Sole survivability in the Irish otter trawl fishery

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Key Findings

A 50% survival rate was obtained in an Irish otter trawl fishery.

1

The trial was conducted in September when air and water temperatures were at their highest providing a worst-case survival estimate.

2

Water temperatures in Galway Bay are higher than the Celtic and Irish Seas suggesting sole survival is likely greater in the latter areas.

3

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An Roinn Talmhaíochta, Bia agus Mara
Department of Agriculture, Food and the Marine

EUROPEAN UNION
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Introduction

Sole *(Solea solea)* landings in the North East Atlantic predominantly occur in the North Sea and in the eastern Celtic Sea in UK waters (Figure 1a). Sole is primarily landed by Irish vessels as bycatch in mixed demersal trawl fisheries. On average, around 185 tonnes of sole were caught and landed annually by Irish vessels between 2016 and 2018 predominantly in coastal shallow sandy areas where they typically constitute less than 2% of landings (Figure 1b). Some 50% of sole were caught in ICES division 7j off the southwest coast. Discarding is considered to be negligible in that area with 1 tonne corresponding to less than 0.5% of total sole catches in 2018. Landings have been well below the Irish quota in 7j in recent years. Quota is much more restrictive in other areas: Further to the East in ICES divisions 7f and 7g, a 1% bycatch quota applies for most months of the year. In ICES division 7a, the Irish Sea, no directed fisheries were permitted in 2019, with Irish vessels allocated a bycatch quota of 74 tonnes (MI, 2019).

Under the landing obligation, low quotas combined with difficulties in reducing unwanted catches can lead to early cessation or choking of fishing effort. Demonstration of high species survival can lead to an exemption under the landing obligation, and a survivability exemption currently applies to sole caught in an otter trawl fishery in ICES division 7d (EU, 2018). This study aimed to assess sole survivability in the Irish otter trawl fishery.

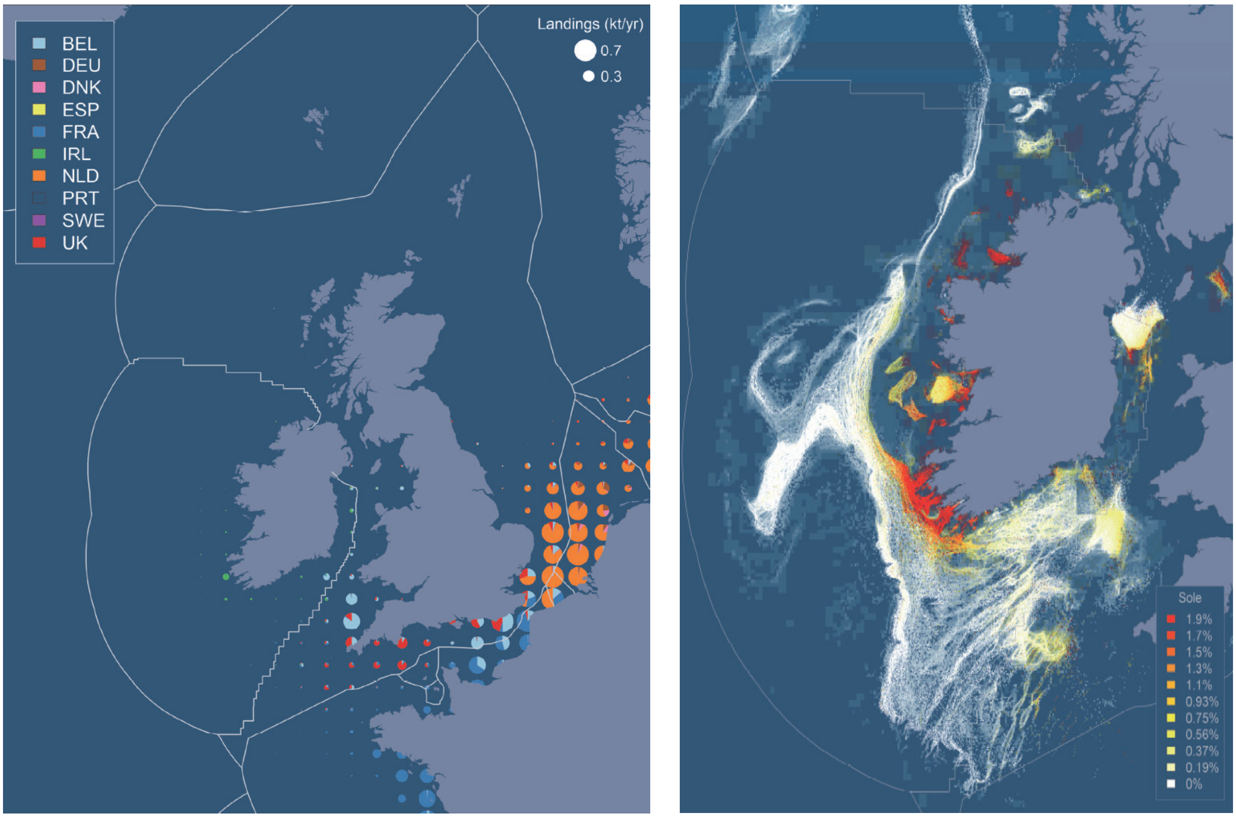

Figure 1. (a) Average distribution of sole landings in the Northeast Atlantic in the period 2011-2016 (MI, 2019)

(b) Proportion of sole in Irish bottom trawl landings (VMS/logbook data 2006-17). The highest proportions of sole occur on shallow sandy grounds. However there are no areas where sole consistently make up more than 2% of the landings (MI, 2018)

Materials and Methods

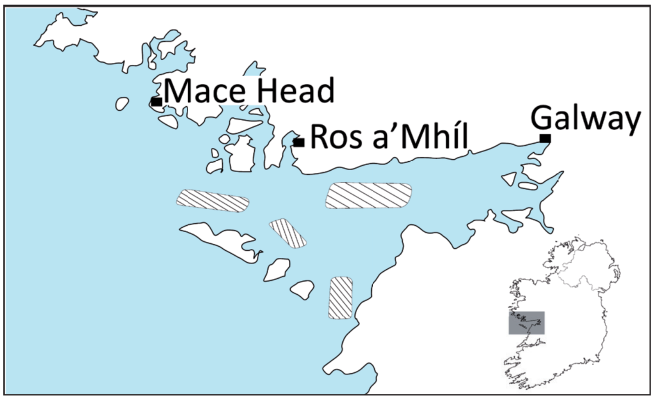

Figure 2. Fishing areas (hatched), and trial vessel MFV Karen Mary

Ethics statement

Prior to commencement of this study, BIM sought clarification on the status of the project under scientific animal protection legislation from the Health Products Regulatory Authority (HPRA). Following discussion of a detailed application and protocol (Appendix I), HPRA determined that the project fell outside the scope of the legislation and that no official authorisation was required. The study followed protocols developed by the ICES workshop on methods for estimating discard survival (ICES, 2016).

Fishing operations

Fish were collected over four days from ICES division 7b on the West of Ireland and Aran fishing grounds from the 2nd to 8th September 2019. Trawling operations were completed in outer Galway Bay within 2.5 hours steaming time of the fishing port, Ros a'Mhíl, where samples were landed daily. The trial was conducted on board the MFV Karen Mary (DA127), an 11.64 m trawler, which fished an otter trawl in single-rig configuration with 120 mm square mesh panel and an 80 mm cod end (Figure 2, Table 1).

Table 1: Gear characteristics

Trawl type	Single-rig otter trawl
Trawl manufacturer	Marine suppliers (Howth)
No. of floats on headline	13
Nominal mesh size (mm)	80
Headline length (m)	46
Footrope length (m)	46
Sweep length (m)	73
Warp diameter (mm)	13
Door manufacturer	Bison
Door weight (kg)	120
Square mesh panel (SMP)	
SMP nominal mesh size (mm)	120
SMP location from codline (m)	9 –12
Codend	
Nominal mesh size (mm)	80
Measured mesh size (mm)	83
Standard error (mm)	0.34

Figure 3. Landing the catch on deck, and storage systems on board the vessel and at the holding facility

Catch sampling and vitality assessment

Test sole were caught in hauls of normal duration ranging from ~ 2 to 4 hours while control sole were caught in hauls of reduced duration (~ 30 minutes) in the same location as test fish. Trawl catches were landed directly onto the deck, sampled immediately in the case of controls, and after the trawl was redeployed in the case of test fish as per normal fishing practices. Sole were initially placed in 50 litre tubs of seawater before being sorted by vitality using an approach modified from Benoît et al. (2010) (Appendix I). Individual fish were assessed for injury using an approach developed by Depestele et al. (2013) and Smith et al. (2015). Sole were stored on board the vessel in fish bins with continual flow through of seawater (Figure 3).

Transit and onshore storage

Sole were kept in the same holding tanks on board the vessel and during transport to the holding facility to help minimise stress associated with fish handling. A refrigerated van with a clean supply of oxygenated seawater was used to transport sole the 42 km between the harbour and onshore holding facility. The onshore facility was located at Galway and Mayo Institute of Technology's (GMIT) main campus and comprised a recirculating seawater system housed in a constant temperature room.

The system comprised four Tropical Marine Centre recirculated seawater systems that incorporate mechanical, sand and biological filters, a protein skimmer and a UV filtration system. Two large glass reinforced plastic tanks with artificial seawater were attached to each system. Each tank was divided in three with modified oyster bags to provide separate compartments (Figures 3 and 4). Coral sand sourced from Seahorse Aquariums Ltd. was placed in the bottom of each tank to facilitate the natural burying behaviour of sole and reduce stress associated with captive holding. Fish were fed ad libitum throughout the trial.

Mortality assessments were conducted daily using a detailed protocol (Appendix I). Fish that failed the assessment were removed from the experiment and humanely euthanised by immersion in a tricaine methanesulfonate solution (TMS or MS-222) by trained aquarium staff. At the end of the experiment all remaining fish were removed and euthanised humanely.

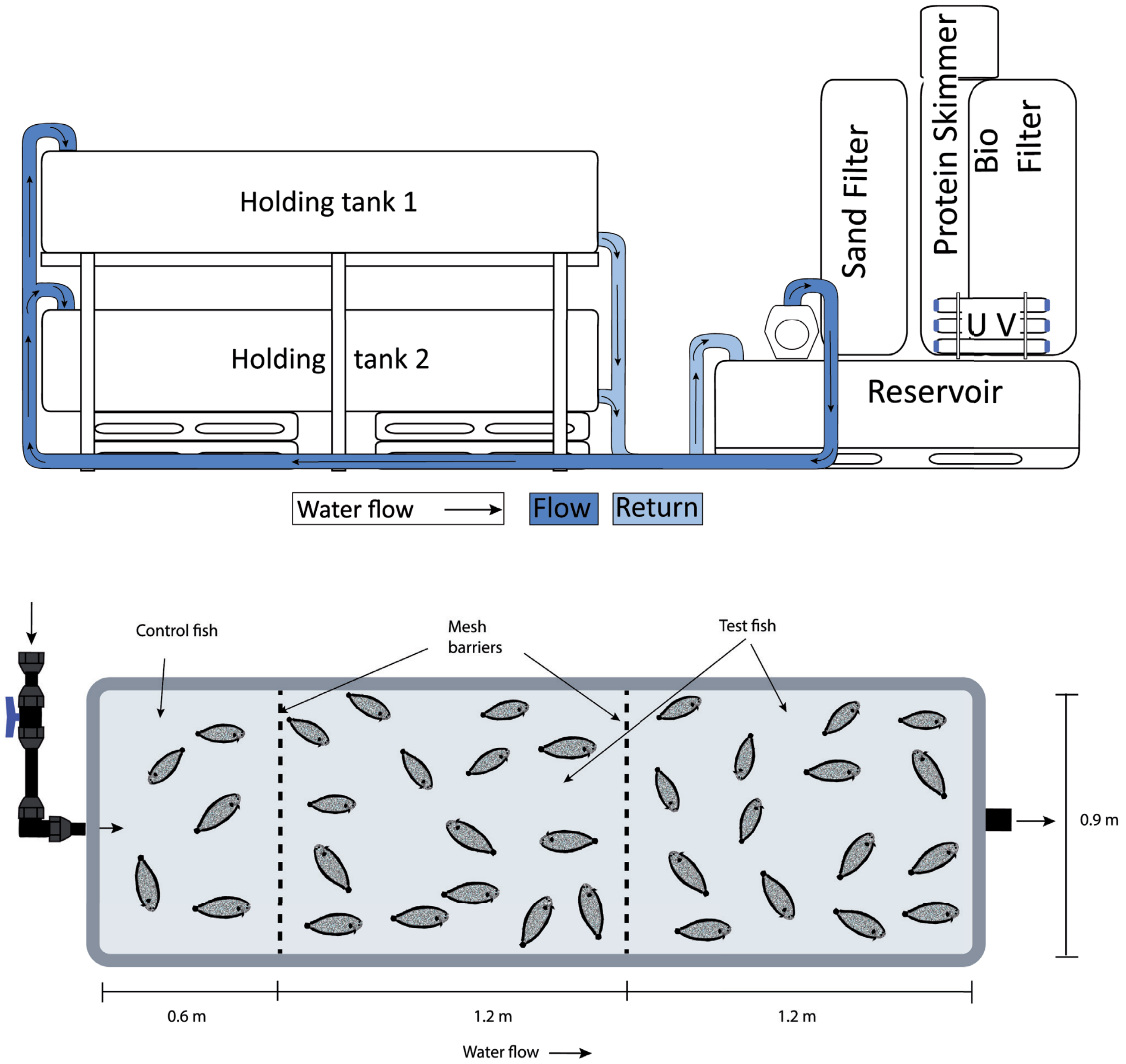

Figure 4. Side and top view of one of four recirculated seawater systems used for onshore storage

Environmental parameters

Data on environmental parameters which could impact survivability such as salinity, water and air temperature, and dissolved oxygen were collected during the trial. Air and surface water temperature were recorded periodically at sea using a digital thermometer while bottom temperature was collected every eight minutes using star oddi data-storage tags (DSTs) that were attached to the trawl headline. Additional parameters such as wave height and wind strength were recorded by the skipper daily. While in captivity, salinity, dissolved oxygen, and air/ water temperature were recorded at least every 24 hours using the *Oxyguard Pacific* system and a *Tetratec Comfort* Hydrometer. Average sea surface temperatures from around the Irish coast were obtained from the Irish weather buoy network (https://data.gov.ie/dataset/weather-buoy-network).

Analysis

Holding wild animals in captivity can induce stress, which can potentially increase mortality in addition to the treatment effect. Moreover, physical damage from being held in tanks on board a moving vessel, changes in salinity, pressure and temperature, and being held in close proximity with other fish, all exert stress on fish. The duration of monitoring in the holding system is a trade-off between ideal scientific needs, available resources, and occurrence of confounding mortality not associated with the process of discarding (Catchpole et al., 2015) or "method induced mortality".

Following a stabilisation with no mortalities occurring on Day 6 and 7, a spike in mortalities occurred on Day 8 with 5 fish dying. All of these dead fish came from 1 compartment (2A) with no mortalities occurring in any of the other 7 remaining compartments with test fish on that day. We investigated if the Day 8 mortalities were consistent with the distribution of mortalities across compartments up to Day 7. The observed proportions of mortalities in each compartment from Day 1 to 7 were plotted to assess potential differences between compartments. Using the distribution of mortalities across compartments from Day 1 to 7 (Figure 5), we investigated the probability of observing 5 mortalities in compartment 2A and 0 mortalities in the other compartments on Day 8. Mortality counts were assumed multinomial across compartments thus providing a means to calculate the probability for the Day 8 result under given probabilities. A likelihood ratio test was conducted between the null hypothesis that the Day 8 observations were drawn from the distribution of mortalities up to Day 7 versus the alternative, a saturated model for Day 8 (probability for compartment 2A was one and the rest zero). We then calculated the odds of 5 mortalities occurring in compartment 2A on Day 8. This analysis helped determine an unbiased period of observed survival.

A Kaplan-Meier estimator which approximates survival probability over time was used to compare survival of test fish with control fish. Survival prediction models are commonly used to forecast survival beyond an initial captive monitoring period. For example, Catchpole et al. (2015) monitored plaice in ICES division 7e for a period of 5 days and predicted survival beyond that period resulting in a survival exemption for that species in divisions 7d and 7e (EU, 2018). Making best use of available unbiased data in the current study, we applied a Weibull distributed cured model (Benoît et al., 2012) to the first 7 days of observations to predict an overall survival estimate for sole in the current study. Confidence intervals were calculated using delta method methodology. It is not possible to include Day 0 in cured models. Hence, mortalities at sea, during transit and during the first 24 h in the onshore holding system were categorised as Day 1 fish. This process took less than 32 h, providing a conservative mortality estimate for Day 1.

Results:

Table 2: Summary trawl operations and catch data

Treatment	Haul date	Haul duration (min)	Haul depth (m)	Fish catch (kg)	*Nephrops* catch (kg)	Crustacea* (kg)	Elasmo-branchs** (kg)	Bulk catch (kg)	Sole retained (N)
Control	02-09-19	32	45	51	0	4	97	152	6
Test	05-09-19	121	30	21	0	5	21	47	14
Control	05-09-19	25	28	105	15	27	0	147	9
Test	05-09-19	244	33	37	3	18	33	92	19
Control	07-09-19	31	66	74	19	72	43	208	2
Test	08-07-19	124	70	41	0	23	11	75	71
Test	08-07-19	181	53	135	42	14	69	259	37
Control	08-09-19	30	53	67	5	43	39	154	2

Crustacea*: Spider crabs, *Liocarcinus* sp.; Elasmobranchs**: lesser spotted dogfish, skate and ray

A total of 8 valid hauls, 4 test and 4 control, were completed over four days fishing during September 2019. Haul duration and depth averaged 168 min and 47 m for the test fish and 30 min and 48 m for control fish.

Catches consisted primarily of mixed fish, elasmobranchs, crusatcea and *Nephrops* (Table 2). Mean towing speed was 2.5 kt for both test and control hauls. All 141 test and 19 control sole caught during the trial were retained for captive monitoring.

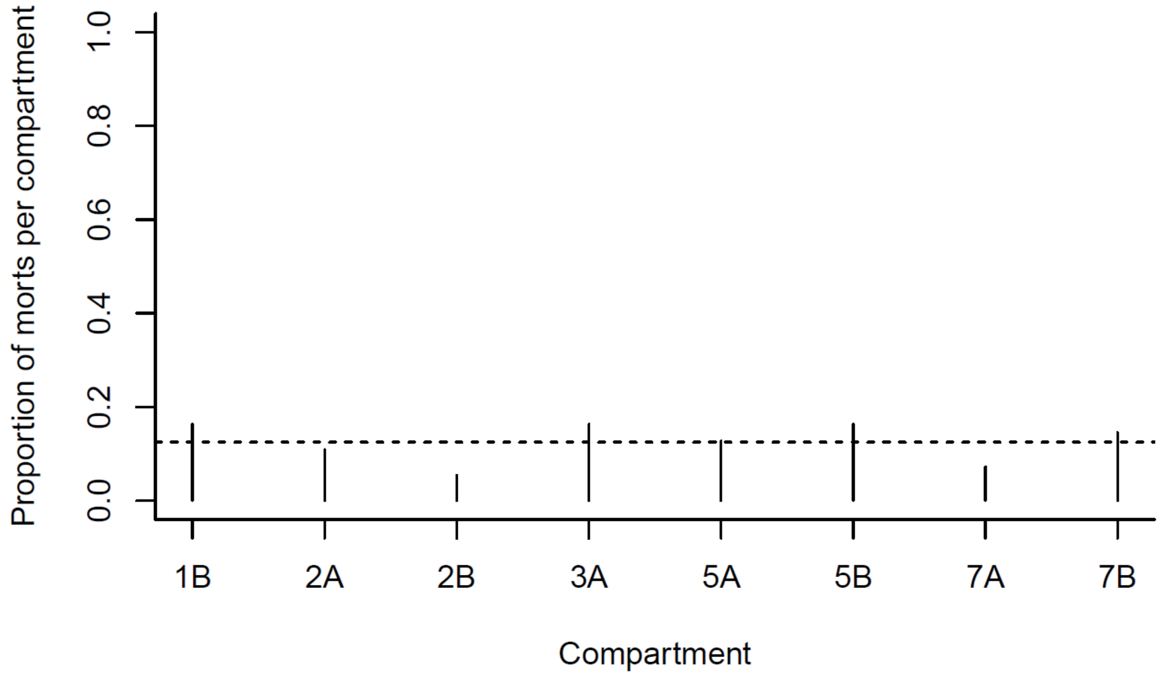

Figure 5. Average (dotted line) and proportions of total mortalities across compartments from Day 1 – 7.

The proportion of total mortalities in compartment 2A from Days 1 – 7 was close to the average across all compartments, indicating nothing unusual in the level of mortalities in that compartment prior to Day 8 (Figure 5). The log-likelihood ratio test showed a highly significant difference in the proportion of mortalities in compartment 2A compared with the other compartments on Day 8, $p = 1.57^{e-5}$. The odds ratio of the Day 8 observations showed a 1 in 63,694 chance of 5 mortalities occurring in compartment 2A on Day 8 based on the distribution of mortalities up to that point. Hence, Day 1 – 7 was determined as the unbiased period of observed survival.

The Kaplan – Meier plot showed a significant difference in survival of test and control fish. Most mortalities occurred early on in the experiment with 32% occurring on Day 1. Over the following three days, mortalities dipped to 5 or 6% per day. On Day 5 just 1 sole corresponding to less than 1% of remaining test fish died while no sole died on Days 6 or 7 (Figure 6). The observed survival rate at the end of Day 7 was 50.35% (95% CI 42.74% - 59.32%). The stabilisation in mortalities prior to Day 7 resulted in a similar predicted survival estimate of 50.35% (95% CI 42.16% - 58.52%) (Figure 7).

The main injuries observed during sampling on board the vessel comprised mucus loss (18%), scale loss (18%), abrasion (17%) and scratches (13%). The vitality assessment showed that from a total of 141 test sole, 18% were excellent, 38% were good, 37% were poor and 8% were dead at the point of the first vitality assessment conducted on board the vessel. At the end of the experiment, 97% of remaining test fish were in excellent condition with the other 3% in good condition. All 19 control fish survived captive monitoring. Seventeen control sole were categorised as excellent and two as good at the initial assessment, with all controls classified as excellent at the end of the experiment. These figures suggest that fish which survived the capture process recuperated well during captive observation.

Test sole ranged in size from 19 – 41 cm with a mean length of 27.7 cm. Control sole were 20 – 32 cm with a mean length of 25.4 cm. Air exposure times on deck ranged from 6 to 11 minutes for the test sole and 1 to 4 min for the control fish. A summary of environmental data collected during the trial is outlined in Table 3. Average sea temperatures in relevant areas around the Irish coast are outlined in Table 4.

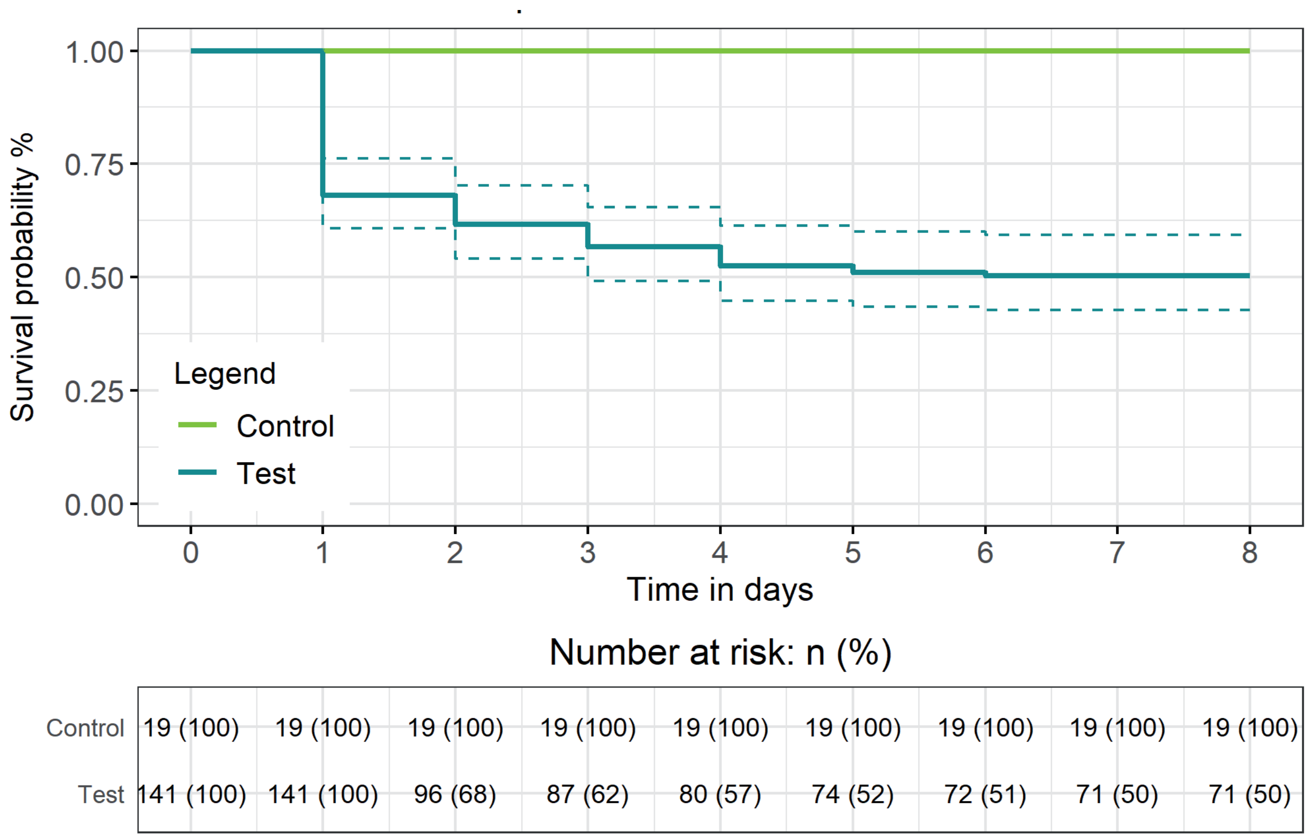

Figure 6. Kaplan-Meier survival plot of test and control caught sole during the 7 day observation period

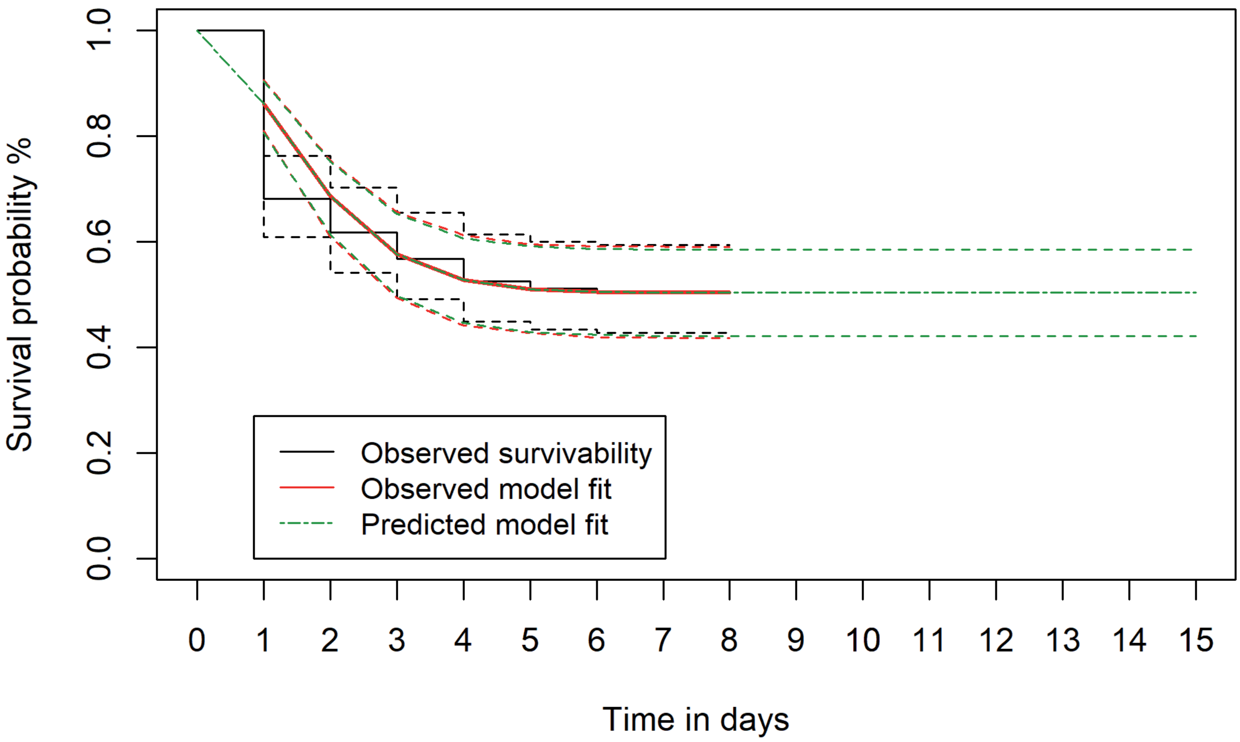

Figure 7. Weibull distributed cure model predicted sole survival

Table 3: Environmental data collected during the trial with mean values in brackets

At sea parameters	Control	Test
Number of hauls	4	4
Air temperature range (mean) in °C	15 - 19 (16.04)	15 - 19 (16.25)
Sea surface temperature range (mean) in °C	16-17 (16.5)	16-17 (16.6)
Sea-surface salinity range (mean) in ppt (‰)	28-34 (30.8)	28-31 (29.5)
Sea-bottom temperature range (mean) in °C	13.8 - 16.6 (15.1)	12.3 - 15 (13.9)
Wave height range (mean) in m	0.31 - 1.63 (0.8)	0.31 - 1.63 (0.8)
Wind speed range (mean) in knots	3 to 27 (15.4)	3 to 21 (12.5)
Onshore parameters	Control	Test
CT room temperature range (mean) in °C	10.1 - 14.9 (12.3)	10.1 - 14.9 (12.3)
Holding tanks temperature range (mean) in °C	13.1 - 17.6 (15.8)	13.1 - 17.6 (15.8)
Holding tanks salinity range (mean) in ppt (‰)	24.5 - 37 (32.2)	30.0 - 37 (32.2)
Holding tanks dissolved O2 range (mean) in mg/l	7.2 - 10 (7.9)	7.2 - 10 (7.9)
Holding tanks % dissolved O2 range (mean)	88.9 - 115 (96.1)	88.9 - 115 (96.1)

Table 4: Average monthly sea surface temperatures (°C) in relevant areas around Ireland from 2015 – 2018. Source: https://data.gov.ie/dataset/weather-buoy-network

	West of Ireland	Celtic Sea	Irish Sea	Galway Bay
January	11.17	10.50	10.43	7.83
February	10.84	9.21	9.10	7.40
March	10.55	8.79	8.44	8.19
April	10.99	9.84	8.74	10.02
May	11.43	11.74	10.01	12.04
June	13.20	14.47	12.46	14.57
July	14.61	15.83	13.48	15.90
August	14.85	15.75	14.06	16.32
September	13.93	15.34	14.25	15.44
October	13.93	14.38	13.98	13.15
November	12.71	13.07	13.09	10.86
December	11.55	11.52	11.41	9.47

Discussion

The 50% survival rate for sole in the current study compares well with a previous study on sole survivability in an otter trawl fishery in the North Sea where an observed survival rate of 46%, and a predicted survival rate of 43% were obtained (Ribeiro Santos et al., 2016). Air and water temperature are known to be highly correlated with mortality of flatfish such as plaice (Kraak et al., 2018). The observed mean sea surface water temperature in the current study of ~ 16.5°C (Table 3) was higher than any of the average monthly water temperatures in the local Galway Bay area over the previous three years (Table 4). The observed mean air temperature of ~ 16°C was also higher than any average monthly air temperatures recorded at the nearest weather station at Mace head (Figure 2) from 2016 to 2019 (Source: Irish Meteorological Service: (www.met.ie/climate/available-data/monthly-data). Hence, the current study provides a worst-case survival scenario and it is highly likely that a greater survival rate would be obtained if the study was repeated during winter months. Water temperatures in Galway Bay are consistently higher than other areas around the Irish coast such as the Celtic and Irish Seas. This suggests that post-capture sole survival is likely greater in the Celtic and Irish Seas.

A key consideration with captive observation is that it does not account for predation effects and so potentially overestimates discard survival levels, which must be made explicit when presenting the results (Raby et al., 2013). Captivity may also exclude stressors that would otherwise be experienced by discarded fish and so it is possible that subjects may survive better in the containment facilities than if released, which may also overestimate survival. However, in general, the additional stressors associated with being contained are considered to have a larger effect on subjects (Portz et al., 2006), i.e. that the containment method is more likely to induce mortality than to increase survival (ICES, 2014).

The reason(s) for mortality of 5 test fish in one compartment following survival stabilisation is unknown. However, the probability analysis suggests that it was highly unlikely that these mortalities reflected the distribution of mortalities across compartments from the preceding days in the trial. The fact that the 5 mortalities occurred in a single compartment, following stabilisation in mortalities across all compartments, suggests a localised effect of the containment method on these 5 fish.

No mortalities occurred in the control fish during the same period. However, no control fish were present in compartment 2A where the 5 mortalities occurred. Also, the control fish came from tows of much shorter duration (30 min versus 120 to 240 min), were in better condition than the test fish, and were much more likely to be resilient to stress associated with long term containment. This is supported by ICES (2016) which states that the observed survival rate should not be corrected relative to a measure of control mortality because this could introduce unpredictable biases.

The likely occurrence of method induced mortality on Day 8 precluded use of observed data after Day 7. Mortalities were observed to stabilise during the first 7 days with just one mortality or < 1% of remaining test fish dying on Day 5, and zero mortalities occurring on Days 6 an 7. Applying the Weibull survival model to the 7 days observations predicted stabilised survival at ~ 50%. A similar approach was applied by Catchpole et al. (2015) who predicted stabilised survival based on 5 days of observations. This latter was assessed by STECF and found to be robust (STECF, 2018), resulting in high survival exemptions for plaice in ICES divisions 7d and 7e (EU, 2018).

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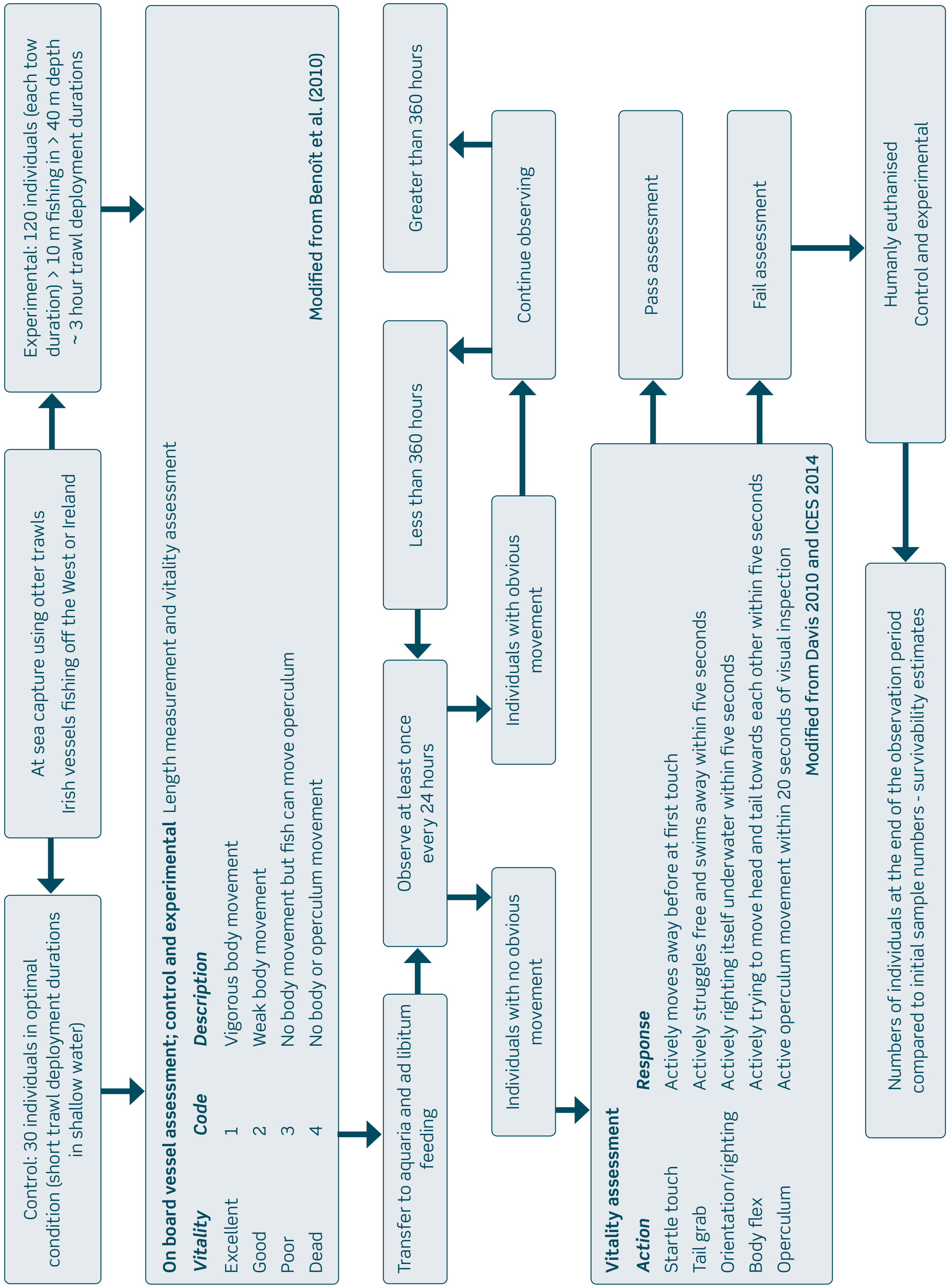
Appendix I.

The fish survivability protocol approved for use in this study



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