2020/06/Summer2018.pdf.

Met Éireann 2018b *Summer 2018 – An Analysis of the Heatwaves and Droughts that Affected Ireland and Europe in the Summer of 2018*. Issued by the Climatology and Observations Division of Met Eireann.

Moriarty, C. 1990 *Fish Kills in Ireland in 1989*. Fishery Leaflet 146, Department of the Marine.

Moriarty, C. 1991 *Fish Kills in Ireland in 1990*. Fishery Leaflet 149, Department of the Marine.

Moriarty, C. 1993 *Fish Kills in Ireland 1991 - 1992*. Fishery Leaflet 157, Department of the Marine.

Moriarty, C. 1994 *Fish Kills in Ireland in 1993*. Fishery Leaflet 159, Department of the Marine.

Moriarty, C. 1996 *Fish Kills in Ireland in 1994 and 1995*. Fishery Leaflet 169, The Marine Institute.

Nagels, J.W., Davies-Colley, R.J., Donnison, A.M. and Muirhead, R.W. 2002 Faecal contamination over flood events in a pastoral agricultural stream in New Zealand. *Water Science and Technology*, **45 (12)**, 45-52.

Napier, G.M, Fairweather, P.G. and Scott, A.C. 1998 Records of fish kills in inland waters of NSW and Queensland in relation to cotton pesticides. *Wetlands (Australia)*, **17 (2)**, 60-71.

Neal, C., Harrow, M. and Williams, R.J. 1998 Dissolved carbon dioxide and oxygen in the River Thames: spring–summer 1997. *Science of the Total Environment*, **210**, 205-217.

Niemi, G.J., DeVore, P., Detenbeck, N., Taylor, D., Lima, A., Pastor, J., Yount, J.D. and Naiman, R.J. 1990 Overview of case studies on recovery of aquatic systems from disturbance. *Environmental Management*, **14 (5)**, 571-587.

NOAA 2018 Office of Response and Restoration. Retrieved from: https://response.restoration.noaa.gov/about.

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

Noone, S., Broderick, C., Duffy, C., Matthews, T., Wilby, R.J. and Murphy, C. 2017 A 250-year drought catalogue for the Island of Ireland (1765-2015). *International Journal of Climatology*, **37 (Suppl.1)**, 230-254.

Nordwall, F., Naslund, I. and Degerman, E. 2001 Intercohort competition effects on survival, movement and growth of brown trout (*Salmo trutta*) in Swedish streams. *Canadian Journal of Fisheries and Aquatic Sciences*, **58 (11)**, 2298-2308

O' Callaghan, P., Kelly-Quinn, M., Jennings, E., Antunes, P., O'Sullivan, M., Fenton, O. and Ó hUallacháin, D. 2018 *Impact of Cattle Access to Watercourses: Literature Review on Behalf of the COSAINT Project*. Environmental Protection Agency of Ireland: Wexford, Ireland.

Ochumba, P.B. 1990 Massive fish kills within the Nyanza Gulf of Lake Victoria, Kenya. *Hydrobiologia*, **208**, 93-99.

Olmsted, L.L. and Cloutman, D.G. 1974 Repopulation after a fish kill in Mud Creek, Washington County, Arkansas following pesticide pollution. *Transactions of the American Fisheries Society*, **103 (1)**, 79-97.

Peterson, J.T. and Bayley, P.B. 2011 Colonization rates of fishes in experimentally defaunated warmwater streams. *Transactions of the American Fisheries Society*, **122 (2)**, 199-207.

Poff N.L. and Ward, J.V. 1990 Physical habitat template of lotic systems: recovery in the context of historical pattern of spatiotemporal heterogeneity. *Environmental Management,* **14**, 629-645.

Rashed, M.N. 2001 Monitoring of environmental heavy metals in fish from Nasser Lake. *Environment International*, **27 (1)**, 27-33.

Reddy, C.M., Eglinton, T.I., Hounshell, A., White, H.K., Xu, L., Gaines, R.B. and Frysinger, G.S. 2002 The West Falmouth oil spill after thirty years: the persistence of petroleum hydrocarbons in marsh sediments. *Environmental Science and Technology*, **36 (22)**, 4754-4760.

Rhodes, K. and Hubbs, C. 1992 Recovery of Pecos River fishes from a red tide fish kill. *The Southwestern Naturalist*, **178-187**.

Rice, A.R., Cassidy, R., Jordan, P., Rogers, D. and Arnscheidt, J. 2021 Fine-scale quantification of stream bank geomorphic volume loss caused by cattle access. *Science of the Total Environment*, **769**, 144468.

Roghair C.N. and Dolloff C.A. 2005 Brook trout movement during and after recolonisation of a naturally defaunated stream reach. *North American Journal of Fisheries Management*, **25**, 777-784.

Ryon, M.G., Beauchamp, J.J., Roy, W.K., Schilling, E., Carrico, B.A. and Hinzman, R.L. 2000 Stream dispersal of dead fish and survey effectiveness in a simulated fish kill. *Transactions of the American Fisheries Society*, **129 (1)**, 89-100.

Sandström, A. and Karås, P. 2002 Effects of eutrophication on young-of-the-year freshwater fish communities in the coastal areas of the Baltic. *Environmental Biology of Fishes*, **63**, 89-101.

Sayer, C.D., Davidson, T.A., Rawcliffe, R., Langdon, P.G., Leavitt, P.R., Cockerton.G., Rose, N.L. and Croft. 2016 Consequences of fish kills for long-term trophic structure in shallow lakes: Implications for theory and restoration. *Ecosystems*, **19**, 1289-1309.

Schnaser, A.C., Mundahl, N.D. 2022 Recovery of a headwater stream population of brown trout after a fish kill in southeastern Minnesota, USA. *Environmental Biology of Fishes*, **105**, 1179–1192.

Schneider, J. 2010 White River Fish Kill: 10 Years of Recovery. *The Herald Bulletin*, **Jan 16**, 2010. http://www.heraldbulletin.com

Sedell, J.R., Reeves, G.H., Hauer, F.R., Stanford, J.A. and Hawkins, C.P. 1990 Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. *Environmental Management*, **14 (5)**, 711-724

Skinner, J.A., Lewis, K.A., Bardon, K.S., Tucker, P., Catt, J.A. and Chambers, B.J. 1997 An overview of the environmental impact of agriculture in the UK. *Journal of Environmental Management*, **50 (2)**, 111-128.

SNIFFER 2011 *River Fish Classification Tool: Science Work*. WFD68c, Phase 3, Final Report. Scotland and Northern Ireland Forum for Environmental Research.

Stephenson, R.R. 1982 Aquatic toxicology of cypermethrin. I. Acute toxicity to some freshwater fish and invertebrates in laboratory tests. *Aquatic Toxicology*, **2 (3)**, 175-185.

Swift, D.R. 1961 The annual growth-rate cycle in brown trout (Salmo trutta Linn.) and its cause. *Journal of Experimental Biology*, **38 (3)**, 595-604.

Swingle, H.S. 1966 Fish kills caused by phytoplankton blooms and their prevention. *FAO World Symposium on Warm-Water Pond Fish Culture*, Rome 1966, 9pp.

Till, A., Rypel, A.L., Bray, A. and Fey, S.B. 2019 Fish die-offs are concurrent with thermal extremes in north temperate lakes. *Nature Climate Change*, **9**, 637-641.

Townsend, S.A., Boland, K.T. and Wrigley, T.J. 1992 Factors contributing to a fish kill in the Australian wet/dry tropics. *Water Research*, **26 (8)**, 1039-1044.

Trimble, S.W. and Mendel, A.C. 1995 The cow as a geomorphic agent—a critical review. *Geomorphology*, **13 (1-4)**, 233-253.

USEPA 2018 Sensitivity of Freshwater Habitats. Retrieved from: https://archive.epa.gov/emergencies/content/learning/web/html/freshwat.html.

Vidon, P., Campbell, M.A. and Gray, M. 2008 Unrestricted cattle access to streams and water quality in till landscape of the Midwest. *Agricultural Water Management*, **95 (3)**, 322-330.

Walsh, S., Copeland, C. and Westlake, M. 2004 Major fish kills in the northern rivers of NSW in 2001: causes, impacts and responses. NSW Department of Primary Industries, Fisheries, Final Report Series, 68, 59pp.

Wilson, C., Clarke, R., D'Arcy, B.J., Heal, K.V. and Wright, P.W. 200 5 Persistent pollutants urban rivers sediment survey: implications for pollution control. *Water Science and Technology*, **51 (3-4)**, 217-224.

Wilton T. 2002 *Stream Fish Community Follow-up Assessment: Fish Community Sampling Results*. Iowa Department of Natural Resources, Environmental Protection Division, Water Resources Section, 22pp.

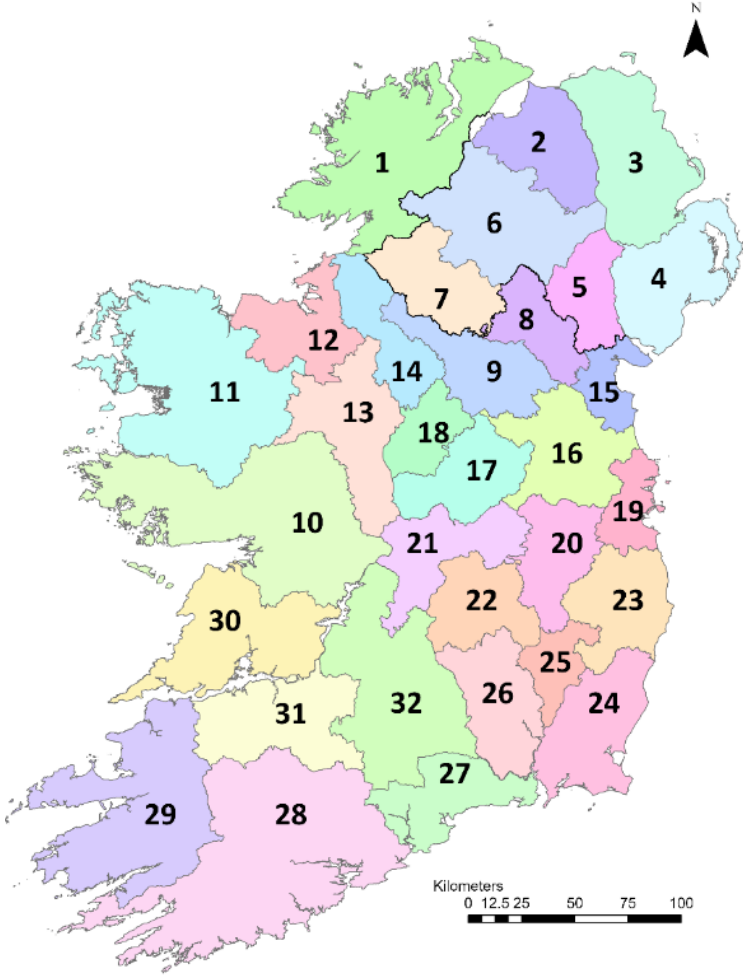
Yau, H. and Gray, N.F. 2005 Riverine sediment metal concentrations of the Avoca-Avonmore catchment, South-east Ireland: a baseline assessment. *Biology and Environment: Proceedings of the Royal Irish Academy*, **105B (2)**, 95-106).

Yount, J.D. and Niemi, G.J. 1990 Recovery of lotic communities and ecosystems from disturbance – A narrative review of case studies. *Environmental Management*, **14 (5)**, 547-569.

Zia, H., Harris, N. R., Merrett, G. V., Rivers, M. and Coles, N. 2013 The impact of agricultural activities on water quality: A case for collaborative catchment-scale management using integrated wireless sensor networks. *Computers and Electronics in Agriculture*, **96**, 126-138.

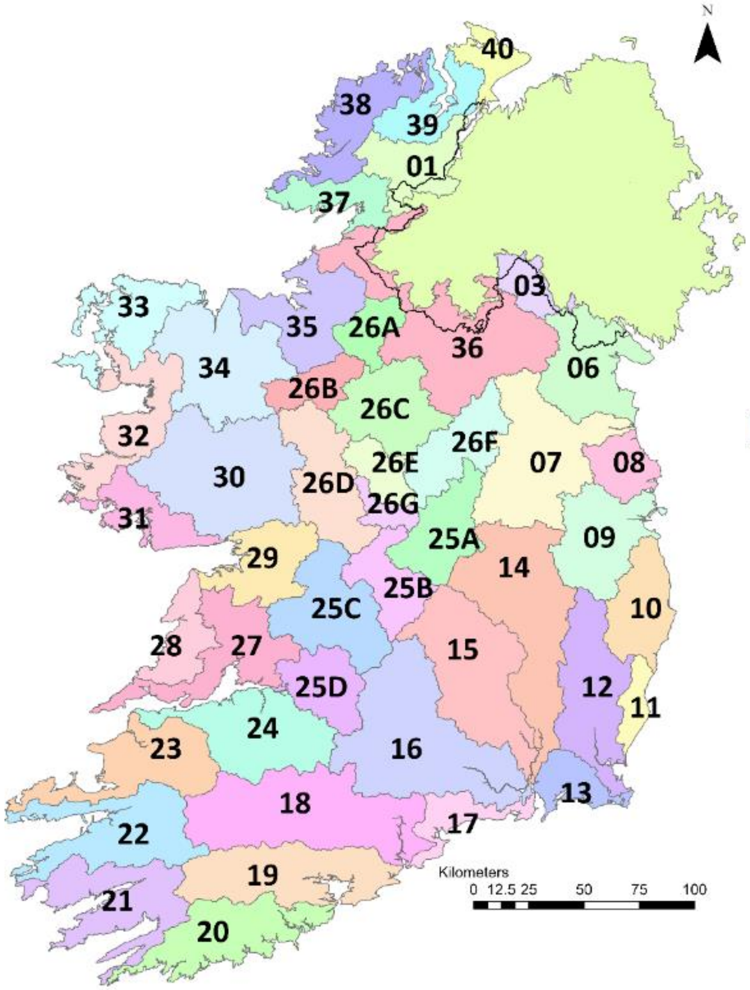
Zippin, C. 1956 An evaluation of the removal method of estimating animal populations. *Biometrics*, **12**, 163-189.

APPENDIX I. Ireland Counties



No.	County	No.	County
1	Donegal	17	Westmeath
2	Derry	18	Longford
3	Antrim	19	Dublin
4	Down	20	Kildare
5	Armagh	21	Offaly
6	Tyrone	22	Laois
7	Fermanagh	23	Wicklow
8	Monaghan	24	Wexford
9	Cavan	25	Carlow
10	Galway	26	Kilkenny
11	Mayo	27	Waterford
12	Sligo	28	Cork
13	Roscommon	29	Kerry
14	Leitrim	30	Clare
15	Louth	31	Limerick
16	Meath	32	Tipperary

APPENDIX II. Ireland Water Framework Directive Waterbodies



No.	Waterbody name	No.	Waterbody name
01	Foyle (01)	25C	Lower Shannon (25C)
03	Lough Neagh and Lower Bann (03)	25D	Lower Shannon (25D)
06	Newry, Fane, Glyde and Dee (06)	26A	Upper Shannon (26A)
07	Boyne (07)	26B	Upper Shannon (26B)
08	Nanny-Delvin (08)	26C	Upper Shannon (26C)
09	Liffey and Dublin Bay (09)	26D	Upper Shannon (26D)
10	Ovoca-Vartry (10)	26E	Upper Shannon (26E)
11	Owenavorragh (11)	26F	Upper Shannon (26F)
12	Slaney and Wexford Harbour (12)	26G	Upper Shannon (26G)
13	Ballyteigue-Bannow (13)	27	Shannon Estuary North (27)
14	Barrow (14)	28	Mal Bay (28)
15	Nore (15)	29	Galway Bay South East (29)
16	Suir (16)	30	Corrib (30)
17	Colligan-Mahon (17)	31	Galway Bay North (31)
18	Blackwater (Munster) (18)	32	Erriff-Clew Bay (32)
19	Lee, Cork Harbour and Youghal Bay (19)	33	Blacksod-Broadhaven (33)
20	Bandon-Ilen (20)	34	Moy and Killala Bay (34)
21	Dunmanus-Bantry-Kenmare (21)	35	Sligo Bay and Drowse (35)
22	Laune-Maine-Dingle Bay (22)	36	Erne (36)
23	Tralee Bay-Feale (23)	37	Donegal Bay North (37)
24	Shannon Estuary South (24)	38	Gweebarra-Sheephaven (38)
25A	Lower Shannon (25A)	39	Lough Swilly (39)
25B	Lower Shannon (25B)	40	Donagh-Moville (40)

Inland Fisheries Ireland
3044 Lake Drive,
Citywest Business Campus,
Dublin 24,
Ireland.
D24 CK66

www.fisheriesireland.ie
info@fisheriesireland.ie

+353 1 8842 600