Nephrops survivability in the Irish demersal trawl fishery

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Key Findings

A 64% survival rate was obtained for *Nephrops* caught in a trawl with a SELTRA selectivity device.

1

The trial was conducted during the summer when air and water temperatures were exceptionally high which provided a worst case survival estimate.

2

Given superior catch compositions in terms of fish bycatch reduction in the dual codend and Swedish grid compared with the SELTRA, an application for a high survivability exemption should be made for all three selectivity devices in ICES area VII.

3

The Irish *Nephrops* scheme which provides additional quota for Irish vessels which employ one of the above selectivity devices would greatly assist in managing a high survival exemption.

4

This would provide a package of practical measures which incentivises and greatly assists the fishing industry in addressing challenges posed by the landing obligation and improving sustainability of the *Nephrops* fishery.

5

Ireland's Seafood Development Agency

EUROPEAN UNION
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Introduction

Dublin Bay prawns or *Nephrops* were Ireland's most valuable species in 2016 with landings of 9,600 tonnes worth €63 million, and more than all other whitefish species combined.

The EU landing obligation raises particular challenges for this sector. The North Western waters control experts group categorised *Nephrops* trawl fisheries in ICES Areas VI and VII as 'very high risk' in terms of non-compliance with the landing obligation, meaning they may require continuous monitoring with cameras or observers (Anon, 2015). Previous landing obligation simulation studies have established that full implementation of the regulation in 2019 will lead to early cessation of fishing effort unless more selective gears are used to reduce bycatch of undersized or over-quota fish species such as whiting, haddock and cod in the *Nephrops* fishery (Cosgrove et al., 2015b; Calderwood et al., 2016). *Nephrops* < minimum conservation reference size (MCRS) which traditionally account for up to 30% of the *Nephrops* catch in some areas are currently required to be landed, deducted from quota and not sold for human consumption. This also has major potential negative economic implications for the Irish fleet in terms of inefficient use of quota and lost opportunity to catch larger more valuable *Nephrops*.

BIM and the Irish fishing industry recently concluded an assessment of three gear modifications aimed at reducing < MCRS *Nephrops*: an increase in codend mesh size (Cosgrove et al., 2015a), *Nephrops* sorting grids (Cosgrove et al., 2016a), and square mesh codends (Cosgrove et al., 2016b). With a 45% reduction in < MCRS *Nephrops*, the increase in minimum codend mesh size from 70 mm to 80 mm was the more effective measure and a new national regulation (S.I. No. 510 of 2016) in that regard came into force in January 2017. *Nephrops* selection by diamond mesh codends is not "knife edged" in that the selection ogive is shallow giving a wide selection range (Frandsen et al., 2010). Hence, it is not currently possible to further reduce < MCRS *Nephrops* catches by increasing codend mesh size without substantial loss of marketable catches.

Another way of dealing with this issue is to demonstrate high survival when a species is discarded. A number of exemptions to the landing obligation have been granted on this basis in *Nephrops* fisheries in other parts of Europe, primarily where vessels use more selective gears to reduce fish bycatch leading to relatively 'clean' catches of *Nephrops* which better survive the capture process (Valentinsson and Nilsson, 2015; Armstrong et al., 2016; EEC, 2016; Mérillet et al., 2017). BIM and the Irish fishing industry have successfully tested a range of gear options which substantially reduce fish catches in *Nephrops* trawls including a Swedish grid (Cosgrove et al., 2016a), a dual codend with inclined separator panel (Cosgrove et al., 2016c), and a SELTRA sorting box (Tyndall et al., 2017). The SELTRA is becoming a popular gear option with Irish vessels due to its effectiveness in reducing fish bycatch, improved *Nephrops* catches and the ease with which it can be deployed and handled. The aim of this study was to assess *Nephrops* survivability using a SELTRA in the Irish demersal trawl fishery for *Nephrops* to support an application for a high survivability exemption for *Nephrops* under the landing obligation in ICES area VII.

Methods

The study followed protocols developed by the ICES workshop on methods for estimating discard survival (ICES, 2016).

Fishing operations

Nephrops were sourced from ICES division VIIb, functional unit (FU) 17 corresponding to the West of Ireland and Aran *Nephrops* fishing grounds. Trawling operations were conducted in the outer Galway Bay area, ~ 1 h steaming from Rossaveal fishing port where samples were landed (Figure 1). Trawl caught (Test) *Nephrops* were collected on board the MFV Karen Mary (Figure 1), an 11.64 m trawler using a SELTRA in single-rig configuration. The SELTRA section was configured with an 80 mm codend mesh size and a 300 mm square mesh panel (Figure 1, Table 1, Appendix I). It is generally accepted that smaller catches (or bulk) are likely to have fewer damaged individuals (e.g. Lancaster and Frid, 2002). Hence, summary information on *Nephrops*, combined fish catch, and total catch weights were obtained for each haul to assess this issue.

Creel caught *Nephrops* which are unlikely to suffer mortality due to their method of capture were used as an experimental control to detect any potential issues with the live holding process. Control *Nephrops* were caught by a 9.8 m creel vessel, the MFV Tranquillity in a small area adjacent to the eastern end of the trawled area (Figure 1). A total of 118 creels were fished with a 24 hr soak time in a mean water depth of 20.5 m from the 9th to 11th July until the target of > 200 creel caught *Nephrops* was reached. The creel caught *Nephrops* were landed in Galway city harbour. Test and Control *Nephrops* were stored on board in standard medium sized *Nephrops* tubes and trays which were stacked horizontally with *Nephrops* facing up in bins with a clean flow through of seawater (Figure 2).

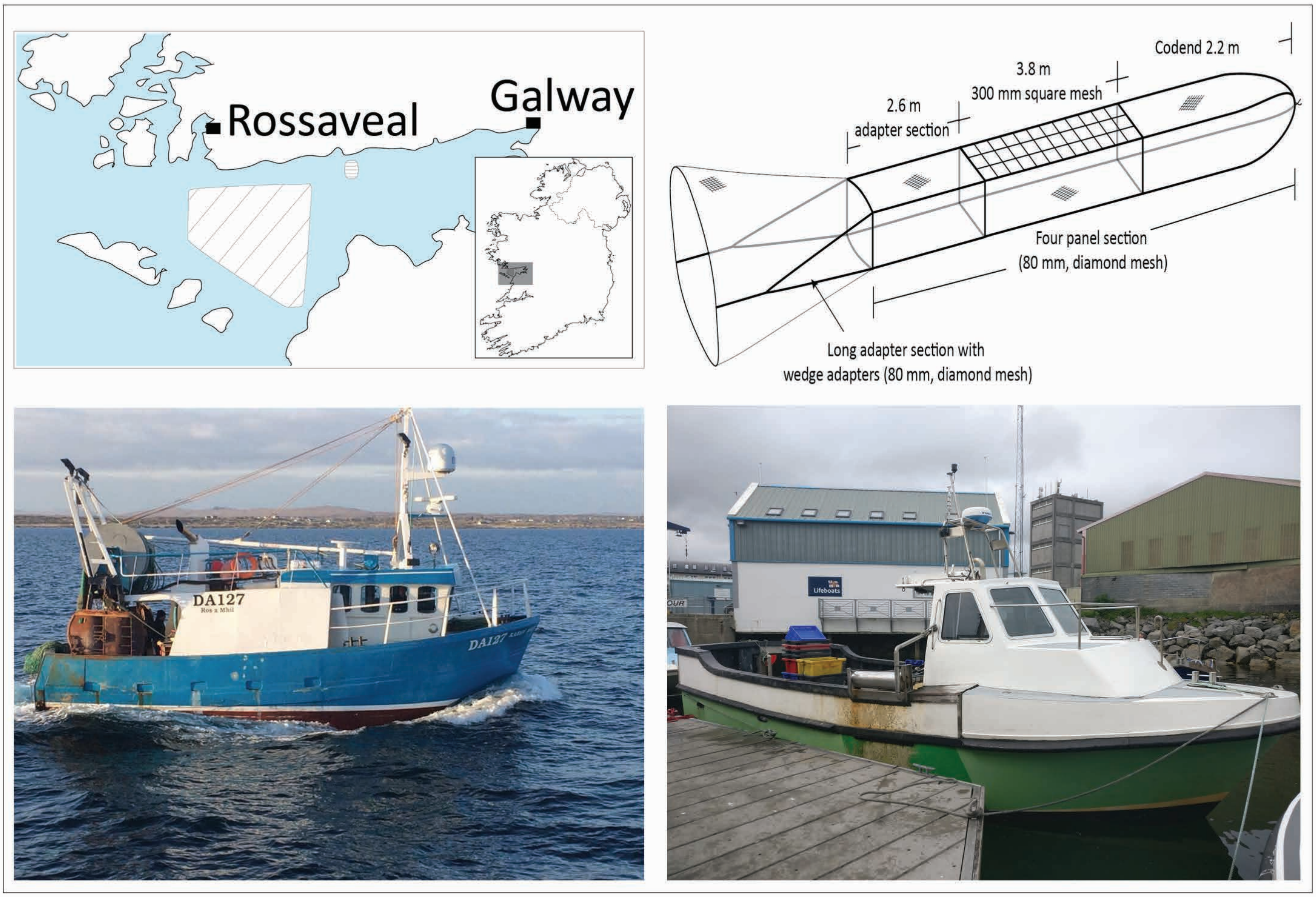

Figure 1. Clockwise from top left: Locations where the trawling (area with diagonal lines) and creel fishing (area with horizontal lines) took place; illustration of the SELTRA used during the trial; MFV Tranquility (creel vessel); MFV Karen Mary (trawler)

Table 1. The characteristics of the trawl and SELTRA used during the trial

Trawl type	*Nephrops*
Trawl manufacturer	Marine suppliers (Howth)
Nominal mesh size (mm)	80
Headline length (m)	38
Footrope length (m)	42
Sweep length (m)	42
Warp diameter (mm)	12
Door manufacturer	Bison
Door weight (kg)	120
Selectivity device	SELTRA
SELTRA manufacturer	Pepe Trawls Ltd.
Square mesh panel (SMP) size (mm)	300
Nominal mesh size (mm)	80
Measured mesh size (mm)	89
Standard error (mm)	0.39
300 mm SMP location from codline (m)	2.2 – 6

Catch sampling and vitality assessment

The trawlers catch was landed directly on to the deck of the boat and transferred to the catch sorting table as per normal working conditions (Figure 2). Once sorting of the catch commenced, random samples of the *Nephrops* catch were collected until the targeted number of *Nephrops* was assessed. A target of 312 was set for each of the first 4 hauls and 208 for each of the last two hauls to provide a total sample number of 1664 Test *Nephrops* collected over a total of 6 hauls. The MCRS for *Nephrops* in Area VII is 25 mm carapace length (CL) in all areas except the Irish Sea where it is 20 mm CL. However, discarding of *Nephrops* generally occurs up to 30 mm CL (MI, 2015). Hence, the entire catch regardless of size was initially randomly sampled to represent variable discarding practices. Samples were subsequently categorised according to the main MCRS for analysis. Control *Nephrops* were also landed on a sorting table with the entire catch retained until a target of over 200 *Nephrops* was reached.

Vitality of each specimen was initially assessed before storage on board the vessels, and subsequently in the onshore holding facility using a vigour assessment based on five categories ranging from excellent to dead (Table 2) (Armstrong et al., 2016). Details of dead *Nephrops* were recorded and they were subsequently removed from the experiment. Additional information on the following

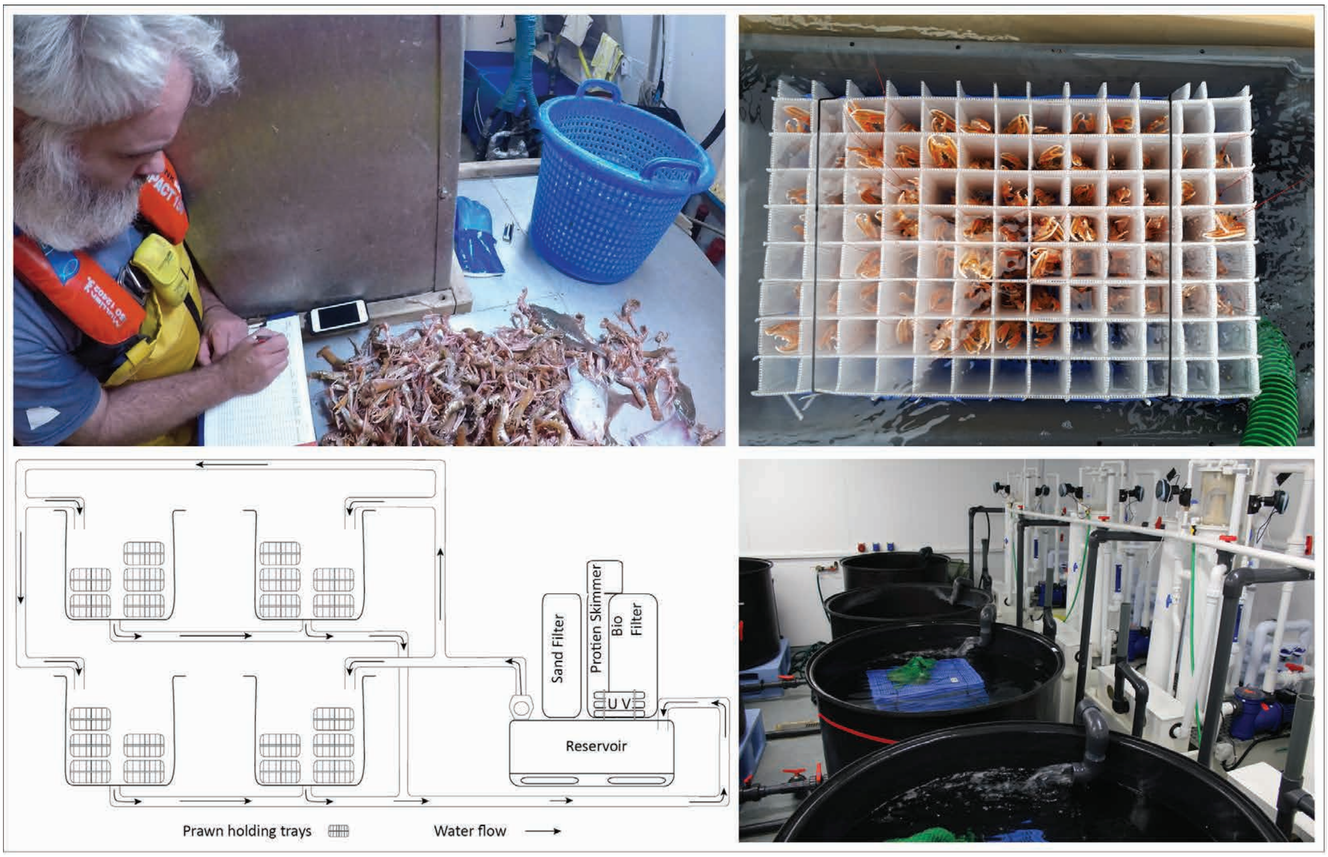

Figure 2. Clockwise from top left: Sampling the catch from the sorting table; *Nephrops* stored in tubes; picture and illustration of the onshore holding system.

characteristics was recorded for each specimen at the first point of sampling to assess potential impacts on mortality: CL to the nearest mm; sex; reproductive stage i.e. whether mature ovaries (termed green head) or eggs were present in females; moulting stage i.e. if the specimen was soft; injury i.e. if one or two claws or other damage was present; or if the *Hematodinium* spp parasite was present. The same two scientific personnel conducted the vitality assessments throughout the experiment to help provide consistency in observations.

Transit and onshore storage

A refrigerated van with a clean supply of oxygenated seawater stored in fish bins was used to transport samples to the onshore holding facility. Transport distances to the onshore holding facility were 42 and 5 km respectively for Test and Control *Nephrops*. 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 (CT) room. The recirculated seawater system was supplied by Tropical Marine Centre and incorporates mechanical, sand and biological filters, a protein skimmer and a UV filtration system (Figure 2). The CT room and recirculation system were used to maintain the *Nephrops* at a stable temperature to remove any potential thermal shock. Water temperature in the on-shore facility was maintained at close to the trawled areas bottom temperature of ~13°C. *Nephrops* survivability was assessed at GMIT over the course of 360 hours (15 days). Samples were removed from the water once each day and checked for mortalities by first visually assessing whether they were moving. If not, a blunt forceps was used to gently lift *Nephrops* out of the cell for further assessment and they were removed from the experiment if found to be dead.

Table 2. Vitality description and code used for assessing individual *Nephrops*

Vitality	Code	Vitality Description
Excellent	1	Vigorous body movement; all limbs moving and tail moves or is held flexed
Good	2	Vigorous body movement; all limbs moving but no movement of tail. Tail hangs limp
Poor	3	Limited or no body movement but movement of maxillipeds
Moribund	4	Any slight movement (response to touching or prodding)
Dead	5	No movement at all (no response to touching or prodding)

Environmental sampling

Data on environmental parameters which could impact survivability such as salinity, water and air temperature, and dissolved oxygen were collected during the trial. Air temperature was collected periodically using a standard thermometer while bottom temperature during trawling was collected every 30 seconds using a Star-Oddi data-storage tag (DST). At the onshore facility a Hach HQ40D portable multi-meter was used to check the temperature and dissolved oxygen while a hydrometer was used to test the salinity twice per day for the trial duration.

Data analysis

Survivability analysis was conducted using a Kaplan-Meir estimator which approximates survival probability over time with values between 0 and 1. Calculations and graphic outputs were completed using the R statistical program (3.3.1) with the "survival" package. Mortalities were categorised by day for the purposes of this study. Any mortalities initially observed on board the vessels were categorised as Day 0. Subsequent mortalities during on board storage, transport, and the first 24 h storage in the onshore holding facility were categorised as Day 1. This process typically took around 30 h providing a conservative mortality estimate for Day 1 in follow up analysis. Kaplan-Meir plots were constructed to compare survival probabilities of *Nephrops* categorised by Test and Control, < and ≥ MCRS of 25 mm CL, vitality code at the start of monitoring, sex, air exposure time on deck, and haul number.

Table 3. Summary trawl operation and catch data

Haul No.	Haul date	Haul duration (min)	Haul depth (m)	Towing speed (kt)	Prawns (kg)	Fish (kg)	Total catch (kg)	Survival rate (%)
1	17/07/17	190	52	2.6	90	25	115	63
2	17/07/17	158	30	2.7	25	15	40	64
3	18/07/17	213	37	2.6	160	20	210	58
4	18/07/17	169	49	2.8	20	5	25	61
5	20/07/17	187	45	2.7	40	30	70	78
6	20/07/17	159	46	2.6	25	20	45	67

Results

A total of 6 tows were carried out over a four day period commencing 17th July 2017, and approximating typical commercial fishing conditions (Table 3). Haul duration, depth and towing speed averaged 179 min or ~ 3 h, 43 m and 2.7 kt respectively. *Nephrops*, combined fish catch, and total bulk weight averaged 60, 19 and 84 kg respectively. *Nephrops* accounted for 71% of the total catches on board the trawler with skates & rays and monkfish the predominant fish species observed in the rest of the catch.

The overall survival rate in relation to the 1664 Test *Nephrops* was 64% at the end of 360 hours or 15 days of onshore monitoring. Forty-four individuals or 7% of the 594 Test mortalities were observed during the first vigour assessment on board the vessel i.e. these *Nephrops* were dead when they were initially removed from the trawl. A consistent mortality rate was observed over the following three days with 19 – 20% of mortalities occurring on each day during onshore storage. The mortality rate subsequently declined and reached an asymptote from day 10 to 15 of monitoring: The Kaplan-Meir analysis showed no significant difference in the probability of mortalities occurring for Test *Nephrops* over the last 5 days of onshore monitoring (Figure 3a).

The Kaplan-Meir plot showed a clear significant difference in survival probabilities between Control and Test *Nephrops* at all stages during the experiment (Figure 3a). A survival rate of 98% was observed from a total of 204 Control *Nephrops* indicating that the live holding process worked well. 97.5% of specimens were excellent and 2.5% were good when the first vitality assessment was conducted on board the creel vessel. At the end of the experiment 96% of specimens were excellent, 1.5% were good, and 2.5% were dead.

Test *Nephrops* ranged in size from 19 to 49 mm with a mean of 30.7 mm CL. Some 150 or 9% of Test *Nephrops* were < MCRS. A 63% survival rate was observed for this component of the catch compared with a 65% rate for ≥ MCRS *Nephrops* (Table 4). The Kaplan-Meir analysis showed no significant difference in survival probabilities between these two categories (Figure 3b). Control *Nephrops* were larger than Test *Nephrops*, ranging in size from 28 to 52 mm with a mean of 38 mm. The sex ratio was also different as 65% of Control *Nephrops* were female compared to 39% of Test *Nephrops*.

In relation to vitality scores, from a total of 1664 Test *Nephrops*, 35% were excellent, 34% were good, 17% were poor, 12% were moribund and 3% were dead at the point of the first vitality assessment conducted on board the trial vessel. At the end of 360 h onshore monitoring 61% of specimens were excellent, 2% were good, 1% were poor, 0% were moribund and 36% were dead.

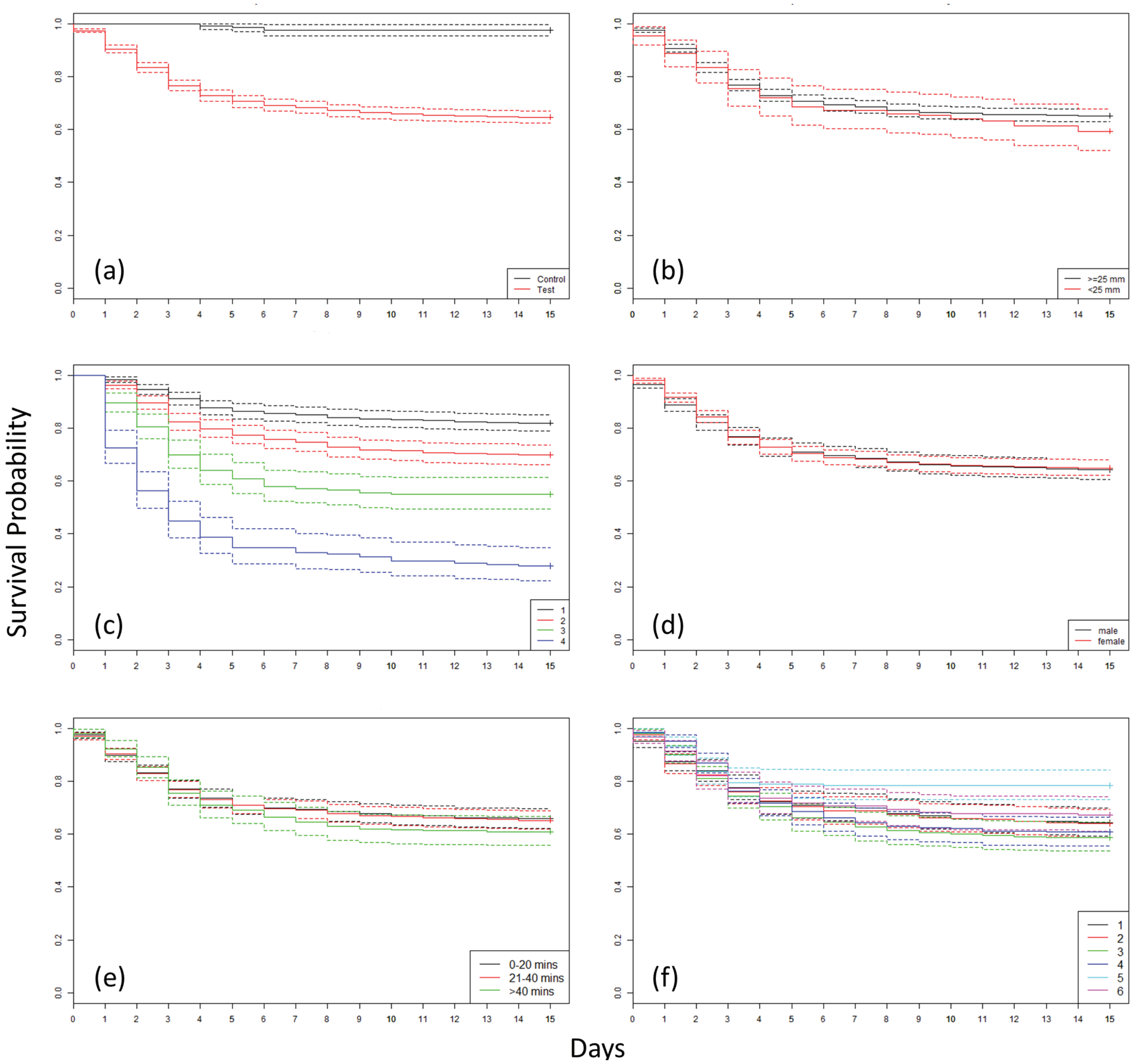

Figure 3. Kaplan-Meir *Nephrops* survival estimates for (a) Test and Control (b) minimum conservation reference size (MCRS) of 25 mm CL (c) vitality index at the outset of the trial (see Table 2) (d) sex (e) air exposure (f) haul number. Survival estimates are shown as solid lines while 95% pointwise confidence intervals are shown as dashed lines

The Kaplan-Meir plot by vitality code showed survival ≥ 70% survival for the first two categories and clear non-overlapping trends between all categories after day three of the experiment (Figure 3c).

Females accounted or 39% of Test *Nephrops*. Test survival was 64 and 65% for females and males respectively, with no significant difference observed between sexes (Figure 3d). Eighty-four percent of females had mature ovaries or 'green head'. Approximately 65% of green head females survived the experiment.

Air exposure times on deck ranged from 6 to 61 minutes and were categorised into 0 - 20, 21 – 40, and > 40 min for analysis, with survival rates of 65, 65 and 61% observed for these categories respectively. The Kaplan-Meir plot showed that the probability of survival over the 15 day monitoring period was not significantly different between these categories (Figure 3e).

Survival rates ranged from 58 to 79% in relation to the 6 individual hauls with no clear difference in trends discernible from the Kaplan-Meir plot (Figure 3f). Slightly reduced survival rates were observed for *Nephrops* with 1 (61%) or 2 (54%) claws missing (Table 4). No incidence of the *Hematodinium* spp. parasite was observed. Details of environmental data collected during the study are outlined in Table 5.

Table 4. Observed Test *Nephrops* survival rates in relation to characteristics categorised at the outset of the experiment

Category	*Nephrops* (N)	Survivors (N)	Survivors (%)
Total Test	1664	1070	64
< 25 mm CL (MCRS)	150	95	63
≥ 25 mm CL	1514	984	65
Vitality code 1	775	661	85
Vitality code 2	572	400	70
Vitality code 3	276	152	55
Vitality code 4	201	56	28
Vitality code 5	44	0	0
Male	1007	650	65
Female	657	420	64
Green head	552	353	64
Soft	2	2	100
No injury	1320	864	65
1 claw missing	296	180	61
2 claws missing	48	26	54

Table 5. Environmental data collected during the study

Parameter	Control	Test
Air temperature range (°C)	—	15 – 19
Air mean temperature (°C)	—	17
Sea surface temperature range (°C)	—	16 – 18.5
Sea surface mean temperature (°C)	17.5	17.5
Sea surface salinity range (ppt)	—	35 – 36
Sea surface mean salinity (ppt)	33	35.5
Sea bottom temperature range (°C)	—	12.9 – 14.6
Sea bottom mean temperature (°C)	14.1	13.5
On-shore CT room temperature range (°C)	5.6 – 9.8	
On-shore CT room mean temperature (°C)	7.1	
On-shore holding tanks temperature range (°C)	10.6 –14.3	
On-shore holding tanks mean temperature (°C)	12.4	
On-shore holding tanks salinity range (ppt)	32 – 35	
On-shore holding tanks mean salinity (ppt)	33	
On-shore holding tanks dissolved O_2 range (mg/l)	10.7 – 12.1	
On-shore holding tanks mean dissolved O_2 (mg/l)	11.5	
On-shore holding tanks dissolved O_2 range (%)	106.2 – 111.6	
On-shore holding tanks mean dissolved O_2 (%)	108.7	

Discussion

The overall observed survival rate of 64% indicates a high level of post-capture survival of *Nephrops* caught with a SELTRA selectivity device. The observed 98% survival rate of creel caught *Nephrops* which were subject to the same experimental treatment suggests that observed mortalities in Test *Nephrops* were primarily caused by the trawl capture process. Minimal differences in survivability in relation to *Nephrops* size and biological characteristics bodes well for the application of study results to other areas or times of year which may have different underlying biological traits. The larger size of Control *Nephrops* was unavoidable due to the greater size selectivity of creels compared to trawls for that species (Leocádio et al., 2012). Very high survivability of the Control and minimal differences in Test *Nephrops* survivability by size category suggest that this size difference did not negatively impact the study.

Study results compare well with a previous *Nephrops* survivability study using the SELTRA. Valentinsson and Nilsson (2015) obtained 38% summer and 59% winter survival rates for *Nephrops* caught with a SELTRA in ICES division IIIa. Focussing on the summer results for comparative purposes, the lower survival rate in the Swedish study compared with the current study was likely due to differences in the escape panel used in the SELTRA. Different selectivity devices have different effects on *Nephrops* survival probability, with designs which exclude or enable escape of larger fish specimens decreasing total catch weight and potential physical stressors in the trawl (Campos et al., 2015; Armstrong et al., 2016). The Swedish study employed a SELTRA with a 270 mm diamond mesh escape panel (pers. comm. Daniel Valentinsson) compared to a 300 mm square mesh escape panel in the current study. This would help explain a substantially higher mean total catch weight of 200 kg per haul in the Swedish study compared with 84kg in the current study. In addition, *Nephrops* accounted for ~ 9% of the catch in the Swedish study compared to 71% in the current study. Valentinsson and Nilsson (2015) also obtained 42% summer and 75% winter survival rates for *Nephrops* caught using a Swedish grid. Mean total catch weight of 113 kg during the summer was closer to the mean catch weight observed in the current study but again *Nephrops* represented a relatively small component of the catch (20%) which may have impacted their survivability.

A lower maximum air exposure time in the current study of 61 min compared with 90 min in the Swedish study may also have contributed to a high survival rate in the current study. Non-significant differences in survival probabilities between *Nephrops* exposed to air for < 20 min and > 40 min in the current study suggest, however, that the impact of this variable was relatively minor. A lower mean haul duration of 179 min in the current study compared with a standard 240 min haul duration in the Swedish study could also have impacted survivability. However, no clear trend is apparent between the range of haul durations (158 – 213 min) and associated survival rates by haul (58 – 78%) observed in the current study (Table 3). Furthermore the effects of haul duration on survivability are likely primarily caused by increased physical stressors associated with greater catch accumulation. Hence, exclusion of most of the fish catch from the trawl using the SELTRA (Table 3) is likely to minimise the impact of haul duration.

Table 6. Average sea surface temperature data from the Irish Weather Buoy network of stations compiled from 2015 and 2016 http://data.marine.ie/Dataset/Details/20972

	West of Ireland	Celtic Sea	Irish Sea	Galway Bay
January	10.89	10.56	10.37	7.72
February	10.44	8.54	8.96	7.12
March	10.20	8.50	8.14	7.87
April	10.75	9.69	8.41	9.78
May	10.99	11.40	9.68	11.69
June	12.88	14.25	12.44	14.39
July	14.22	15.47	13.33	15.86
August	14.79	15.66	13.92	16.07
September	14.68	15.38	14.35	15.29
October	13.92	14.36	14.16	13.28
November	12.92	13.08	13.00	11.02
December	11.30	11.70	11.47	9.58

Table 7. Reductions in catches, and proportion of *Nephrops* in the catch in three selectivity devices compared with a standard trawl with a 70 mm diamond mesh codend

Selectivity device	Time of year	Location	Reduction in fish catch weight (%)	Reduction in total catch weight (%)	Proportion of *Nephrops* in catch (%)
SELTRA	Sep-16	Irish Sea	69	47	58
Dual codend	Oct-16	Celtic Sea	85	59	76
Swedish Grid	Sep-15	Irish Sea	77	23	91

Temperature is known to be a key factor affecting *Nephrops* discard survival (Castro et al., 2003; Broadhurst et al., 2006; Lund et al., 2009). This was also demonstrated by Valentinsson and Nilsson (2015) who observed significantly reduced survival during summer compared to winter for both the SELTRA and grid. The current study was conducted during the summer when air and sea surface temperatures are highest in order to provide a worst case scenario or conservative survival rate estimate. It is highly likely that a higher survival rate would be obtained if the study was repeated during winter months but this should not be necessary given the observed 64% survival rate during the summer. Indeed, air and sea surface temperatures were exceptionally high during the current study. Mean air temperature of 17°C during trawling operations was higher than any mean monthly temperature recorded around the Irish coast over the last 4 years https://www.met.ie/climate/monthly-data.asp?Num=275. Mean sea surface temperature of 17.5°C was also higher than normal for Galway Bay further supporting our contention that the study was conducted under a worst case scenario in terms of temperature. Furthermore, higher water temperatures in the Galway Bay area compared to other areas around the Irish coast bodes well for the application of study results to those areas (Table 6).

Armstrong et al. (2016) conducted a *Nephrops* survivability study using a netgrid selectivity device in the North Sea in winter and achieved a 62% *Nephrops* survival rate. Based on their findings and those of Valentinsson and Nilsson (2015), the authors concluded that it would be reasonable to extrapolate survival rates from one study to another where catch composition and environmental conditions are similar. While the SELTRA is highly effective in terms of reducing fish bycatch, further improvements in catch composition have been demonstrated with two other selectivity devices tested under similar environmental conditions in Irish waters, the dual codend and Swedish grid. Summarised results from catch comparison studies of these three selectivity devices, tested against a standard 70 mm codend are outlined in Table 7. The SELTRA achieved a 69% reduction in fish catch, mainly attributed to substantially lower catches of lesser spotted dogfish, whiting, haddock and flatfish, and a 47% reduction in total catch weight (Tyndall et al., 2017).

The dual codend achieved an 85% reduction in fish catch and a 59% reduction in total catch weight in the codend which retained the *Nephrops* catch, due to effective separation of *Nephrops* and fish into two separate codends (Cosgrove et al., 2016c). The Swedish grid achieved a 77% reduction in fish catch due to substantial reductions in lesser spotted dogfish and whiting. A lower 23% reduction in total catch weight can be explained by the fact that most of the retained catch were *Nephrops* in both the trawl with the grid (91%) and the standard trawl (73%) (Cosgrove et al., 2016a).

The SELTRA, dual codend, and Swedish grid are included in a '*Nephrops* scheme' which provides additional quota to vessels which use more selective gear. https://www.agriculture.gov.ie/seafood/seafoodpolicy/forms/*Nephrops*schemefortheuseofselectivefishinggears/. Participants in the scheme are required to have regular port inspections by the Irish control agency to confirm that they are using the specified gear, and to carry on board observers to facilitate biological data collection (DAFM, 2017). Hence, a survivability exemption for these three gears would be relatively easy to manage. It would also help create a package of practical measures which incentivises and greatly assists the fishing industry in addressing challenges posed by the landing obligation and improving sustainability of the *Nephrops* fishery.

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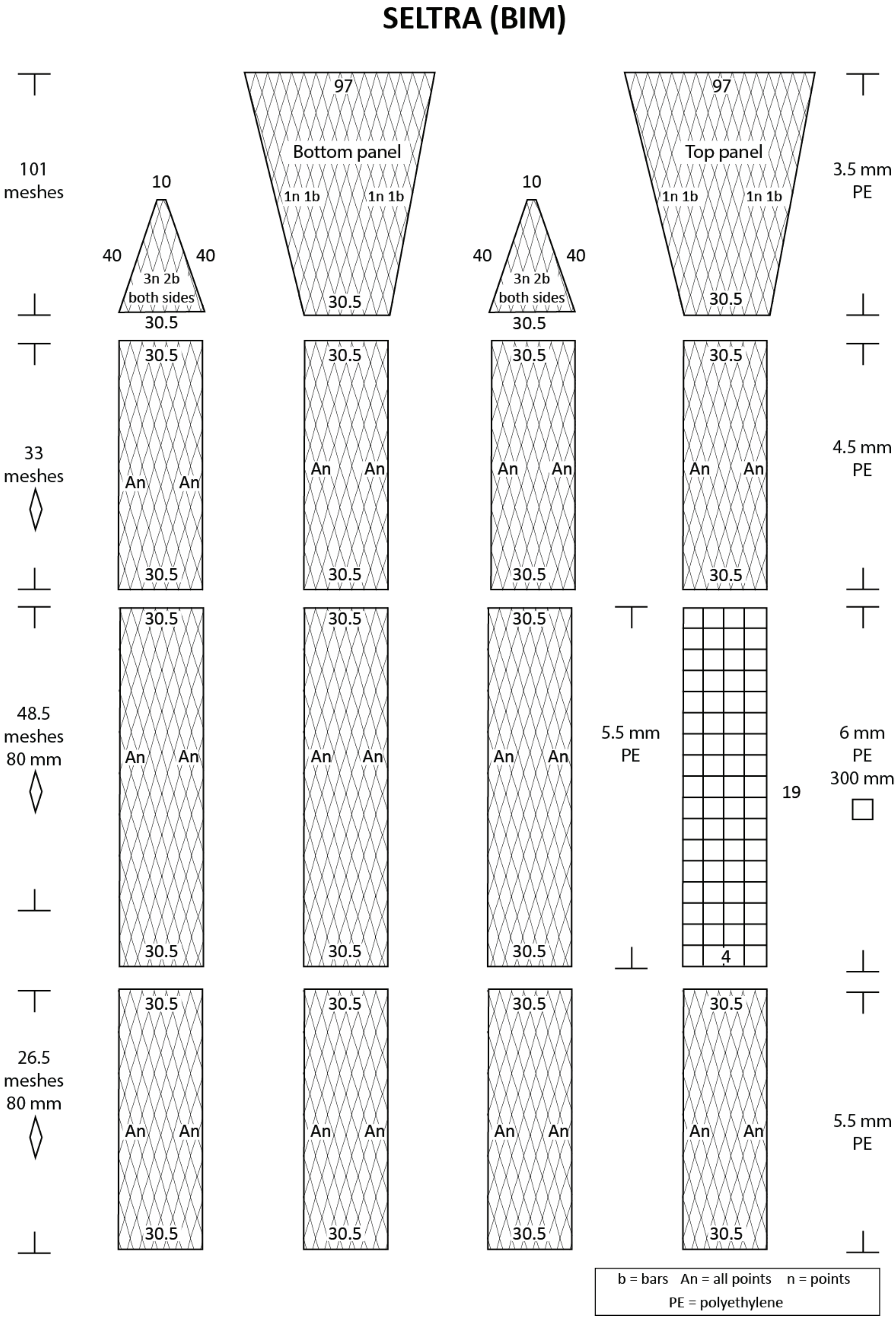
Appendix (I)

A net diagram of the SELTRA section, used during the trial



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