

How COVID-19 changed the dynamics of a fishery

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Abstract – Northern Ireland went into COVID-19 enforced lockdown with the rest of the UK in March 2020. A stay-at-home order banned “non-essential” travel and contact with others, and closing schools and businesses. Such closures also impacted commercial fishing activities, including the Lough Neagh eel fishery. The eel fishery in Lough Neagh, Northern Ireland is the largest in Europe with an annual mean catch of around 330 t, valued at ~£3 M. The effect of the Northern Ireland lockdown was the reduction of the Neagh fleet by 60% and delay to the start of the yellow eel fishing season by 2 months. The pandemic reduced the market demand for Lough Neagh yellow eel from ~280,00 kg yr⁻¹ to 100,000 kg yr⁻¹. The objective of the study was to assess the impact of the regulations on silver eel output and the socio-economic effects on fishers and the fishery. The main impact of the market disruption was for an increase in silver eel escapement of about 15% and for those fishers who remained in the fishery, at least in the short term, a continuing livelihood. In contrast, there were direct socio-economic consequences; the fishery had to reduce in size with associated cultural and heritage loss. Upon the lifting of COVID-19 restrictions the former fleet size did not and has not returned highlighting the wide ranging socio-economic impacts from the pandemic. As of November 2023, the market demand for eel across Europe remains deflated.

Keywords: COVID-19 / *Anguilla anguilla* / Lough Neagh

1 Introduction

The COVID-19 viral outbreak brought 165,000 deaths and 20.8 million cases to the United Kingdom as it swept across the globe in its worldwide pandemic of the SARS-CoV2coronavirus. The virus reached the UK in late January 2020 with each of the three devolved administrations in Scotland, Northern Ireland and Wales introducing public health and supportive economic measures, including new laws, to mitigate its impact.

The COVID-19 pandemic reached Northern Ireland in February 2020. On 23 March 2020, Northern Ireland went into lockdown with the rest of the UK. A stay-at-home order banned “non-essential” travel and contact with others, and schools, businesses, venues, amenities, factories and places of worship were shut. These closures also included commercial fishing activities, such as the Lough Neagh eel fishery in the centre of Northern Ireland, at the time (and still) home to the largest wild eel fishery in Europe, producing 13.6% of EU catch (ICES, 2021). The lockdown was gradually lifted in

June–July 2020, as infection and death rates dropped. The infection rate (or positivity rate) rose again in September and restrictions were re-imposed. On 16 October, Northern Ireland went into an eight-week lockdown, although schools remained open, and some restrictions were eased for one week. This second lockdown was mostly lifted on 11 December 2020. Following a brief easing of restrictions at Christmas, a third and final lockdown was imposed on 26 December 2020, as the positivity rate rose sharply. A mass UK wide vaccination program began, and the infection rate began to fall in early 2021. The lockdown was gradually lifted from late April 2021 and almost a year later all restrictions were removed in March 2022.

European eels are believed to spawn in the Sargasso Sea (Fig. 1) (McCleave et al., 1987; Tesch and Wegner, 1990). The eggs hatch as leptocephalus larvae and drift across the Atlantic Ocean to the continental shelf of Europe, where they metamorphose into post-larval, transparent glass eels and migrate towards and into estuaries (Cresci, 2020; Tesch, 2003). Glass eel migrate upstream in shoals, their shoaling behaviour changing from passive migration to active migration during the migration season (Harrison et al., 2014). This immigration phase is generally followed by a settlement period, and metamorphosis into the pigmented elver stage and the start of

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feeding (Tesch, 2003). After which they then embark on a secondary active migration in early summer, which is strongly influenced by temperature (White and Knights, 1997 a and b) and commence the juvenile yellow eel phase. After a period of time the yellow eel mature into the silver eel stage and migrate downstream for spawning (Tesch, 2003).

In Europe, as the virus spread into central regions the effects of the COVID-19 pandemic reached right across the eel's distribution range with varying degrees of impact – the influences of these impacts were more locally felt dependent on timing and its occurrence within the seasonality of glass eel and silver eel migration (ICES, 2020a). Many Country Reports submitted at the ICES Working Group Eel stock assessment meeting in 2020 highlighted that the impacts fell largely into 3 groups (ICES, 2020b):

- Interruption/cessation of scientific monitoring and national stocking programmes (across all life stages).
- Interruption/cessation of national stocking programmes (glass eel and on-grown yellow eel stages).
- Closure/delay in commercial fishing (glass eel and yellow eel stages) due to movement restrictions and/or loss of markets because of social lockdowns.

Many scientific institutes reported reductions in fieldwork activities, stocking, sampling of yellow eels, silver eel escapement monitoring and significant back logs of laboratory processing. Of the 68 Datasets included in the recruitment trend used in the ICES advice for the 2020 Datacall, 12 indices (17%) recorded significant reductions to these sampling efforts directly attributed to COVID-19 impacts (ICES, 2021). The bulk of these reductions occurred across the western edge of Europe, coinciding with the spread of COVID-19 across the continent during Spring affecting six sites from the North Sea (NS series), four from the Elsewhere series (EE), and two for yellow eel recruitment. Out of the total dataset (the database also includes series too short, or too biased to be included in the analysis) 17 out 95 series were affected.

2 Materials and methods

2.1 Study area

Lough Neagh is a large (385 km²), shallow (mean depth 9 m), hypertrophic lake in Northern Ireland (Fig. 2). The Lough drains north to the Atlantic Ocean via the River Bann (38 km long). The estuary extends 9.7 km upstream from the mouth to The Cutts where prior to the 1930s further tidal ingress was prevented by a natural fall and by three sluice gates post-1930s. The River Bann is a heavily regulated system designed to control the flow of water leaving Lough Neagh.

2.2 Description of the fishery

A detailed description of the Lough Neagh eel fishery can be found in Aprahamian *et al.* (2021) and ICES (2022).

The eel fishery in Lough Neagh, Northern Ireland has an annual catch of around 330 t and a value of ~£3M (2010 – 2019) (Darby, 2022) and provides an economic foundation for the surrounding local economies (Close, 2022). The main demand for Lough Neagh eels is Germany, Holland and

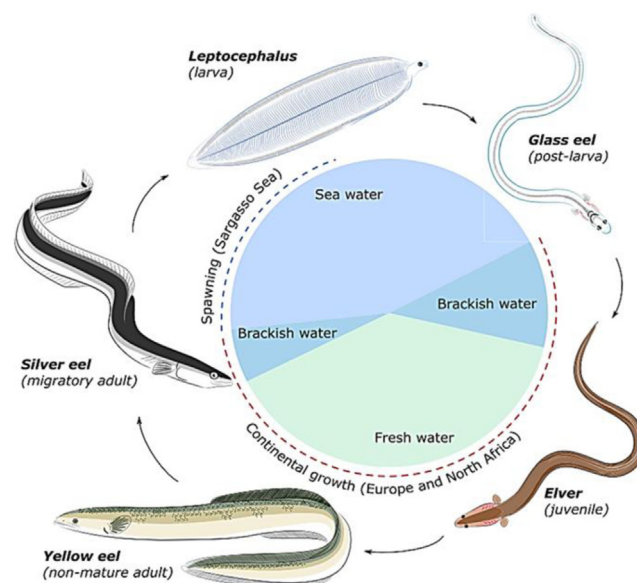


Fig. 1. Life cycle of the European eel *Anguilla anguilla* (from Fleming *et al.*, 2023).

England (Close, 2022), and in 2020 with Europe wide lockdowns and the suspension of all tourist travel, the demand for yellow eel on the European market collapsed by ~50% to 100,000 kg (pers comm LNFCS). The aim of this study is to assess the impacts of these major interventions on the dynamics of the fishery at that time and note any rebound effects upon the return to normal life post-COVID-19.

The yellow eel is currently exploited by two main methods: longline and draft net. The season runs from May to September. Longlines of 1,200 hooks are fished overnight baited with either earthworms (*Lumbricus* spp.), whole fish fry, pieces of fish flesh, or more recently mealworms (various Coleopteran larvae available through the pet food trade). Draft nets 80–100 m in length with a 14 mm cod-end are deployed from a boat in open water. Changing market forces and the ageing fisher population has meant that boat numbers have fallen from about 200 in 1985 to around 87 in 2020 and have decreased further post-pandemic to 52 boats (Lough Neagh Fishermen's Co-operative Society Ltd (LNFCS), pers. comm.).

Yellow eel fishery conservation measures include a two-day weekend close period, and daily quotas (a cap on the weight of eel which the LNFCS will buy from any fisher, which can vary through the season from 38–50 kg boat⁻¹ day⁻¹ driven by market demand. The LNFCS applies a minimum marketable grading length for yellow eel of 400 mm with any undersized eels returned to the water at their point of capture.

Emigrating silver eels are caught in fixed Coghill nets lowered into the flow at two weirs on the River Bann, at Toome at the outlet of the Lough and at Kilrea 28 km downstream (Fig. 1). Silver eel migration is seasonal, with the majority leaving from early September to late December (ICES, 2020a). The migration is primarily linked to flow and the onset of a new moon and secondary to low pressure storm events bringing favourable southerly winds (Frost, 1950). This association is well known, and fishing effort is targeted towards these environmental conditions.

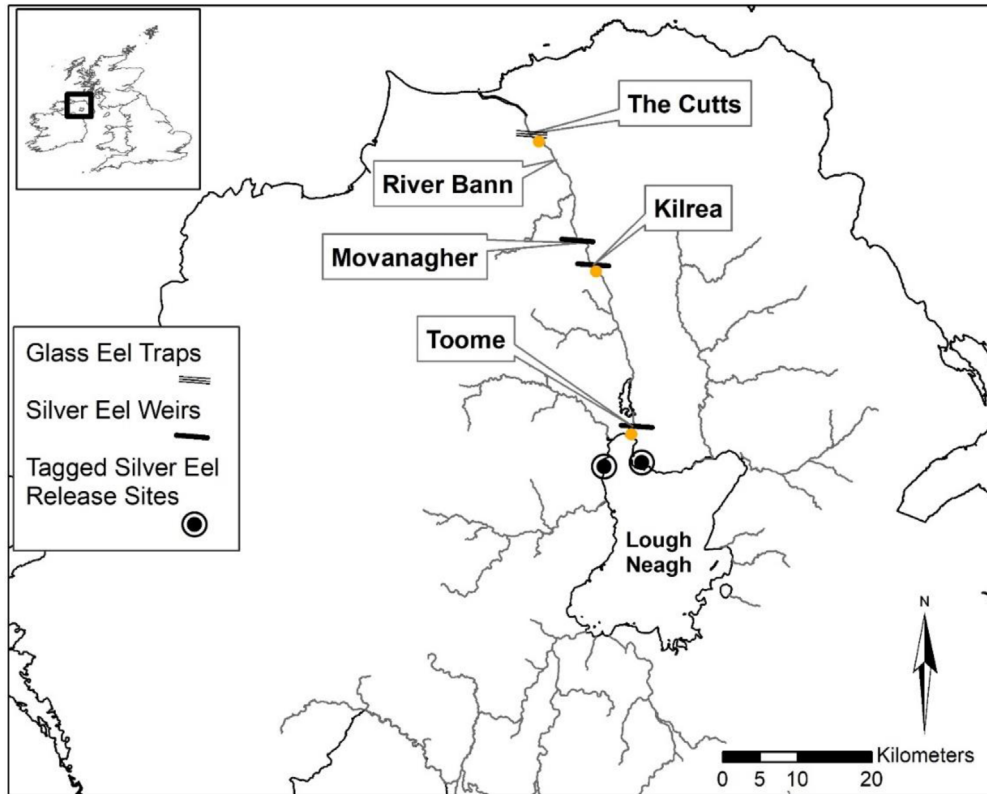


Fig. 2. Lough Neagh showing the location of the glass eel traps at The Cutts and the silver eel weirs at Kilrea and Toome. The location of the silver eel release sites (circles), sluice gates (orange circles) and weirs (dashed line).

2.3 Pandemic induced constraints upon fisheries

Much of the reported disruption to commercial eel fisheries was focused on suspension or disruption of glass eel fisheries that are in season during late spring (Aprahamian and Wood, 2021) and delays to the opening of yellow eel fisheries throughout more inland portions of the EU (ICES, 2020b). Economic support was given to struggling businesses including a furlough scheme for employees; whereby such a scheme provides for a temporary leave by employees due to special needs of a company or employer, which may be due to economic conditions of a specific employer or in society as a whole. Information on financial support schemes for fisheries was not available from all countries but a range of Furlough, “tie up” and hardship payment initiatives were operable in Poland, Holland, UK and France (ICES, 2020b).

However, whilst of obvious short term financial benefit to fishers and their families, a recurring comment from these communities was that after a prolonged enforced break from the activity of fishing, many may decide never to return, even as markets re-open and restrictions are lifted. An additional consideration within these comments was the typical older age of eel fishers as a contributing factor to the unlikelihood of their return having “broken the link with the mind set” for what it takes to fish eel (ICES, 2020b).

It was also noted that as of September 2020, the market demand for eel across Europe remained low after a summer

of falling consumption driven by reduced tourism and increasing, often sporadic, local lockdowns. However, in some regions, reductions in fishing capacity combined with the current market demand led to a new equilibrium in terms of improved livelihood for those that returned to fishing (ICES 2021).

2.4 Methods

By analysing catch and market data metrics within the pandemic period, and cross referenced against historic comparative data, the study aimed to illustrate any changes and impacts associated with societal lockdowns and constraints in force.

2.4.1 Data available

Yellow (C^{yellow}) and silver (C^{silver}) eel catch data (Kg) together with yellow eel effort (f) measured as boat days (individual vessels, fishing per day per 20 week season) were available from the LNFCS. Silver eel escapement (A^{silver}) was measured using mark-recapture tagging as described in Aprahamian et al., (2021). Yellow eel catch was converted to silver eel equivalents as described in Aprahamian et al., (2021). Silver eel equivalents are defined as the number of silver eels that would have been expected to emigrate if the yellow eels had not been caught and is calculated as described in Aprahamian et al. (2021).

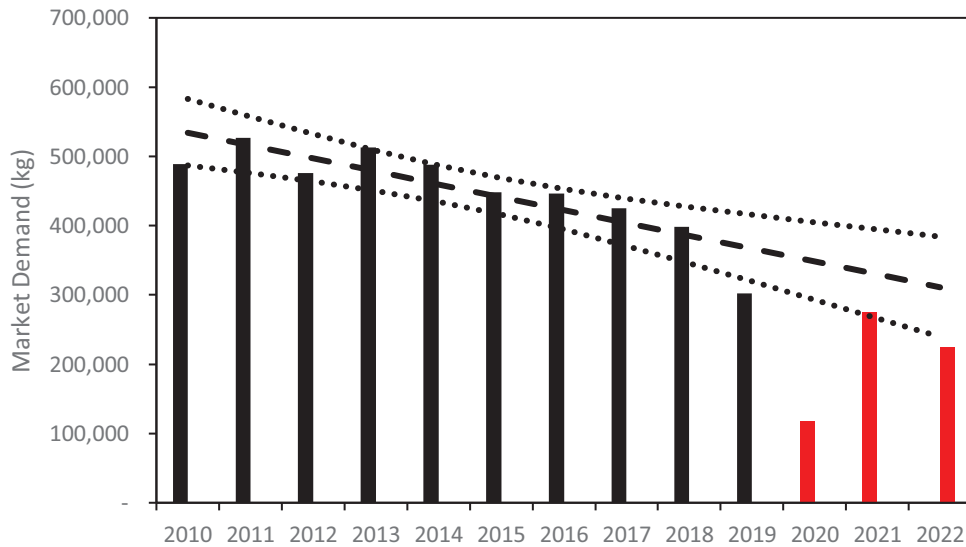


Fig. 3. Demand for yellow eel between 2010–2022 (Kg). Dashed line represents trend line dotted lines represent 95% confidence intervals based on 2010–2019 and extended to 2022, black columns represent pre-COVID-19 and red columns post COVID-19 years.

2.4.2 Fishery mortality

Fishery mortality (Y) is the quantity of the potential escapement that is caught and removed by the fisheries, measured as the instantaneous rate, and can be partitioned into silver (Y^{silver}) and yellow (Y^{yellow}) eel fishery mortality, from their respective catches. Potential escapement is the sum of the quantity of silver eel escaping to the sea (A^{silver}) together with the silver eel catch (C^{silver}), and yellow eel catch as silver equivalents (C^{yellow}).

$$Y = -\ln(1) - \frac{(C^{yellow} + C^{silver})}{(C^{yellow} + C^{silver} + A^{silver})}. \quad (1)$$

2.4.3 Market demand

The daily market demand for yellow eel was estimated by multiplying the number of boats fishing on a given day by that days daily catch quota issued by the LNFCS management team. Weekly and/or annual market demands were the cumulative of these daily demands.

3 Results

3.1 Market demand

Over the period 2010–2019 the quota driven market demand for yellow eel declined from ~500,000 kg between 2010–2013 to ~300,000 kg in 2019 (Fig. 3). If the decline in demand continued to follow this downward trend, then the predicted demand for yellow eel (had COVID-19 not happened) across the period 2020–2022 was estimated at 348,000 kg and 330,000 kg in 2020 and 2021 respectively and a post-covid demand of 311,000 kg in 2022. However, as Figure 3 illustrates all 3 yr across this period had market demands falling short of that predicted/expected.

For the yellow eel fishery, the market demand is filled on a weekly supply basis. In 2020 the first eight weeks of the season

were lost representing 27% of the total catch. On a pro rata basis this would consequently reduce the potential yellow eel market from 348,000 kg to 254,000 kg (Fig. 4). There was no change in the silver eel market demand which is not quota based.

3.2 Fishing effort

The main impact of the pandemic societal restrictions was to reduce the amount of effort (boat days) in the yellow eel fishery (Fig. 5). Pre 2020 the fishing season started on May 1st. In 2020, COVID-19 restrictions meant the season started on July 1st. In addition to the delay the fishing fleet was reduced compared to previous years to 36 boats as opposed to 87. The impact of this was the reduction in the number of boat days from a mean of 9,132 days (95% C.I. ± 675.7) for the previous 10 yr (2010–2019) to 2,945 days in 2020. Upon the further EU wide lifting of restrictions in 2021 and 2022 the number of boat days increased to 5,310 and 4,195 days, respectively (Fig. 4), yet remained a fraction of the previous 10 yr average at 45.9%.

There was no change in the silver eel fishing effort associated with COVID-19 societal restrictions. Silver eel migration is seasonal, with the majority leaving from early September to late December.

3.3 Catch and escapement

The catch of yellow eel in 2020 declined to 96,800 kg, 34.8% of the mean of the previous 10 yr of 278,300 kg (95% C. I. $\pm 27,100$). In 2021 the catch recovered to 153,800 kg, (55.3% of the 2010–2019 mean catch), but in 2022 declined once more to 95,900 kg (34.5% of the 2010–2019 mean catch) (Fig. 5). In terms of supply and demand the yellow eel catch was able to meet 62.3% (range: 57.1–73.4%) of the pre-COVID-19 demand. However, during and post COVID-19 this remained similar with a mean of 60.4% (range: 42.7–82.3%). There was

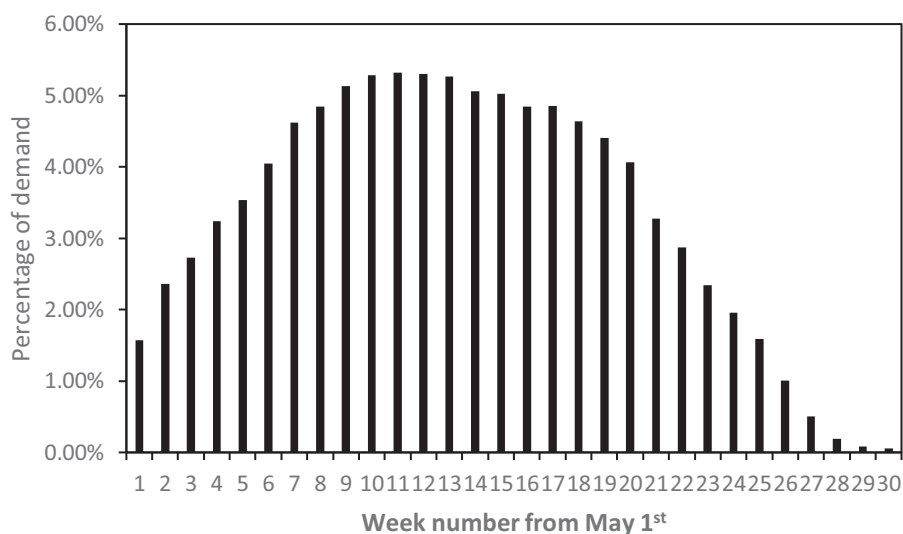


Fig. 4. Mean percentage of the total yellow eel demand by week from May 1st between 2010–2019.

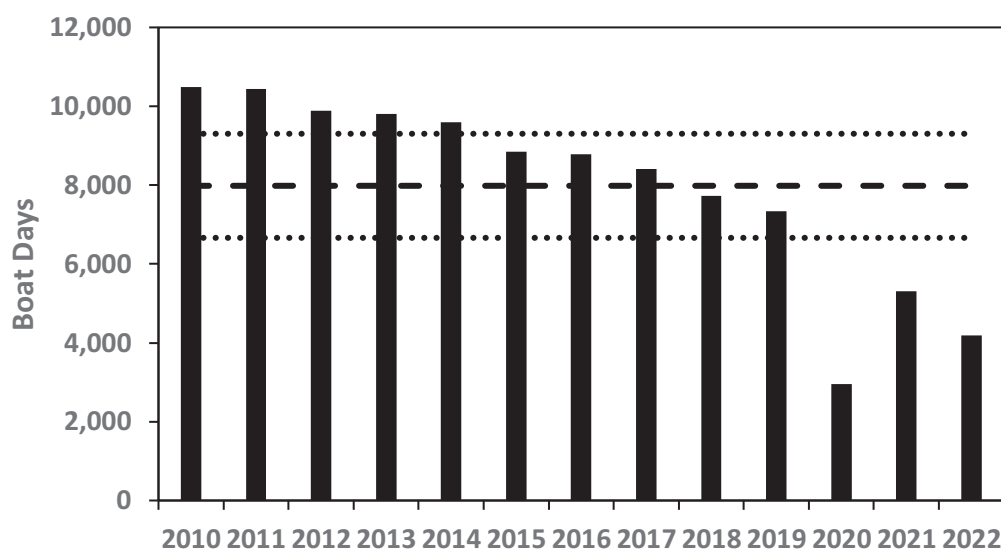


Fig. 5. Trend in yellow eel fishing effort (boat days) 2010–2022., dashed line indicates 2010–2022 mean, dotted line 95% confidence intervals.

no significant difference between the two periods (Mann Whitney: $P > 0.05$).

In contrast, there was little change in the silver eel catch in 2020 and 2021 being, 64,900 kg in and 63,600 kg, respectively, in comparison to the 10 yr mean of 68,100 kg (95% C. I. $\pm 10,500$) (Fig. 6). However, the silver eel catch in 2022 declined markedly to 46,000 kg.

Similarly in terms of silver eel escapement, there was little change (Fig. 5), with 198,900 kg and 244,500 kg escaping in 2020 and 2021 respectively, compared with the 10 yr mean of 225,900 kg (95% C.I. $\pm 42,500$). Though provisional, the assessed silver eel escapement for the 2022 season was slightly lower at 189,000 kg.

The total output (yellow eel catch, silver eel catch and silver eel escapement), in 2019 of 361,300 kg was 62.8% of the 10 yr mean of 573,500 kg (95% C.I. $\pm 50,500$) and in 2020,

461,900 kg representing 80.2% of the 10 yr mean, whilst for 2022 the total output was 330,900 kg (57.7% of the 2010–2019 mean). There was a change in the proportion of each of these fishery components compared with the period 2010–2019 (Tab. 1).

3.3.1 Socio-economic

The number of boats fishing reduced by 58.6% from 87 during the period 2010–2019 to 36 in 2020, increasing by 44.4% to 52 in 2021 and 2022. The catch of yellow eel per boat declined from a mean of $3,199 \pm 287.4$ kg during the period 2010–2019 to $2,498.8 \pm 658.2$ kg between 2020–2022. If the full fleet had been fishing during and post-COVID-19 the decline would have been greater at 42% ($1,328 \pm 430.6$ kg).

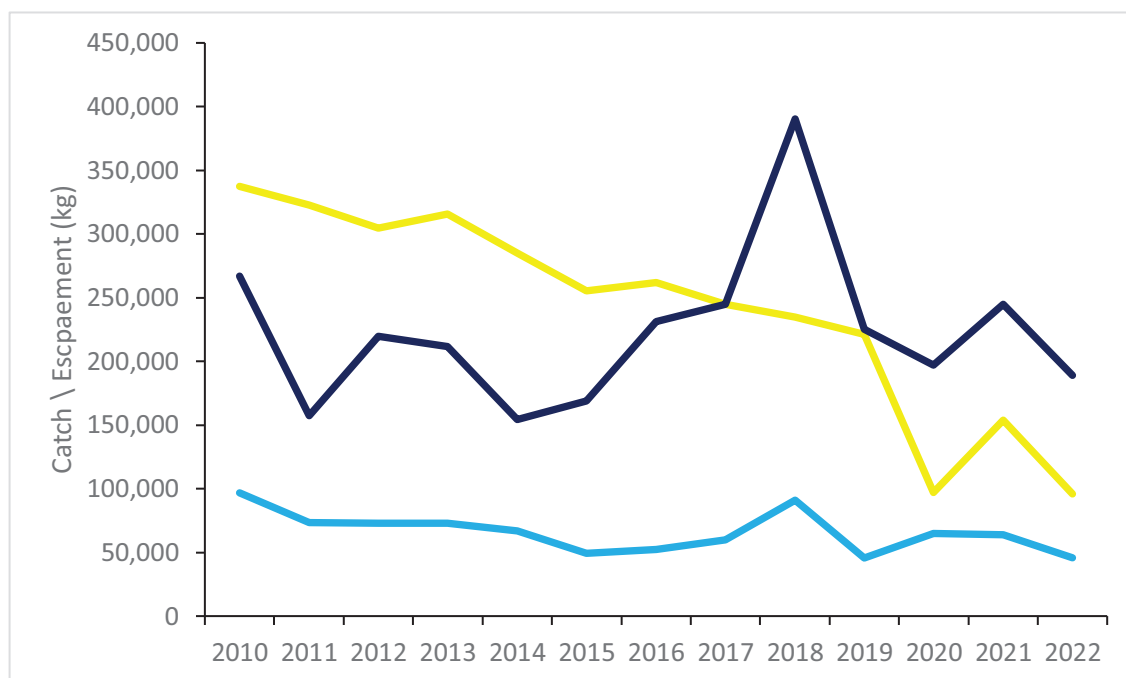


Fig. 6. Catch of yellow and silver eel and escapement of silver eel 2010–2022, yellow eel catch (yellow), silver eel catch (light blue) and silver eel escapement (dark blue). Silver eel escapement data for 2022 is provisional.

Table 1. The yellow eel catch, silver eel catch and silver eel escapement compared as a percentage of the total output for the period 2010–2019 and between the COVID-19 impacted years of 2020 to 2022.

Year	Yellow eel catch (%)	Silver eel catch (%)	Silver eel escapement (%)
2010–2019 Mean (95% C.I.)	49.4 (±4.7)	11.7 (±0.9)	38.9 (±4.9)
2020	27.0	18.1	54.9
2021	33.3	13.8	52.9
2022	29.0	13.9	57.1

3.4 Fishery mortality

Silver eel fishery mortality has remained relatively stable (Fig. 7), with the possibility of a slight increase post 2020, being a consequence of the decline in the yellow eel catch. The yellow eel fishery mortality has been steadily declining over the period with a marked decrease post 2020. The yellow eel fishery mortality pre and post the COVID-19 outbreak declined by 48.5% from $0.5510 \pm 0.073 \text{ yr}^{-1}$ (2010–2019) to $0.2838 \pm (0.0429 \text{ yr}^{-1})$ (2020–2022) and was related to the reduction in effort which fell 54.6% from $9,132 \pm 676$ days (2010–2019) to $4,150 \pm 1,329$ days (2020–2022), (Fig. 8).

Post COVID-19 the decline in yellow eel fishery mortality is in line with that predicted from the relationship between fishery mortality and effort for the period 2010–2019 (Fig. 8).

4 Discussion

The COVID-19 outbreak had the effect of reducing the demand for eel from the Lough Neagh fishery by approximately half from 278,300 to 115,600 kg. Similar responses

were recorded in Maine (USA) where the decline in demand resulted in a reduction of 75% in the market price of juvenile eel (Chase, 2020). Likewise, in Indonesia restrictions brought in by the Government limited the logistics and transportation of eel, with a follow on decrease in demand (Muthmainnah et al., 2020).

The effect of COVID-19 movement restrictions on the fishing community around Lough Neagh was to delay the start of the 2020 yellow eel fishing season by two months and reduce the size of the fishing fleet from 87 to 36 boats. This lower number was influenced by the high age of fishers (mean 64 yr) with concerns about social activity and becoming infected and the NI government provision of a hardship payment scheme to self-employed workers to remain at home (such as fishers). The loss in continental markets for yellow eel as a direct result of lockdowns/loss of tourism in Holland and Germany was well known through the fishing community manifesting as low market demand. This had a significant influence on the “desire” to fish under what would consequently be low daily quotas issued by the LNFCS, resulting in low daily pay. As such,

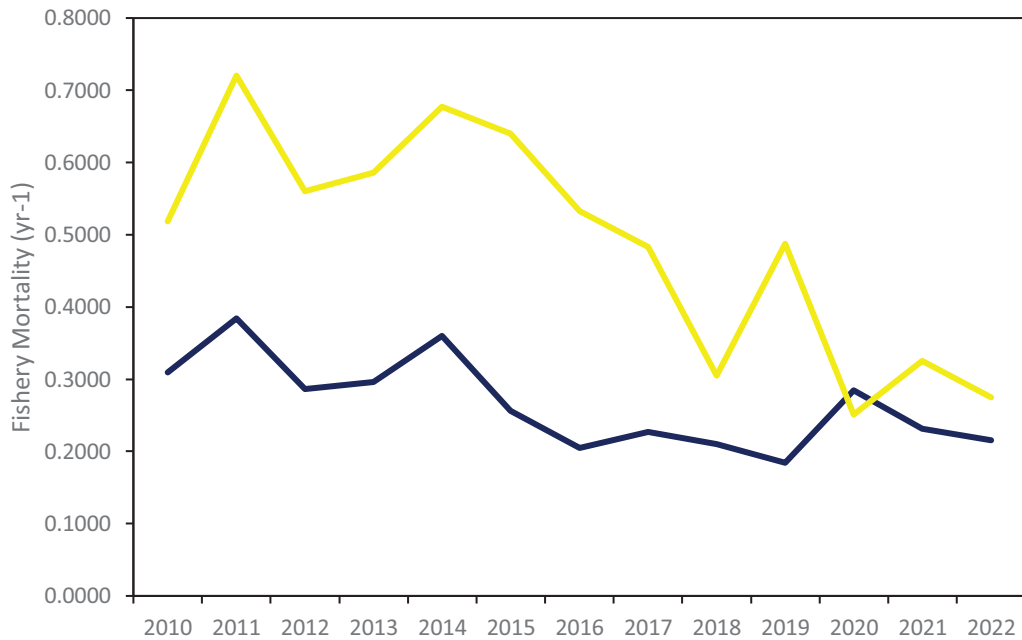


Fig. 7. Silver eel fishery mortality (dark blue solid line) and yellow eel fishery mortality (yellow solid line) 2010–2022.

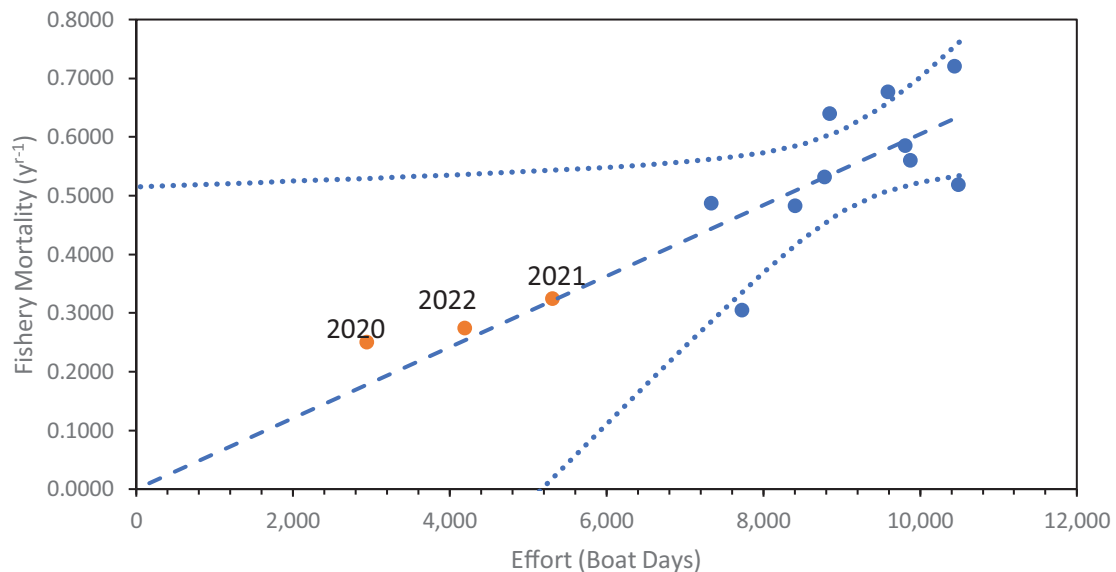


Fig. 8. The relationship between yellow eel fishery mortality and effort (boat days), dashed line represents $Y^{yellow} = 6.04 \cdot 10^{-5} (\pm 6.96 \cdot 10^{-6})$ $f(P=0.05)$ trend line with dotted line 95% confidence intervals derived from the 2010–2019 data and extrapolated back to the origin.

signing up to a hardship scheme whilst mooring their boat would have been a financially more rewarding scenario. This combined reduction in overall effort (days x boat nos.) in the yellow eel fishery had the consequential effect of reducing yellow eel fishery mortality, by ~50%. This resulted in an increase in the quantity of silver eel produced, which in turn increased the number of escaping and captured silver eel over what might have been expected if yellow eel fishing had been carried out at “normal”

historic levels (Aprahamian et al., 2021). In essence, older eels which had not been caught in the yellow eel fishery had the opportunity to metamorphose to silvers and to migrate as spawners in the autumn. Similar impacts of a reduction in fishery mortality attributable to the market disruption were also reported in the glass eel fishery of the River Severn (England) where the exploitation rate was estimated to be between 35 and 51% lower because of the reduced market (Aprahamian and Wood, 2021).

Pre COVID-19 the silver eel catch was relatively stable with the exception of 2018. In 2018 the high silver eel catch and escapement was likely related to the very warm summer across N Ireland. For silver eel the transition from yellow is characterised by a rapid increase in growth and that August, one – two months prior to migration, is a key transitional month for moving from stage III (pre-migratory) to stage IV (Durif et al., 2005; Durif et al., 2009). Growth of eel increases with temperature (Tesch, 2003; Sadler, 1979) and when favourable, induces eel to silver rapidly (Vøllestad, 1988, 1992; De Leo and Gatto, 1995; ICES, 2021). It is hypothesized that the relationship with August water temperature reflects growth opportunity. In warmer years, the better growth conditions enable more yellow eels to transition to silver, generating a higher than predicted catch / total output. Conversely the growth opportunity will be less during colder Augusts and the catch / total output lower than that predicted. Similar conclusions were reached by Poole et al. (2018). The warm summer of 2018 may explain the higher than might be expected silver eel catch and escapement; the mean August (2018) water temperature being approximately 1.15 °C higher than the 1993–2016 mean ($\pm 95\%$ C.I.) of 16.87 (± 0.39) °C at 18.02 °C, these effects extending further into September.

The market demand during COVID-19 declined massively due to falling consumption driven by reduced tourism and sporadic local lockdowns across the continent culminating in 39% of the demand of 2019 (Pititto et al., 2021). Much of this demand fulfilled the needs of new, or enhanced online markets, suitable for societal lock downs. For those that remained in the fishery there were some comments that their catch returns had improved and locally a few fishers noted improvements in earnings (D. Evans, Pers. Comm). This situation and associated commentary was particularly evident in 2021 when the market increased from ~90,000 kg to ~153,000 kg. This encouraged the return of fishers which increased by 44% from 36 in 2020 to 52 in 2021 and 2022 but was still (and remains at) only 60% of pre-pandemic levels. That the fishery didn't close suggests that whilst earnings is the primary motivator, fishing as an activity has nuanced and complicated meanings for fishers. It is unlikely they would continue such a time-consuming and tiring occupation while other options are available. This is clear even from the fact that the catch per boat decreased by ~500 kg when compared to pre-covid levels.

Yellow eel metabolism and activity increase with temperature (Baisez et al., 2000; Tesch, 2003), necessitating the need to feed, which in turn elevates the likelihood of capture in a commercial fishery setting. The other possibility is that whilst the fishery fleet reduced by ~60% the reduction in expertise was not random, with the less successful fishers opting to take advantage of the available hardship payment scheme – effectively these fishers were paid not to fish. In a study on the social, economic and conservation value of the Lough Neagh eel fishery, Steele (2023, unpublished PhD) found that of the respondents interviewed a third relied completely on fishing eels for their livelihoods. For others it is a primary source of income, but supplemented by other income-generating work, either during the off-season or more importantly, alongside fishing.

That in 2021 and 2022, there were 35 fewer boats operating would suggest, that following a break from fishing, these fishers have stuck with that decision not to return to the lough.

Upon markets re-opening, tourists returning, demand increasing, and restrictions lifted, the ageing Lough Neagh fishing community has not bounced back in contrary to what has happened elsewhere (Coll et al., 2021). The ever-widening unseen socio-economic effects from the pandemic have fundamentally impacted such people with a loss in fishers, culminating in the associated losses to their cultural and rural livelihoods while some would argue the further loss in fishing method expertise (Close, 2022).

5 Conclusion

In conclusion, the market disruption brought about by COVID-19 has had both positive and negative effects. There were direct socio-economic consequences; whereby the fishery had to reduce in size by between 40–60% to remain viable with a resulting loss of expertise and heritage. Whilst the pandemic end brought with it rising market availability which drove the return of an additional 16 boats to the fleet, there was an associated drop in catch of 500 kg per boat. However, in the cooperative based fishing community that is the Lough Neagh Fisheries Co-operative Society, the ethos is that it is much better to have more households with access to a livelihood than having a few with an improved catch.

Compared with other fisheries this noted market disruption and associated impacts was not an isolated incident having been reported by others, Macusi et al. (2022); Monirul Alam et al. (2022) and Khan et al. (2023). These changes continue to impact Lough Neagh with markets having yet to return to pre COVID-19 levels.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author, [DE].

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