Assessment of cod survival in the Irish seine-net fishery using pop-up satellite archival tags

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Key findings

- Cod survival was poor due to barotrauma
- Alterations to fishing operations to reduce barotrauma are technically feasible but unlikely to be commercially viable
- The pop-up satellite tags were highly effective in assessing cod survivability
- This new method will be of major benefit in addressing future fisheries conservation challenges

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Introduction

Poor stock status has led to parts of the Celtic Sea having no directed fishery permitted for Atlantic cod (*Gadus morhua*) where the quota is exclusively for bycatches in fisheries for other species (EU. 2020). Irish fishers need to reduce cod catches to help improve stock sustainability and avoid early cessation of fishing operations under the EU landing obligation.

Bottom-trawlers can use raised fishing line gear (McHugh et al., 2017) or change fishing grounds to avoid cod in the Celtic Sea. Bottom-seiners do not have this gear option, and limited grounds suitable for seining are available outside the Celtic Sea which restricts their movements.

Irish fishers reported that seine-caught cod are in excellent condition and requested an assessment of post-capture survival towards application for an exemption under the landing obligation. Survival studies are typically conducted through observations in live-holding systems whereby fish caught during fishing operations are monitored for 15 days or more to assess survival rates. For example, Oliver et al. (2020) assessed the survival of seine-net caught plaice in Celtic Sea by monitoring them in onshore holding tanks resulting in a survival exemption for that species. Onshore monitoring is more suited to smaller less mobile species such as plaice and is much more challenging in relation to larger species such as cod due to their morphology and swimming behaviour.

Tagging methods can also be used to assess mortality rates. Mark and recapture techniques can often require large-scale studies to tag and recover enough fish, and tag reporting is not always consistent. Pop-up satellite archival tags (PSATs) transmit data via the ARGOS satellite system and do not require tagged fish recapture. Used extensively in studies on fish behaviour, more recently they have been used to assess fish survival (e.g., Knotek et al., 2019; Nielsen et al., 2018). Here, we assess post-capture survival of cod from the seine-net fishery using PSATs.

Methods

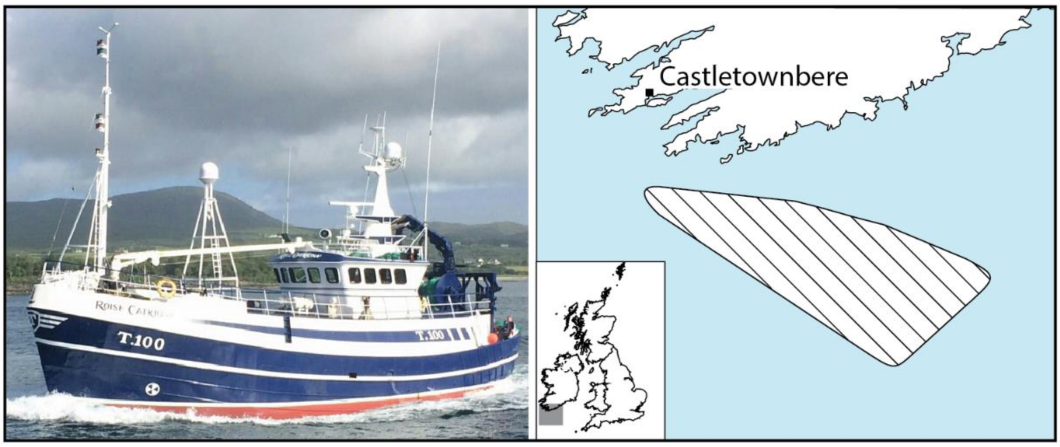

Figure 1: Study vessel and study location (hatched area)

<u>Fishing operations</u>

The MFV Róise Catriona, a 24 m steel Scottish seine (SSC) vessel caught the cod during commercial fishing operations on fishing grounds south of Castletownbere off Irelands south-west coast in ICES divisions 7.j.g between the 20^{th} – 23^{rd} July 2022 (Figure 1). The vessel fished a standard seine net with a 100 mm T90 codend (Table 1). A detailed description of the SSC fishing method is outlined in Oliver et al. (2020). Data were recorded on operational parameters that could affect survivability such as depth, duration and total catch weight for each haul.

Table 1. Gear characteristics

Gear type	Seine
Sweep length (m)	55
Headline (m)	60
Footrope (m)	68
Fishing circle (No. Mesh × mm)	480 x 120
Seine rope length (m)	2860 × 2
Seine rope diameter (mm)	32
Codend	T90
Nominal mesh (mm)	100
Measured mesh (mm)	109
Length (no. meshes)	49.5
Circumference (no. meshes)	80

Catch sampling and condition assessment

The vessel landed catches directly into a holding hopper and the crew sorted the catches by species from a conveyor during net redeployment or when fishing had ceased. Taken directly from the conveyor, all cod caught during the trip were measured, weighed and condition assessed.

The condition assessments followed guidelines developed by the ICES Guidelines on Methods for Estimating Discard Survival (Breen and Catchpole, 2021). The vitality assessments were based on a modified approach from Benoît et al. (2010) that categorised visible barotrauma - partial or full bloating - as major injuries (Table 2) thereby precluding such fish from tagging. This follows on from research on capture-based aquaculture of cod where such fish are removed during catch sorting as they are considered poor survival candidates (Humborstad et al., 2009).

Injuries were scored as 1 = present or 0 = absent for each cod (Catchpole et al. 2015; Randall et al., 2021). Reflexes were scored as 1 = present if a vigorous response was shown during assessment, and 0 = absent if a weak or no response was obvious during assessment (Catchpole et al., 2015; Humborstad et al., 2009). Summed injury and reflex scores were divided by the total number of cod sampled to do derive a mean proportional occurrence across all sampled fish (Appendix I).

Table 2. Vitality categorisations modified from Benoît et al. (2010)

Vitality	Abbreviation	Description
Excellent	1	Vigorous body movement; no or minor[a] external injuries only
Good	2	Weak body movement; responds to touching; minor[a] external injuries
Poor	3	No body movement but fish can move operculum; minor[a] or major[b] external injuries
Moribund	4	No body or operculum movements (no response to touching)

([a]) Minor injuries were defined as minor bleeding, or minor tear of mouthparts (≤10% of the diameter), or minor surface abrasion. ([b]) Major injuries were defined as major bleeding, or major tear of mouthparts, or major surface abrasion, or partial or full bloating

Cod tagging procedure

A Health Products Regulatory Authority (HPRA) approved scientist conducted tagging in collaboration with the Irish Marine Institute. Wildlife Computers (Seattle, USA) supplied ten PSATs for survival studies. The model used in the study was the sPAT (survival pop-off archival transmitting tags) which record data for a maximum of six days prior to pop up. Tags were set to pop up after a maximum of 30 days deployment or prior to this if vertical movement was restricted for > 24 h: the tag floated at the surface; or depth variance did not exceed 2 m e.g., the fish stayed on the seabed. The latter criteria were used to determine when mortality occurred.

We restricted tagging to cod in excellent (V1) or good (V2) condition. Due to a relatively high tag cost, for the purposes of this study, it was assumed that cod in poor (V3) and moribund (V4) condition died, resulting in a conservative survival estimate.

We chose a minimum fish length of ~ 55 cm and weight of ~ 2000g. This follows advice from Wildlife Computers that these PSATs which are 60 grams in air should weigh less than 3 – 5 % of fish body weight. It also corresponds to the median size of cod caught by the Irish seine-net fleet (Pers. Comm Marine Institute). Hence, if the survival study were successful, any application for a survival exemption would be restricted to fish ≥ 55 cm and all condition assessments were conducted on this basis.

The tagging procedure closely followed the method outlined in O'Neill et al. (2018). Cod were held in 310 L holding tanks with a flow through of fresh seawater prior to tagging. When ready for tagging, anaesthesia was induced by immersing the cod in a mixture of seawater and tricaine methane sulfonate (MS-222) in a smaller 70 L tank. Once equilibrium was lost and gill rhythm was slow but constant, the cod was placed dorsal-side up into a lined cradle with a damp cloth placed over the eyes. A constant flow of seawater/MS-222 mixture was pumped across the gills during the tagging procedure.

Figure 2: Tagged cod being released from the vessel

The sPAT was attached to the fish using a bridle system similar to that outlined in O'Neill et al. (2018). Rubber-backed plastic mounting plates were placed on the fish musculature between the first and second dorsal fin. Spinal cannulae needles were inserted through the plates and musculature, with the inserts of the needles then being removed. Sterilised 0.9 mm stainless steel wire was passed through the needle hollows and the needles then withdrawn. The wire was then tightened by hand on both sides of the fish and the wire ends cut and folded in place to prevent unravelling. Fish length (cm) and weight (g) were taken at this point and an additional Floy tag was applied to allow for identification.

The tagged specimen was then placed into another 310-litre holding tank with fresh seawater flow-through and allowed to recover from the tagging procedure. Once equilibrium had returned and gill rhythm was regular and strong, the fish was released from the stern of the vessel using a cradle lowered to the water's surface (Figure 2).

Survival analysis

A Kaplan-Meier (KM) estimator plot was used to assess survival of cod ≥ 55 cm with V3 and V4 cod assumed dead at time zero. The number of days alive was calculated by deducting one day from the total tag deployment period to take account of the last 24 hours when mortality occurred in line with the criteria described above.

Environmental data

Data on environmental parameters that could affect cod condition at haul level was also recorded. The skipper recorded swell height (m), wind speed (knots), and sea surface temperature (°C). Additionally, air temperature (°C) was recorded using a digital thermometer and bottom water temperature (°C) using data storage tags (DSTs) which were attached to the headline of the seine net and set to record every 10 minutes (Appendix I)

Results

A total of 19 successful hauls were conducted over four consecutive days fishing. The main commercial species caught were hake, haddock, megrim, and monkfish (Table 3). Unwanted catches consisted of lesser spotted dogfish, grey gurnard, squid, and boarfish.

Mean towing speed was 1.06 kt. Haul duration ranged from 02:10 – 03:25 hours with a mean of 02:26 hours. Bottom fishing depths ranged from 93 – 118 m with a mean of 107 m. Bulk catch per haul ranged from 83 – 717 kg with a mean of 335 kg. Cod catches throughout the study ranged from 1 – 11 individual cod per haul (Table 4).

Of the 96 cod caught during the trial 53 (~ 55 %) were ≥ 55 cm with 18 (~ 34 %) of these found to be in V1 or V2 condition (Table 5). The survival probability at time zero was 34 % in line with the latter observation. The survival probability dropped to 21 % between days 5 and 10, 10 % on day 13 and gradually decreased to zero at day 20 when all fish were assumed to have died (Figure 3). The mean survival period of tagged fish was 10 days.

Table 3. Species catches

Species	Weight (kg)
Hake	2150
Haddock	1130
Megrim	650
Unwanted catches	589
Monkfish	500
Plaice	300
Whiting	277
Lemon sole	275
Cod	248
Skates and rays	80
John Dory	80
White pollack	40
Red gurnard	25
Red mullet	20
Total catch	6364

Table 4. Summary fishing operation, cod catch and tag data

Haul ID	Date	Haul duration (hours)	Bottom Depth (m)	Bulk catch (kg)	Swell Height (m)	Wind speed (knots)	Cod (n)	Tagged cod (n)	Average survival (days)
1	20/07/2022	02:20	111	83	2.1	21	3	-	-
2	20/07/2022	02:20	111	320	1.9	16	2	-	-
3	20/07/2022	02:15	111	333	2.0	16	5	1	13
4	20/07/2022	02:15	111	467	1.7	16	7	1	20
5	20/07/2022	02:25	111	264	1.7	16	6	-	-
6	20/07/2022	02:10	111	290	1.6	10	1	1	11
7	21/07/2022	02:20	97	277	1.0	6	4	2	3.5
8	21/07/2022	02:20	97	365	0.5	6	10	1	5
9	21/07/2022	02:30	93	467	0.7	6	4	1	17
10	21/07/2022	02:35	93	198	0.4	6	9	-	-
11	21/07/2022	02:30	98	243	0.3	6	2	1	1
12	22/07/2022	02:30	108	355	0.6	6	2	2	13.5
13	22/07/2022	02:10	109	544	0.6	6	5	-	-
14	22/07/2022	02:35	109	234	0.8	10	4	-	-
15	22/07/2022	02:05	109	397	1.1	10	1	-	-
16	22/07/2022	02:20	109	186	1.2	10	3	-	-
17	22/07/2022	03:25	109	430	1.3	10	2	-	-
18	23/07/2022	02:45	118	192	2.0	16	5	-	-
19	23/07/2022	02:25	118	717	2.0	16	11	-	-

Table 5: Summarised cod vitalities

Vitality	Count (n)	Proportion (%)
≥ 55 cm		
1	11	21
2	7	13
3	28	53
4	7	13
Total	53	100
< 55 cm		
1	4	9
2	4	9
3	11	26
4	24	56
Total	43	100

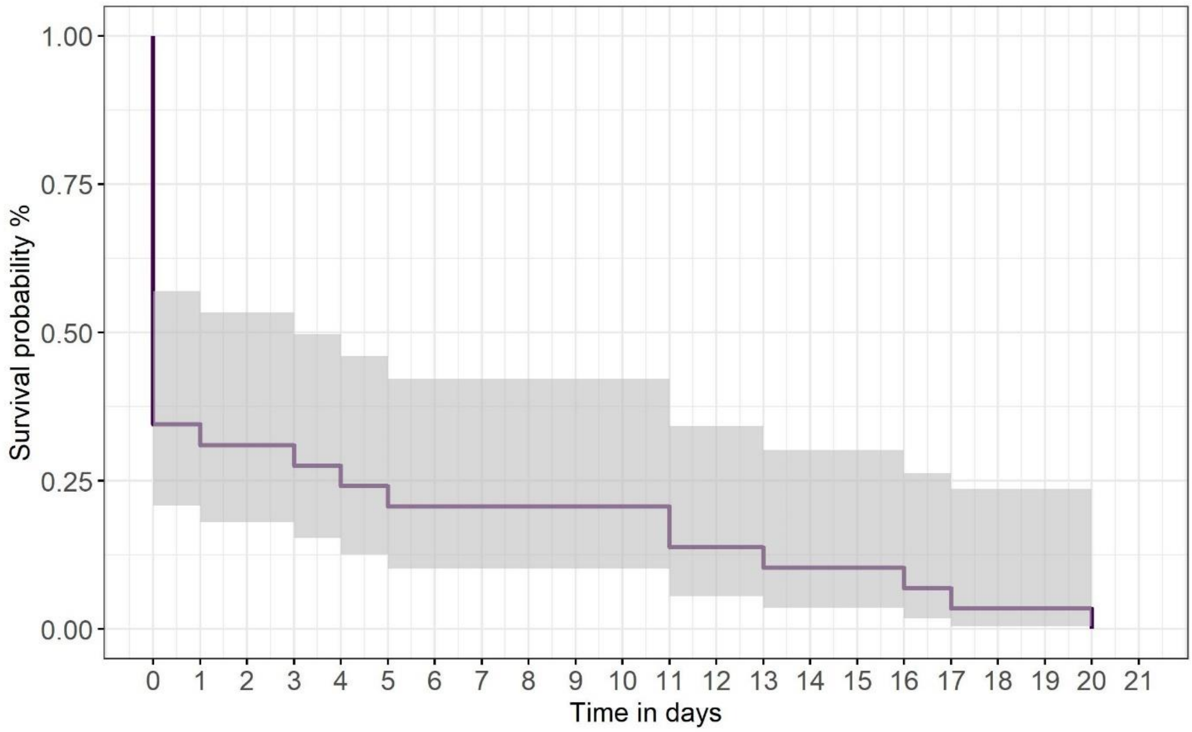

Figure 3: Kaplan-Meier estimator for cod ≥ 55cm

Tagged cod ranged in length and weight from 59 – 100 cm and 1850 – 11980 g. Air exposure for tagged cod ranged from 4 – 16 minutes. Tag deployments ranged from 2 to 21 days (Table 6). Six fish demonstrated bottom-orientated and four fish surface-orientated behaviour prior to tag pop off (Figure 4).

Net marking was the most common injury type followed by full or partial bloating related to barotrauma. Righting was the poorest reflex response (Appendix 1).

The weather was calm to fresh throughout the study with swell heights ranging from 0.3 – 2.1 m and wind speeds of 6 – 21 knots. Sea surface temperature was relatively high as expected for the month of August while bottom temperature was > 3°C cooler than surface temperatures. Air temperature inside the shelter of the vessel was 18 °C during the study (Appendix I).

Table 6: Tagged cod data

Tag ID	Start date	Tag release date	Tag deployment period (days)	Vitality score	Size (cm)	Weight (g)	Air exposure (min)
1	20/07/2022	03/08/2022	14	1	61	2215	16
2	20/07/2022	10/08/2022	21	2	59	1850	12
3	20/07/2022	01/08/2022	12	2	71	4135	9
4	21/07/2022	25/07/2022	4	1	100	11980	10
5	21/07/2022	26/07/2022	5	1	61	2680	15
6	21/07/2022	27/07/2022	6	2	80	6000	8
7	21/07/2022	08/08/2022	18	2	69	4165	8
8	21/07/2022	23/07/2022	2	1	59	2220	11
9	22/07/2022	03/08/2022	12	1	85	6835	4
10	22/07/2022	08/08/2022	17	1	85	6945	8

Discussion

Study results suggest poor cod survivability in the current Irish bottom-seine net fishery. Elevated levels of visible barotrauma resulted in just 34 % of ≥ 55cm cod assumed to have initially survived the capture process. Representative of this catch component, tag data demonstrated an average survival period of 10 days, while the KM estimator demonstrated 10 % survival probability after 15 days and 0 % survival probability after 20 days. Generally, a minimum survival probability of 50 % after 15 days or longer is needed before a case can be made towards a survival exemption so results fell well short of that level.

It is possible to reduce barotrauma and physical stressors in seine-net caught cod by reducing hauling speeds and using canvas lining in the codend, as evidenced by the results observed in a Norwegian fishery (Dreyer et al., 2008). The latter is a highly specialised operation, however, which targets cod for capture-based aquaculture and it would be difficult to implement such measures in the Irish wild-capture fishery: cod are not a target species and a canvas lining would greatly reduce size selectivity for all species. Also, the Irish fishery is relatively deep (mean bottom depth 106.5 m). At these depths cod would require more than 10 h decompression time to avoid rupturing the swim bladder (Nichol and Chilton, 2006; Tytler and Blaxter, 1973). The net took ~ 20 min to travel from seabed to the surface during the current study. Some increase in this hauling period would be possible but extending to > 10 h would not be commercially viable in the Irish fishery.

Results of the latter studies suggest that all cod caught during the current study suffered barotrauma which was simply not visible for fish in excellent or good condition. Cod can recover from barotrauma if they can submerge quickly and are not negatively impacted by other injuries e.g., in recreational fisheries (Ferter et al., 2015). Cumulative impacts including barotrauma, physical stressors in the codend, air exposure, and injuries observed under commercial fishing conditions in the seine-net fishery are likely, however, to have negatively affected cod survival in the current study.

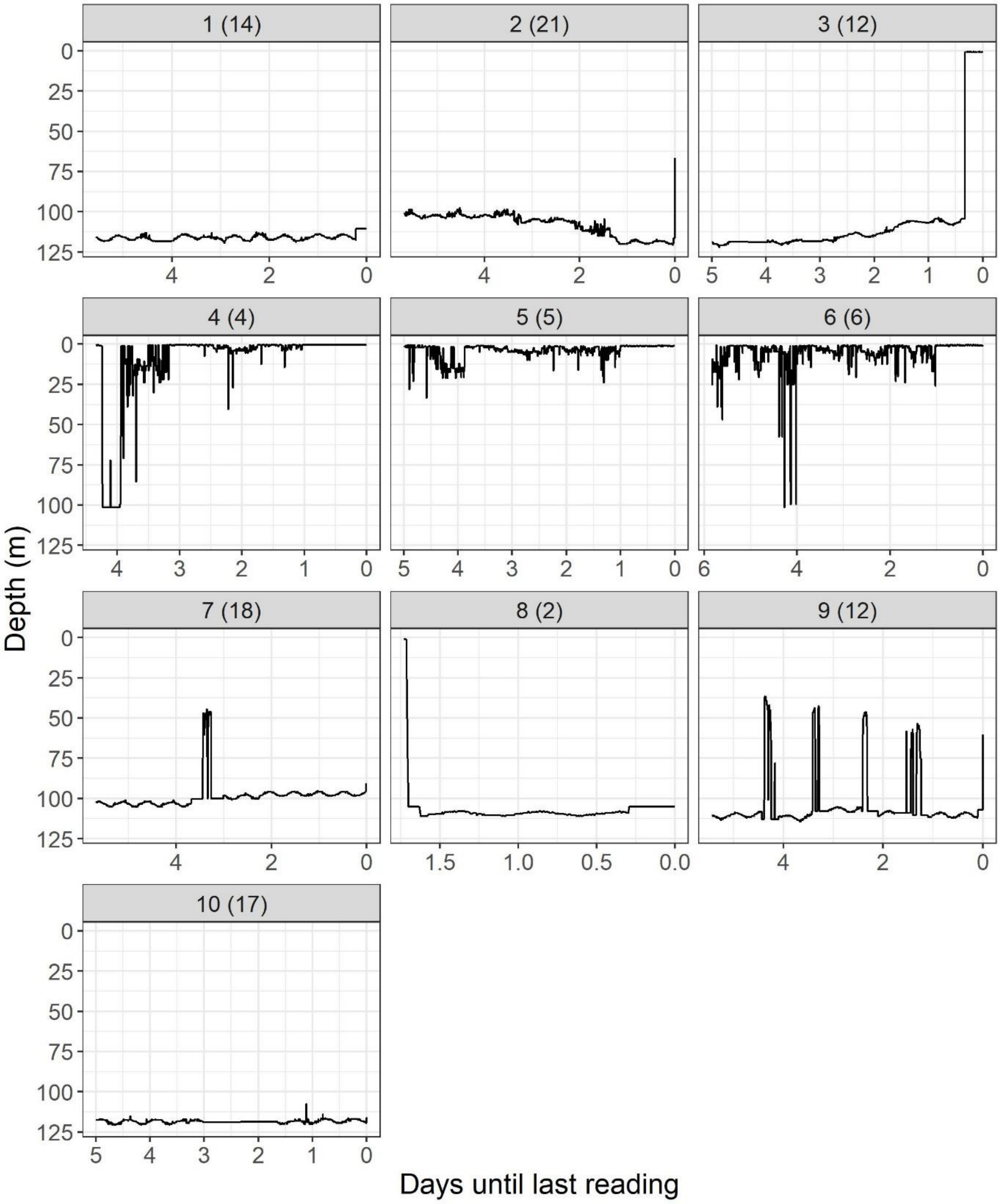

Figure 4: Vertical behaviour for tagged cod up to six days prior to tag pop off. Figure headings consist of fish ID number with total deployment period in brackets7

Some of our sPAT tagged cod likely suffered from barotrauma: Behaviour patterns attributed to barotrauma have been observed in pacific cod (*Gadus macrocephalus*) tracked with data storage tags (DST). These often include an initial escape dive to the bottom, followed by a quick return to shallow water, and a gradual descent back to the bottom (Nichol and Chilton, 2006). The 10 sPAT tags restricted data collection to the 6 days prior to pop off but 4 of these were deployed for ≤ 6 days permitting observations of initial diving behaviour.

With the exception of one fish which likely died almost immediately, all of these fish displayed surface-orientated behaviours more consistent with barotrauma than the normal bottom-orientated behaviour associated with Celtic Sea cod (Neat et al., 2014): Fish 8 likely died soon after release given a rapid descent to the bottom followed by minimal variance in depth and pop-off in less than 2 days total tag deployment period. Fish 4 initially exhibited a typical barotrauma response with an escape dive to the bottom followed by a gradual ascent to depths < 25 m but subsequently failed to return to the bottom with tag pop-off occurring after > 24 h floating at the surface. Fish 5 remained at shallow depths before pop-off at the surface. Fish 6 remained shallow for almost 2 days before conducting several bounce dives in quick succession to greater depths followed by a period in shallow water before pop-off (Figure 4).

Longer term tag deployments (fishes 1, 2, 3, 7, 9 and 10) all returned to deeper depths. However, although > 2 m (the threshold for pop-off), minimal differences in depth occurred over the 6 days prior to pop-off for all except fish 9 (Figure 4). It is possible that some of these fish were dead during this period with movements from tidal cycles and currents preventing tag pop-offs.

Stress associated with carrying sPAT tags may have been partly responsible for tagged fish mortalities: Neat et al. (2014) showed that 33 Celtic Sea cod with DSTs caught in a modified commercial trawl survived for extended periods (114.8 ± 133.7 days) before recapture. Internally implanted DSTs may be easier for cod to carry compared with dorsally mounted pop-off tags. However, PSATs have been successfully deployed for extended periods in behavioural studies on other species of a comparable size such as European sea bass (*Dicentrarchus labrax*) (O'Neill et al. 2018) and Atlantic salmon (*Salmo salar*) (LaCroix, 2013) suggesting that the tagging method was not directly responsible for poor cod survival in the current study.

However, Neat et al. (2014) reduced haul-up and air exposure times to optimise fish condition prior to release whereas cod were caught under normal fishing conditions in the current study. As outlined above, a variety of combined stressors likely caused mortalities, and we cannot discount the possibility that sPATs contributed in this regard.

Net marking was the main injury observed for all cod but this is considered to have a minor effect on fish condition and survival (Benoit et al., 2010; Humborstad et al., 2009). The ability of cod to right - or actively swim into correct orientation - was the poorest observed reflex response across all cod which may be linked to rupture of the swim bladder which is used to control buoyancy. Tagged fish suffered relatively minor surface abrasion injuries and did not suffer from the righting impairment (Appendix I).

Study results have implications for survival of escapees during bottom fishing. Ingólfsson et al. (2021) demonstrated how around 50% of undersize haddock escapement occurred as the net approached the surface. These fish likely experienced higher mortality due to barotrauma-related stress than fish escaping at the fishing depth during the towing process. Underwater footage of the codend during hauling in the current study confirmed barotrauma in species other than cod. Widescale rupturing of swim bladders was observed in hake the main catch species once the net reached ~ 20 m from the surface (Figure 5).

Ingólfsson et al. (2021) recommend the use of codend mesh with the meshes open throughout its length such as T90 mesh to facilitate escapement of fish at depth. T90 mesh has been shown to be highly effective in reducing catches of undersize haddock, whiting and cod in Irish fisheries (Browne et al., 2016; Browne et al., 2019). Further testing of T90 in the seine net fishery by BIM and the Irish fishing Industry confirmed benefits in relation to reductions in undersize fish but also demonstrated increases in market sized catches (McHugh et al., 2019). Consequently, T90 mesh is currently widely used by the Irish seine net fleet which assists in escapement, survival and conservation of undersized fish.

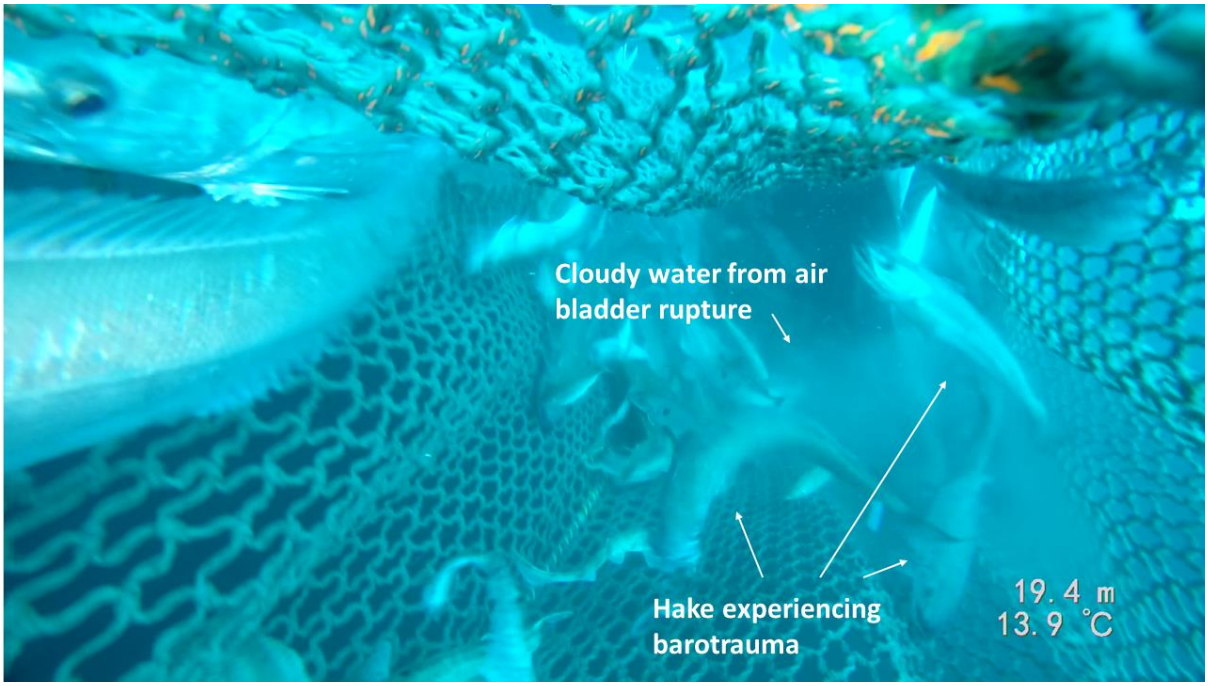

Figure 5: Bloating and air bladder rupture (cloudy water) in hake when the codend reaches ~ 20 m from sea surface

The sPATs and tagging procedures used in this study worked very well with all 10 tags successfully reporting data on fish behaviour which greatly assisted in estimating cod survival rates and elucidating mortality causes. Development of this new fish survivability assessment technique builds on previous BIM work on developing fixed (e.g. Oliver et al., 2017) and mobile (e.g. Oliver et al., 2020) captive monitoring facilities.

Current survivability exemptions in Irish waters e.g. Nephrops in ICES sub area VII (Oliver et al., 2017) and seine caught plaice (Oliver et al., 2020) are legislated for until the end of 2023 and may require further supporting evidence post 2023. Further survivability work may also be required in relation to vulnerable species such as skates and rays in response to the EU Biodiversity Strategy and new Marine Strategy Framework Development Measures. The development of multiple assessment techniques and expertise among Irish Scientists in this field will assist the Irish fishing Industry in addressing these new challenges.

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Appendix I

Mean injury occurrence across 96 observed cod

Injury	Description	≥ 55 cm (%)	< 55 cm (%)
Abrasion	Haemorrhaging red area from abrasion.	11	12
Bleeding	Obvious bleeding from any location.	6	5
Bruising body	A body injury to underlying tissues in which the skin is not broken, often characterized by ruptured blood vessels and discolorations	4	9
Bruising fin	A fin injury to underlying tissues in which the skin is not broken, often characterized by ruptured blood vessels and discolorations.	15	12
Fin fraying	Fins damaged, possibly with slight bleeding.	28	37
Internal organs exposed	Internal organs exposed with wounds.	0	0
Net marks	Any type of clearly visible net marks on body from trawl, gillnet, etc.	75	95
Scale loss	Obvious area of scale loss.	62	88
Scratches	Thin shallow cut or mark on (a surface).	15	37
Partial bloating	Abdomen swollen, due to inflated swim bladder, slack to touch, fish floats at surface of tank when not swimming.	32	44
Full bloating	Abdomen swollen, due to inflated swim bladder, tight to touch, fish floats at surface of tank and cannot dive.	30	37
Wounding	Nicks or cuts on body.	6	9

Cod reflex occurrence across 96 sampled cod

Reflexes	Description	≥ 55 cm (%)	< 55 cm (%)
Body flex	Attempts to escape when restrained.	90	50
Evade	Attempts to avoid capture.	50	30
Head complex	Regular pattern of ventilation with jaw and operculum.	100	60
Righting	Returns to normal orientation when turned upside down.	40	20
Tail grab	Burst movement away from tester.	70	40
Vestibular – ocular response	Eyes roll when body rotated around long axis.	90	60

Injuries and reflexes for tagged cod

Tag ID	Days alive	Net marks	Scale loss	Scratches	Abrasion	Body flex
1	14	Present	Present	Present	-	-
2	21	Present	-	-	-	-
3	12	Present	-	Present	Present	-
4	4	-	-	-	-	-
5	5	-	-	-	-	-
6	6	-	-	-	-	Absent
7	18	-	Present	-	-	-
8	2	-	-	-	-	-
9	12	-	-	-	-	-
10	17	-	-	-	-	-

Environmental data collected during the study

Parameters	Values
Swell Height (m)	0.3 - 2.1 (1.19)
Wind speed (knots)	6 - 21 (10.75)
Sea surface temperature °C	14.7 - 17.3 (16.44)
Bottom temperature °C	10.6 - 15.6 (13.14)
Air temperature on vessel °C	18