

Management in Practice**Rapid response achieves eradication – chub in Ireland**Joe Caffrey^{1,2,*}, Kevin Gallagher³, Dermot Broughan² and Jaimie T.A. Dick⁴¹*Inland Fisheries Ireland and* ²*INVAS Biosecurity Ltd, 82 Lakelands Close, Stillorgan, Co Dublin, Ireland*²*Inland Fisheries Ireland, Ashbourne Business Park, Dock Road, Limerick, Ireland*³*Agri – Food and Biosciences Institute, 18A Newforge Lane, Belfast, BT9 5PX, U.K.*⁴*School of Biological Sciences, Queen's University Belfast, MBC, 97 Lisburn Road, Belfast BT9 7BL, U.K.*Author e-mails: joecaffrey@invas.ie (JC), kevin.gallagher@afbini.gov.uk (KG), dermot.broughan@fisheriesireland.ie (DB), j.dick@qub.ac.uk (JD)

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This study was contributed in relation to the 20th International Conference on Aquatic Invasive Species held in Fort Lauderdale, Florida, USA, October 22–26, 2017 (<http://www.icaais.org/html/previous20.html>). This conference has provided a venue for the exchange of information on various aspects of aquatic invasive species since its inception in 1990. The conference continues to provide an opportunity for dialog between academia, industry and environmental regulators.

Abstract

Rapid reaction to the initial discovery of invasive alien species (IAS) is key to eradication, but this is often frustrated by lack of resources and coordinated actions. However, examples of successful eradications may encourage and empower others to follow. Chub (*Squalius cephalus*) were illegally introduced into the River Inny in Ireland in the late 1990s or early 2000s, reputedly by anglers. The habitat in this river is favourable for chub and, should this species establish, it would likely compete with the indigenous fish communities and impact on other flora and fauna. Central Fisheries Board (now Inland Fisheries Ireland) coordinated chub removal operations and provided the necessary resources (manpower and equipment) to effectively remove chub from this large river. Three electric fishing crews supported by two tank boats and land-based personnel were required in each operation to effectively remove the chub. These crews worked on this task each year between 2006 and 2013. Between 2006 and 2008, 24 adult and two juvenile chub were removed and euthanised. In 2008, two chub were radio-tagged, released back to the river and tracked monthly for 12 months. Over the next two years these “Judas” chub, and two untagged male chub that were located in proximity to the tagged fish, were removed from the river. Intensive electric fishing of the river and regular contact with the local angling community between 2010 and 2017 revealed no further chub specimens. Monitoring of the fish populations in the river will continue but it is suspected that chub may have been eradicated from this river system and, hence, from the island of Ireland. This provides a rare case study of the potential to eradicate aquatic IAS when rapid reaction is resourced and coordinated.

Key words: invasive species, freshwater fishes, rivers, competition, electric fishing**Introduction**

The introduction of species outside their natural range is widely recognised as one of the main threats to biodiversity and the second leading cause of animal extinctions (MEA 2005). With increased globalisation, the number of invasive alien species (IAS) in Europe has increased by 76% between 1970 and 2007

(Butchart et al. 2010) and this has impacted native ecosystems (Nunes et al. 2015). The trend in IAS introductions in Ireland has increased dramatically since the beginning of the twentieth century and has accelerated in the last two decades. This is particularly the case in inland waters, where the rate of increase among high-impact IAS has been greatest since the early 1980s (O'Flynn et al. 2014).

Eradication is the removal of every potentially reproducing individual of a species or the reduction of their population density below sustainable levels (Myers et al. 2000). In Europe, relatively few eradications have been successfully completed and most of these have been on small islands or at a local scale. In addition, the majority of these eradications have involved terrestrial vertebrates, with invertebrates, plants or marine organisms (including fishes) rarely featuring (Genovesi 2005). However, once IAS have become established in an ecosystem, eradication may be an unachievable management option (Leuven et al. 2017).

One reason why there are not more examples of successful eradications relates to the often limited ability to detect early invasions and to rapidly react in a sufficiently robust manner when IAS incursions are detected. It is clear that early detection coupled with appropriate rapid response will increase the likelihood of preventing the establishment and spread of recently introduced IAS. For early detection and rapid response to be successful, three main components are required: (1) processes and plans to guide the detection and response actions, (2) tools with which to respond, and (3) the capability and resources to see the response to a successful conclusion (Wotton and Hewitt 2004). It is clear, also, that the response must be made sufficiently early in the invasion process to prevent the more widespread establishment and impact of the target IAS. Being an island nation on the western edge of Europe, Ireland's freshwater fish community is less rich than that of Britain or mainland Europe (Moriarty and Fitzmaurice 2000). However, Ireland has an international reputation as a destination for recreational anglers seeking wild fish stocks in relatively unspoilt and unpolluted aquatic environments. Recreational angling and angling tourism have been estimated to be worth €755 million *per annum*, supporting 10,000 jobs, to Ireland in 2012 (Tourism Development International 2013).

Many non-native and potentially invasive fish species have been deliberately stocked in the wild, aiming to promote the development of commercial fisheries and recreational angling (Gherardi et al. 2009; Tricarico 2012). In fact, fishing/angling has been identified as being among the most important pathways of initial introduction of invasive fishes in Europe (Gozlan et al. 2010; Nunes et al. 2015). Further, the introduction of non-native fish species for recreational angling is recognised as a global environmental problem and considered one of the principal causes of biodiversity loss in freshwater ecosystems (Cambray 2003). The main angling categories in Irish fresh waters are salmonid (primarily Atlantic salmon *Salmo salar* Linnaeus and brown trout *Salmo trutta* Linnaeus), coarse fish and pike

(*Esox lucius* Linnaeus). Coarse angling is most popular on Ireland's large river, canal and lake systems, particularly in the midlands of the country. The species most sought after include roach (*Rutilus rutilus* Linnaeus), bream (*Abramis brama* Cuvier), roach × bream hybrids, rudd (*Scardinius erythrophthalmus* Linnaeus), tench (*Tinca tinca* Linnaeus) and perch (*Perca fluviatilis* Linnaeus). While the market among domestic Irish anglers for coarse fishing is significant, that among visiting English anglers, and particularly English competition anglers, is far greater.

Currently, there are four freshwater fish species that are considered invasive in Ireland and are on the list of non-native species that are subject to restrictions under the EC (Birds and Natural Habitats) Regulations 2011 (Statutory Instrument 477/2011). These are dace (*Leuciscus leuciscus* Linnaeus) and roach, common carp (*Cyprinus carpio* Linnaeus) and chub (*Squalius cephalus* Linnaeus). Dace and roach have been in the country since they were introduced by English anglers in 1889 (Fitzmaurice 1984). The roach has spread widely in Irish watercourses in recent decades and is now regarded as being naturalised in the country (Caffrey et al. 2008). The spread of dace in Ireland, on the other hand, has been a more recent phenomenon and currently is directly impacting on native fishes in invaded rivers for food, habitat and spawning substrates (Caffrey et al. 2007). The first reported introduction of common carp into the country was in 1626 (Grosart and Boyle 1886; Brazier et al. 2012). The fourth invasive species is chub, which was only confirmed to be present in Ireland, in the River Inny, in 2005. Indications from angling reports were that small numbers of chub (no indication of numbers is available) had been illegally introduced by anglers on at least one occasion but that their presence was still localised in this large river system. On confirming the presence of chub in the river in autumn 2005, Central Fisheries Board (CFB) (which became Inland Fisheries Ireland (IFI) in 2010) put forward a programme to rapidly respond to this deliberate introduction of a non-native and potentially invasive fish species, and to make every effort to eradicate it from the river before it spread to the wider network of connected watercourses in Ireland.

Chub is indigenous to many parts of Europe, including England (Hellowell 1971). It is a slender-bodied cyprinid that reaches an average fork length (FL) of 30 to 45 cm and weight of 1.0 to 1.5 kg, although fish to 80 cm (*c.* 7.5 kg) are known from Europe. Chub typically have a life expectancy of 10 to 12 years. Chub thrive in lotic habitats with shallow water and coarse gravel substrates. Young fish form schools in shallow water, while larger specimens tend

to be solitary, often residing under overhanging trees or roots (Wheeler 1998). Fry and juvenile fish feed extensively on aquatic invertebrates, while fish up to the age of *c.* 5 years consume mostly vegetation and aerial insects (Mann 1976). Chub exhibit an ontogenetic shift and become piscivorous when they reach *c.* 15 cm FL, after which the proportion of fish in their diet increases directly with length (Mann 1976). The presence of a significant population of adult chub in the River Inny could, therefore, have a dramatic impact on stocks of native fishes.

Chub is a highly prized angling species in Britain and Europe and its absence from rivers in Ireland provoked controversy among some visiting English anglers (Caffrey et al. 2008). It was their opinion that chub should be deliberately introduced to a number of the larger rivers in Ireland, where excellent habitat conditions for the species could be found. According to them, this would increase the biodiversity of Irish fish fauna and provide an additional angling opportunity for anglers. It was made clear, however, that the Fisheries Boards in Ireland would prohibit the introduction of non-native and potentially invasive fishes (CFB internal document). This reflected the fact that introduced fish species could compete with our native fishes for food and space, and could introduce fish diseases and parasites hitherto unrecorded in Ireland. A parallel stable isotope study of the River Inny fish community concluded that the long-term assimilated diet of chub was similar to that of the native and conservationally important fishes brown trout, European eel (*Anguilla anguilla* Linnaeus) and Atlantic salmon (Gallagher 2017). Potential niche overlap between chub and these conservation species has also been noted in other studies (Hellawell 1971; Mann 1976).

Between 2001 and 2004, there were a number of unconfirmed reports from anglers of chub being caught on the River Inny, a major tributary of the River Shannon (D Broughan, pers. comm.). No specimens, however, were retained for identification and verification. In 2005, three live chub were caught on the River Inny and officially identified by fisheries scientists from the Central Fisheries Board (CFB). It is contended that these fish had been illegally introduced to the river by English anglers with a view to establishing a population of the species in Ireland (Caffrey et al. 2008). In 2006, an electric fishing survey to determine the status of chub in the River Inny was conducted by CFB. On this occasion, 17 chub were removed at just one location on the river, a few kilometres upstream from Lough Ree, into which the river discharges (Caffrey et al. 2008).

This paper describes rapid response (2006) and persistent management (2007 to 2016) efforts that

were undertaken by CFB (and IFI) to remove all of the chub from the River Inny, thus limiting the risk of further spread of this potentially invasive species within the river and to other rivers in Ireland.

Materials and methods

Site description

The River Inny, an order 5 river, is one of the major tributaries to the River Shannon. The river is 88.5 km long and occupies a catchment area of 782.46 km². The river flows through a number of large lake systems before discharging into Lough Ree. The river is renowned among anglers for the abundant stocks of wild coarse fish present. The River Inny, from Lough Derravaragh to Lough Ree (42 km), was surveyed during the present study as no reports of chub being seen or caught by coarse anglers or IFI staff were reported upstream of Lough Derravaragh. The river between Loughs Derravaragh and Ree is wide, varying between 25 and 30 m. For much of its length the river is relatively deep (mean depth 2.3 m) and moderately slow flowing, although long, shallow riffle sections are present (see Figure 1). As part of electrical fishing operations, metrics relating to the river habitat (e.g. width, depth, flow rate, substrate, bankside cover) were recorded. While river width and water depth were measures where discernible changes occurred, flow rate and substrate were not quantified but subjectively assigned to a standard scale.

Chub removal operation

Electric fishing operations were conducted each year between 2006 and 2011 to determine the detailed distribution of chub within the River Inny between Loughs Derravaragh and Ree (Stretches 2 and 3 in Figure 1). In spring and autumn of 2006 and 2007, this full 42 km channel was electrofished. Each operation took between four and five days. All chub captured were chemically euthanised. In 2008 and 2009, the full channel length was electrofished in spring only, as this was the time in previous surveys that chub were captured. Electric fishing in August 2008 and 2009 was confined to the Ballinalack, Abbeyshrule (N53035.460; W7039.039) and Shrule Bridge areas. These areas were electric fished on at least two occasions during each event. A length of channel measuring *c.* 4 km long, that included the areas where the chub had previously been captured, was electric fished on these occasions. Between 2010 and 2012, only spring electric fishing operations were conducted, again in the Ballinalack and Shrule Bridge areas. The full channel was again electrofished in spring 2013.

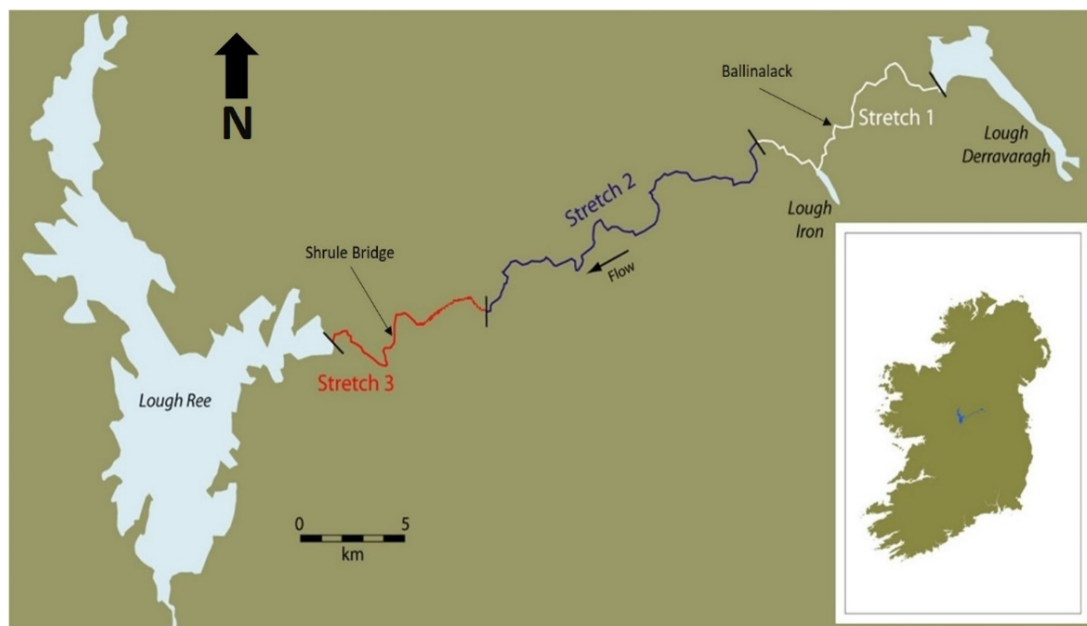


Figure 1. The three sections of the River Inny sampled during the current study.

Three electric fishing crews operated in parallel across the river to cover the channel width with electric current. The electric fishing equipment in each boat comprised a 16 horsepower generator that produced a maximum of 600 volts pulsed direct current, with a maximum current of 30 amps. Electricity was discharged into the water through an insulated handheld anode and a 6m-long trailing copper cathode. Each crew comprised three experienced IFI staff members: one drove the boat using a 25 horsepower outboard motor, a second stood on the bow of the boat and held the anode ring in the water, and a third stood alongside the anode operator and retrieved stunned fish with a landing net and placed them in tanks of aerated water on the boat. The nine-man electric fishing team was closely followed by two boats that picked up any fish that are missed by the electric fishing. Land support was provided for all operations. This involved a personnel input of 15 staff for each day of operations.

During the summer of 2007, micromesh seine nets (5 mm mesh size) were used to sample the river in search of chub fry or juveniles. Thirty suitable sites in the river between Loughs Derravaragh and Ree (see Figure 1) were netted and all fishes captured were examined for evidence of chub.

In 2008, the two chub that were captured during electric fishing operations upstream of Shrule Bridge were fitted with VHF radio transmitters (ATS F1520) and released alive at the capture site. It was anticipated

that these “Judas” chub, at some stage in the next few months, would join other chub in the river and, thereby, enable their detection and removal. The two chub were anaesthetised in a phenoxy-2-ethanol solution before a 35 mm incision was made in the ventral surface, anterior to the right pelvic fin. A biopsy needle was used to pass the trailing antenna (200 mm) through the abdominal wall of the fish and the transmitter unit was implanted in the abdominal cavity between the abdominal wall and the peritoneum. The wound was closed using 3–4 interrupted absorbable sutures. The fish were permitted to recover in oxygenated water before being released. Fish movements were manually monitored weekly between May and October 2008, and at least monthly thereafter until May 2009. Between May 2009 and May 2010, because of a lack of resources, tracking was conducted only occasionally and no more than six times during this period. A VHF receiver (ATS model R2000) and a four element Yagi antenna was used to monitor fish movement. The exact location of the fish was determined through triangulation and coordinates were recorded using a Garmin Etrex GPS system (± 5 m).

Each year between 2006 and 2017, IFI staff monitored angling catches throughout the River Inny, attending any angling competitions that were held and conducting occasional angler surveys. These were mainly conducted between spring and autumn, although surveys were also conducted in winter during

Table 1. Number of chub captured using electric fishing apparatus from Ballinalack and Shrule Bridge areas of the River Inny between 2006 and 2012 (M = male, F = female).

Year	Extent of Survey	Location Of Capture	Season	Number	Sex
2006	42km	Shrule Br	Spring	17	M & F
	42km		Autumn	0	
2007	42km	Shrule Br	Spring	5	M & F
	42km	Ballinalack	Spring	2	M
	42km		Autumn	0	
2008	42km	Shrule Br	Spring	1	M
	8km	Shrule Br	Autumn	1	M
2009	8km	Shrule Br	Spring	2*	M
2010	8km	Shrule Br	Spring	2*	M
2011	8km		Spring	0	
2012	8km		Spring	0	
2013	42km		Spring	0	

* One each of these chub was captured and tagged in 2008.

the prime pike angling season. During these surveys, anglers were questioned about the presence of chub in the river or in their catches.

Results

Between 2006 and 2012, a total of 28 chub were captured during 12 electric fishing operations on the River Inny (Table 1). During these operations, chub were captured at just two locations (Ballinalack – N53.630633, W7.474388 in Stretch 1 and Shrule Bridge – N53.552526, W7.797005 in Stretch 3), each separated by *c.* 30 km. The specific areas where the chub were taken were relatively short (*c.* 0.8 km), shallow (≤ 1 m) and moderate to fast flowing, with a gravel and boulder-strewn substratum. The river in the Ballinalack area had undergone arterial drainage in the past and the banksides were relatively steep and bare, while the river channel in the vicinity of Shrule Bridge was low-lying and characterised by tall, overhanging deciduous trees.

The chub captured over the six year period ranged 15–42.1 cm FL and 33–1,177 g in weight (Table 2). The fish ranged in age from III+ to X+ (Caffrey et al. 2008). Their diet comprised insects, fish, plant material and detritus. They displayed a linear growth pattern and fast growth rates compared to chub in British rivers (Caffrey et al. 2008).

The majority of the chub were taken in the first electric fishing operation in spring 2006, when 17 chub were captured. All were taken in the riffled section of river upstream of Shrule Bridge. There was no evidence of chub in other sections of the river that were fished on this occasion. In spring 2007, five chub were taken in the fast flowing section of river

upstream of Shrule Bridge and two in the riffle section at Ballinalack. Autumn fishing throughout the river in 2006 and 2007 recovered no chub.

In spring and autumn 2008, one chub was captured during each of the localised fishing operations that targeted Ballinalack, Abbeyshrule and Shrule Bridge, where chub had been previously taken. Both fish were captured upstream of Shrule Bridge. Rather than remove them from the river, both fish were fitted with VHF radio transmitters and released back to the channel from which they had been taken. The locations and movements of these two chub were closely monitored over the next 12 months. Following heavy rainfall and the consequent rise in water levels, both chub normally moved upstream out of the fast-flowing riffle into the less turbulent glide section of river. These movements rarely spanned more than 1 km.

In spring 2009, the river in the vicinity of Shrule Bridge was electric fished. On this occasion two male chub were captured, although only one was tagged. These fish were removed from the river and chemically euthanised. In spring 2010 an intensive electric fishing of the Shrule Bridge section of the River Inny recovered two male chub, one with a VHF transmitter embedded. Both fish were removed from the river.

In spring of 2011 and 2012, the River Inny in the vicinity of Ballinalack and Shrule Bridge was electric fished. No chub were observed or captured. In 2013 the full 42 km of channel from Lough Derravaragh to Lough Ree was again electric fished and no chub were taken (Table 1).

During seine netting operations in the River Inny in 2007, large numbers of coarse fish fry and juvenile

Table 2. Fork length (FL), weight (Mass) and sex of the chub captured in the River Inny between 2006 and 2010, with the season and location where they were taken. Whether the chub were radio-tagged and tracked is also indicated (M = male, F = female, I = immature).

Number	Year	Season	Site	FL (mm)	Mass(g)	Sex	Tracked
1	2006	Spring	Shrule Bridge	320	520	F	No
2	2006	Spring	Shrule Bridge	330	550	F	No
3	2006	Spring	Shrule Bridge	340	590	F	No
4	2006	Spring	Shrule Bridge	330	620	F	No
5	2006	Spring	Shrule Bridge	330	580	F	No
6	2006	Spring	Shrule Bridge	360	740	F	No
7	2006	Spring	Shrule Bridge	290	340	M	No
8	2006	Spring	Shrule Bridge	310	510	M	No
9	2006	Spring	Shrule Bridge	320	570	M	No
10	2006	Spring	Shrule Bridge	320	610	M	No
11	2006	Spring	Shrule Bridge	340	650	M	No
12	2006	Spring	Shrule Bridge	350	740	M	No
13	2006	Spring	Shrule Bridge	350	650	M	No
14	2006	Spring	Shrule Bridge	380	850	M	No
15	2006	Spring	Shrule Bridge	410	1060	M	No
16	2006	Spring	Shrule Bridge	150	33	I	No
17	2006	Spring	Shrule Bridge	190	100	I	No
18	2007	Spring	Shrule Bridge	230	187	M	No
19	2007	Spring	Shrule Bridge	230	187	M	No
20	2007	Spring	Ballinalack	350	810	M	No
21	2007	Spring	Ballinalack	330	560	M	No
22	2007	Spring	Shrule Bridge	390	960	F	No
23	2007	Autumn	Shrule Bridge	350	700	M	No
24	2007	Autumn	Shrule Bridge	260	330	M	No
25	2008	Autumn	Shrule Bridge	311	462	M	Yes
26	2008	Spring	Shrule Bridge	381	900	M	Yes
25	2009	Spring	Shrule Bridge	326	568.4	M	Yes - recapture
27	2009	Spring	Shrule Bridge	345	693.3	M	No
26	2010	Spring	Shrule Bridge	400	1036.9	M	Yes - recapture
28	2010	Spring	Shrule Bridge	421	1177	M	No

fish were captured. Each haul was examined for the presence of chub, but none were present.

No electric fishing operations were conducted on the River Inny between 2013 and 2017 but IFI staff surveyed anglers with respect to the presence of chub in their catches or reports of chub in the river. These surveys were conducted at club meetings and during angling competitions on various stretches of the river. No evidence of chub was forthcoming from any of the surveys.

Discussion

While no scripted rapid response strategy to remove potentially invasive fish species in Ireland was in place, the Board and management of CFB were committed to tackling invasive species in Ireland where they impacted on fish, fish habitats or the pursuit of recreational angling. Towards that end a team of scientists, supported by field staff from around the country, was put in place to address invasive species problems in and adjacent to inland fisheries waters. In 2005, the aquatic plant species *Lagarosiphon major* was

detected in a large lake in the west of Ireland. On detection, CFB launched a rapid response campaign to tackle this highly invasive aquatic plant (Caffrey et al. 2011).

Also in 2005, the presence of non-native and potentially invasive chub was confirmed in the River Inny. CFB had considerable experience in assessing fish stocks in rivers and in selectively removing unwanted fishes (e.g. predatory pike *Esox lucius* L. or perch *Perca fluviatilis* L.) from designated salmonid river fisheries. Not only had CFB the experienced staff to complete selective fish removal operations in rivers but it also had a wide array of electrical fishing and netting equipment for this purpose. The organisation was, therefore, clearly in a position to attempt to remove the newly detected chub from this river system. CFB scientists and management assessed the risk that chub could pose to native fishes in the River Inny and connected watercourses and, in consultation with colleagues in the Environment Agency (UK), recommended that urgent efforts should be made to remove/eradicate the chub from this river system. On foot of this, a management decision was made to

deploy staff and resources to assess the status of the chub in the river and, based on this, to put in place a structured chub removal/eradication plan.

During winter 2005/2006 a programme of measures was put in place by CFB to determine the locations and status of chub in the river and to eradicate these, if possible. Anglers and angling clubs that fish the River Inny were canvassed for any information on the illegal stocking(s) of chub. They were also alerted to the fact that CFB was committed to eradicating these fish from the river. Provision for staff and equipment to complete the chub removal was made to staff Business Plans for 2006 (and subsequent years).

Results from electric fishing operations in spring and autumn 2006 recovered mostly adult chub, at just one location, although a single fish aged III+ was captured during these operations. No fry were observed. These results suggested that the chub were relatively localised and probably had not successfully spawned. In light of these positive preliminary results, CFB formulated a targeted chub removal/eradication plan, to continue until the chub was eradicated or numbers were so reduced that the population would be unsustainable. The use of the radio-tagged Judas chub between 2008 and 2010 was novel and gave confidence that there were relatively few chub in the river during this period.

Based on the fact that no chub were captured during electric fishing operations in the river between 2011 and 2013 (see Table 1), it was decided to cease electric fishing but to continue to monitor angler catch data, between 2014 and 2017, for any further evidence of the species. No reports of chub being caught in the River Inny, or any other river in the country, were made during this time.

It is reasonable to suggest that the rapid reaction by CFB to the confirmed incursion of chub in 2005 and the persistence of effort up to 2017 has resulted in the eradication of this potentially invasive species from the River Inny and the country as a whole. IFI staff will continue to monitor angling on the River Inny and to be watchful for any chub that may be caught. We thus provide a rare and detailed account of rapid reaction to an aquatic IAS that has resulted in likely eradication. This is the first recorded probable eradication of an invasive fish species in Ireland. Targeted seine netting, electric fishing and the novel “Judas” chub methods may be appropriate for other such IAS.

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