Bord Iascaigh Mhara
Irish Sea Fisheries Board

Assessment of an increase in cod-end mesh size in the Irish Sea *Nephrops* fishery

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Key Findings

- **Proportional reductions in *Nephrops* catches between the 70 and 80 mm cod-ends were around 12% by weight and 5% by value during a gear trial in the Irish Sea.**
- **Similar to two other studies conducted in the Irish Sea and Bay of Biscay, the 80 mm cod-end caught proportionally less small *Nephrops* compared with the 70 mm cod-end.**
- **In the context of the Landing Obligation, economic projections for a range of plausible *Nephrops* length compositions showed increases in profitability from around 4% to 6% by using an 80 mm cod-end over the course of a fishing season.**
- **A national increase in minimum cod-end mesh size to 80 mm would likely increase the total annual value of Irish *Nephrops* landings by between €1.53m and €3.14m.**
- **In the short term an increase in cod-end mesh size beyond 80 mm is not considered to be economically feasible for reducing catches of small *Nephrops.***

September 2015

Introduction

As part of the new Common Fisheries Policy, EU regulation 1380/2013, an obligation to land all catches of demersal species which are subject to catch limits will be phased in from January 2016. The principal aim of this new policy is to incentivise lower levels of unwanted catches and to gradually eliminate discards. An increase in fishing opportunities will likely occur to take into account the fact that fish which were previously discarded will legally be required to be landed. This is likely to result in quota uplifts largely based on differences between total landings and catch advice, which may lead to economic gains if unwanted catches and discards can be minimised. In terms of impacts on the Irish fishing industry, from 2016, the Landing Obligation (LO) will apply to *Nephrops* fisheries in all Irish waters, the whiting fishery in the Celtic Sea, and the haddock fishery in the Irish Sea and in the Northwest (ICES Division VIa). From 2017 it is likely that there will be a gradual phasing in of requirements to land other species up until 2019 when the regulation will apply to all quota species. A limited amount, or 'de minimis', level of permitted discarding will continue if improvements in selectivity are considered to be very difficult or if a need arises to avoid disproportional costs of handling unwanted catches. Recently submitted to the European Commission, a discard plan for demersal fisheries in North Western Waters (NWW) applied for a 7% de minimis for total catches of *Nephrops* in ICES sub area VII based on technical and economic difficulties associated with improving selectivity.

Nephrops landings by Irish vessels in the Western Irish Sea in 2013 were 2465 t corresponding to a 100% uptake of available quota. The average proportion of discarded *Nephrops* in the Western Irish Sea from 2011 to 2014 was ~ 28% in numbers or 17% in weight. The minimum landing size (MLS) in the Irish Sea is 20 mm carapace length (CL). However, historical annual length composition data (Fig. 1) shows that discarding commences at ~≤ 25 mm CL for females and at a slightly larger size again for males (MI, 2014). As part of the LO, the MLS will be replaced with a minimum conservation reference size (MCRS) to take account of the obligation to land catches regardless of size.

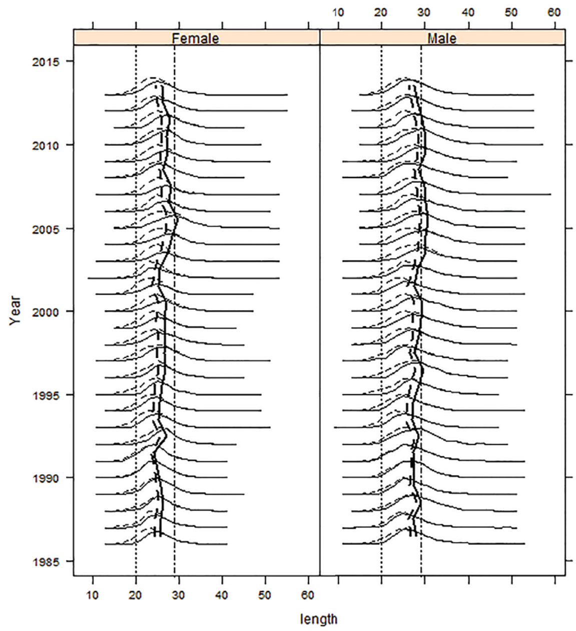


Figure 1. *Nephrops* Irish Sea West annual length composition of catch (dashed) and landed (solid). Males (right) and females (left) from 1986 (bottom) to 2013 (top). The vertical dashed line is mean length in the catches and the vertical solid line is mean length in the landings. The straight vertical lines correspond to 20 mm (MLS) and 29 mm carapace length (MI, 2014).

Catches of species affected by the LO which are below MCRS and fall outside de minimis exemptions must be landed but cannot be sold for human consumption. Diamond mesh is currently the only mesh type used in Irish *Nephrops* fisheries and minimum mesh sizes of 70 or 80 mm apply in the Irish Sea depending on the catch composition of *Nephrops*. However, ~ 90% of trips conducted by Irish vessels in the Irish Sea in 2014 used ~ 70 mm minimum mesh size (SFPA, pers. comm.). Assuming a similar *Nephrops* discard rate in 2016 to 2014 of 17%, and deducting a de minimis exemption of 7% of total catches, ~ 10% of *Nephrops* catches which were formerly discarded would legally be required to be landed in 2016. Unless selectivity can be improved, such catches will be deducted from quotas in 2016, leading to reduced opportunities to catch larger more valuable *Nephrops* and reductions in the total value of *Nephrops* landings.

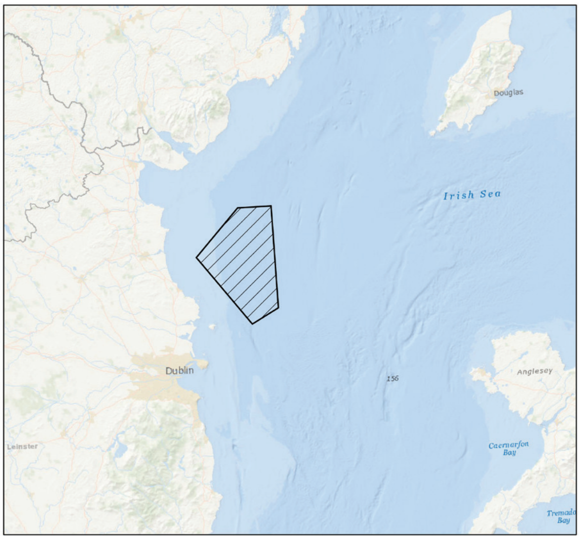


Figure 2. Gear trial location (striped area)

BIM are currently engaged in a work programme to assess a range of measures which have potential to reduce catches of below MLS *Nephrops* including increased cod-end mesh size, modified cod-end mesh shape and orientation, and sorting grids. It is clear from a variety of studies (eg. Briggs *et al.,* 1999; Briggs, 1986; Catchpole and Revill, 2008; Catchpole *et al.,* 2006; Frandsen *et al.,* 2011; Graham and Ferro, 2004; ICES, 2007; Nikolic *et al.,* 2015; Sala *et al.,* 2015) that there are pros and cons to each of these measures depending on the nature of the fishery and desired catch composition. Moreover, off the shelf solutions for improving *Nephrops* selectivity without suffering some degree of associated losses of marketable *Nephrops* or other species do not currently exist.

In terms of the practicalities of introducing new measures, an increase in minimum mesh size would be the simplest and easiest to implement in terms of cost and practical considerations. Although different diamond cod-end mesh sizes do not generally affect the selection range, they do affect the quantities of *Nephrops* retained (Catchpole and Revill, 2008) with mixed results reported in various gear trials.

For example, a recent study in the Bay of Biscay showed a 9% reduction in amounts of *Nephrops* discards (< 26 mm CL) with no associated loss of marketable *Nephrops* by increasing cod-end mesh size from 70 to 80 mm (Nikolic *et al.,* 2015). In the case of the *Nephrops* trawl fishery in the Irish Sea, an increase in cod-end mesh size from 70 to 80 mm was previously shown to reduce total *Nephrops* catches by ~ 20% in trawls using the same twine diameter as the current study. In general, the proportions of *Nephrops* retained by the 80 mm cod-end mesh gradually decreased in relation to smaller *Nephrops* lengths, indicating that the 80 mm mesh caught proportionally less small *Nephrops* than the 70 mm mesh cod-end. (Briggs *et al.,* 1999). The conclusion drawn from the latter study that losses of marketable catches were unacceptable was made in the context of a management regime which permitted discarding of all catches below MLS. In the context of the LO, the economic impact of losses of marketable catches associated with an increase in mesh size is likely to be mitigated by reductions in < MCRS catches and increased opportunities to catch higher quantities of larger more valuable *Nephrops* over the course of a fishing season. The principal objective of this study was to compare the catches of ≥ and < MCRS *Nephrops* in a range of diamond cod-end mesh sizes in a *Nephrops* trawl fishery in the Western Irish Sea with a particular focus on 70 and 80 mm mesh. Based on methods developed under a study which simulated LO impacts (Cosgrove *et al.,* 2015), the economic implications of an increase in cod-end mesh size were modelled to better understand how such a measure would impact profitability over the course of a fishing season, and the merits of a potential increase in minimum mesh size are discussed.

Methods

Table 1. Gear specification

Trawl type	Quad-rig *Nephrops*
Trawl manufacturer	Pepe Trawls Ltd.
Head-line length (m)	27.4
Foot-line length (m)	32.9
Fishing circle (m)	380 X 80
Sweep length (m)	50 + 20
Warp diameter (mm)	20
Door spread (m)	68.6
Door type	Dunbar 7′6″
Door weight (kg)	492
Clump weight (kg)	680

Fishing operations

The trial took place on board a 22m multi-rig *Nephrops* trawler operating in the Western Irish Sea in ICES Division VIIa (Fig. 2). A total of 13 hauls were carried out over a 5 day period commencing on the 18th July 2015. Fishing operations approximating normal commercial hauls were carried out with haul duration, towing speed and depth of ground fished averaging 4:47 hours, 3.1 knots and 48 m respectively. Fishing gear consisted of a quad–rigged 18 fathom *Nephrops* trawl set up using a triple warp and centre clump arrangement. Four test diamond mesh cod-ends with nominal mesh sizes of 70, 80, 90, and 100 mm, constructed with single 6 mm polyethylene twine were towed simultaneously during the trial. Mean omega mesh gauge measurements in relation to these cod-ends were 70.8, 80.8, 92.6 and 103.0 mm respectively, although the previous mesh size descriptors are used for the purposes of this report. Cod-ends were rotated daily so that each cod-end was attached to each of the 4 nets for a minimum of one day or 3 hauls, so that potential differences in fishing power depending on net position could be accounted for in subsequent analyses. The mesh size in the top and bottom panels behind the head-line and in the lower wing ends was 80 mm, while meshes in the upper wing ends were 160 mm. Square mesh panels of 120 mm mesh size were mounted 9 to 12 m from the cod-line as per EU Regulation 2015/741. Although the scope of that regulation does not include the Irish Sea, the practice of leaving the "Celtic Sea SMP" in place is common on board *Nephrops* vessels that fish in both the Irish and Celtic Seas.

Sampling

Total catches and randomly selected representative subsamples were weighed. Subsamples were separated to species level with all commercial fish species measured to the nearest cm below. The quantity of *Nephrops* in each subsample was weighed and a representative subsample was randomly selected for measurement to the nearest mm below (Carapace Length (CL)). Digital callipers linked wirelessly to a Toughbook pc were used to sample a total of 16,909 *Nephrops* out of a total estimated catch of 369,482 individuals caught during the trial.

Biological analysis

Although sex sampling was not conducted, the exploitation rate between sexes is similar for *Nephrops* in the Western Irish Sea (MI, 2014), and hence, the length weight relationship used for males in Briggs *et al.* (1999), $X = 0.00032CL^{3.21}$, was used to obtain estimated *Nephrops* weights in relation to CL for comparative purposes in relation to cod-end mesh size. Tables and Length frequency distributions were constructed for total numbers, weight, and value of *Nephrops* and key fish species caught using different cod-end mesh sizes. A P_{80} statistic was calculated for each haul based on proportional number of *Nephrops* in each 1mm length category retained in the 80 mm mesh cod-end from combined catches in the 70 and 80 mm mesh cod-ends. P_{80} values were plotted and compared with a previous study of a similar nature in the Irish Sea Briggs *et al.* (1999). A generalised linear mixed model (GLMM) was applied to test if carapace length had a significant effect on P_{80} values and to optimise the model fit. Relationships between random effects in the model i.e. haul level variability, and covariates with potential to impact the dependent variable, haul duration, net position, and bulk catch quantities, were examined to select appropriate covariates for inclusion in the model.

Economic analysis

The largest difference in catches between the 70 and 80 mm cod-ends in the current study occurred in relation to tailed *Nephrops*. It was important therefore to use the best available price information to ensure that the economic consequences of a potential increase in mesh size were appropriately evaluated. *Nephrops* sales note data available for the Irish Sea in 2014 consisted of average values for combined size grades, and presentation states i.e. frozen and fresh, for whole and tailed *Nephrops* (Source SFPA). Hence it was not possible to use these data to allocate price information to specific size grades of *Nephrops* caught during the trial. Instead detailed price information from two recent BIM gear trials, one fishing for the frozen market and one fishing for the fresh market, were used. Averages of these data were used to derive estimated values for *Nephrops* based on the following numbers of *Nephrops* and associated prices kg^{-1}: 11 – 15, €13; 16 – 20, €10.75; 21 – 30, €7.75; 31 – 40, €5.35; 41 – 50, €4.75; < 50, €5.70 (tails, tails to live weight conversion factor 1:3). The resulting average prices kg^{-1} for whole (€6.38) and tailed (€5.70) *Nephrops* were similar to compiled average prices for whole (€6.39) and tailed *Nephrops* (€5.69) in the Irish Sea in 2014. Hence, although the sample size of sales notes used to derive price information in the current study was small, the resulting prices seem to be reasonably representative of compiled data for the Irish Sea.

Data from a previous study simulating the impact of the LO (Cosgrove *et al.,* 2015) suggested that a net loss of ~ €200 per tonne was incurred by vessels dealing with catches < MCRS which were sold for non-human consumption. Therefore a price of -€0.20 kg^{-1} was assigned to catches of *Nephrops* < MCRS. The optimal P_{80} CL model formed the basis of a simulation of the economic impacts of an increase from 70 to 80 mm cod-end mesh over the course of a typical fishing season in the Irish Sea. The length composition of *Nephrops* caught in the current study was relatively large with relatively poor representation of *Nephrops* below the MCRS of 20 mm CL. However, *Nephrops* length distributions are generally relatively normally distributed (eg. The current study; Briggs *et al.,* 1999; MI, 2014) and, based on the modelled proportional difference in catches between cod-end mesh sizes, a series of *Nephrops* length distributions with a range of mean sizes were simulated in order to assess likely differences in profitability under different scenarios related to variable length composition in catches. This analysis was based on the assumption that the same numbers of *Nephrops* were caught for the same numbers of hauls in the simulated length distributions compared with the observed length distributions for the 70 and 80 mm cod-ends. Also the simulated length distributions were not considered to be representative of true catch compositions, but were considered suitable for comparing proportional differences in profitability between cod-end mesh sizes.

This information was used to derive total catch weights and values of *Nephrops* per haul, trip, and a notional fixed annual catch allowance of 100 t. Based on communications with Industry, a typical fishing trip in the Irish Sea was considered to consist of 5 days and 20 hauls. Irish demersal vessels are currently subject to monthly catch retention and landing restrictions which effectively equate to maximum annual limits on landings of species such as *Nephrops*. Given a 100% uptake in quota of *Nephrops* in the Western Irish Sea, it is reasonable to model economic impacts of technical measures in relation to a fixed catch limit. Approximately 30 quad-rig vessels currently catch most of Ireland's annual landings of ~ 3000 t of *Nephrops* in the Irish Sea (Colm Lordan, MI, pers. comm.) so 100 t was considered appropriate to roughly correspond to a notional annual catch allowance. Detailed operational economic information received from the participating vessel was also used to derive costs per trip which permitted an assessment of profitability under the different mesh and catch length composition scenarios. Expenses incurred during each fishing trip consisted of wages, fuel during steaming and fishing, ice, net mending, duties and levies, port fees, insurance, transport of landings, repayments, ship maintenance and food. With the exception of wages none of these expenses were considered to vary between 70 and 80 mm mesh sizes. Based on communications with Industry members, wages were based on (net profit less expenses)/2. Hence, wages were linked to catch values in order to accurately estimate profitability in the 100 t model.

Results

Nephrops

The length of *Nephrops* caught during the trial was relatively large with just 8 individual or < 0.05% of sampled *Nephrops* measuring < 20 mm CL. Mean lengths from raised counts of *Nephrops* differed little between cod-end mesh sizes, ranging from 30.01 ± 7.13 SD mm CL in the 70 mm cod-end to 30.70 ± 7.27 SD mm CL in the 100 mm cod-end. Estimated total count, weights and value of *Nephrops* in relation to different cod-end mesh sizes and relevant size grades are outlined in Table 2 and Fig. 3. The 80 mm cod-end retained ~ 12% less *Nephrops* while the 90 and 100mm retained ~ 20% less *Nephrops* by weight compared with the 70 mm cod-end. Reductions in total values of retained *Nephrops* were lower than total weights as predominantly smaller less valuable *Nephrops* were lost in the larger cod-end mesh sizes.

The proportional reduction in total value of *Nephrops* lost in the 80 mm cod-end was ~ 5% while the % loss in value in the 90 and 100 mm cod-ends was ~ 11% compared with the 70 mm cod-end. A major reduction of ~ 45% of *Nephrops* < 25 mm CL by weight was observed in the 80 mm compared with the 70 mm cod-end. However further increases in cod-end mesh size resulted in marginal improvements in this regard e.g. a reduction of ~ 55% of *Nephrops* < 25 mm CL by weight in the case of the 100 mm cod-end. Most losses which occurred in relation to increased cod-end mesh size were related to *Nephrops* which were too small to be retained whole but were instead tailed and sold at a lower value than larger whole *Nephrops*. The proportional reduction in the value of whole *Nephrops* lost in the 80 mm compared with the 70 mm cod-end was < 1% while the % value loss in the 90 and 100 mm mesh was ~ 5% compared with the 70 mm cod-end.

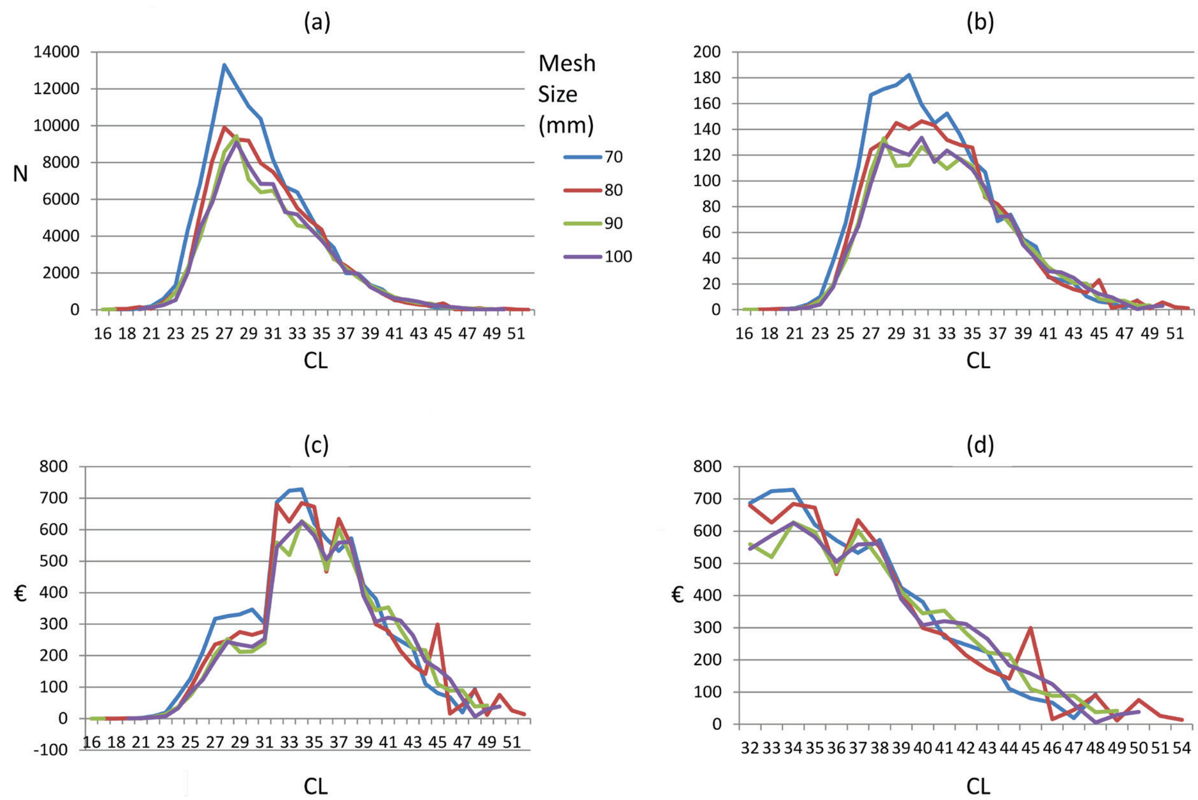


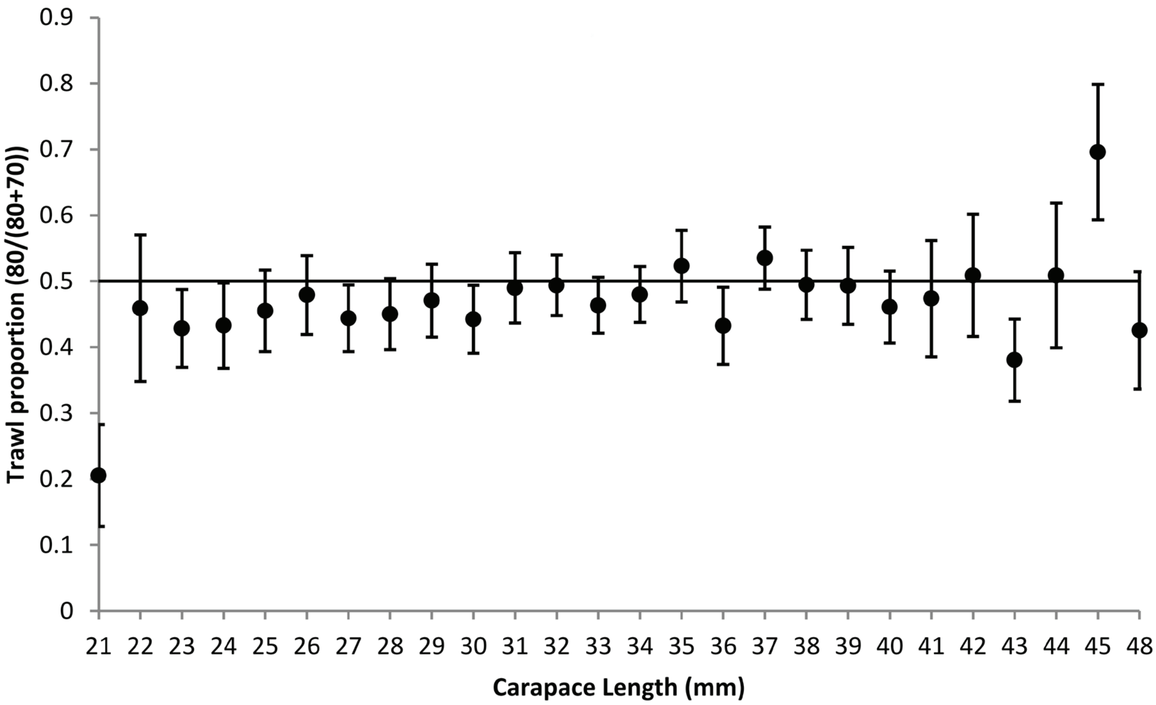
Figure 3. Length frequency plots of raised (a) number (b) weight (c) value of *Nephrops* (d) value of whole *Nephrops*, retained in relation to cod-end mesh size

Table 2. Estimated counts, weights and value of *Nephrops* in relation to cod-end mesh size

Cod-end mesh size (mm)	70	80	90	100	Total
Total Count (N)	112455	93572	81518	81938	369482
Δ 70 mm (%)		16.79	27.51	27.14	
≥ 25 mm CL (N)	105845	89793	77766	78953	352357
Δ 70 mm (%)		15.17	26.53	25.41	
< 25mm CL	6610	3779	3752	2985	17125
Δ 70 mm (%)		42.82	43.24	54.84	
Total Weight (kg)	2093	1837	1642	1662	7234
Δ 70 mm (%)		12.23	21.55	20.59	
≥ 25 mm CL (kg)	2040	1808	1612	1638	7098
Δ 70 mm (%)		11.39	20.97	19.71	
< 25mm CL (kg)	53	29	30	24	136
Δ 70 mm (%)		44.70	43.85	54.73	
Total Value (€)	8496	8039	7486	7562	31584
Δ 70 mm (%)		5.37	11.88	10.99	
≥ 25 mm CL	8395	7984	7430	7517	31327
Δ 70 mm (%)		4.90	11.50	10.46	
< 25mm CL	100	55	56	46	257
Δ 70 mm (%)		45.20	43.98	54.61	
> 31 mm CL (whole)	6434	6413	6107	6164	25118
Δ 70 mm (%)		0.34	5.10	4.20	
≥ 20 ≤ 31 mm CL (tails)	2061	1627	1380	1398	6466
Δ 70 mm (%)		21.09	33.06	32.17	

Δ = Difference from

(a)



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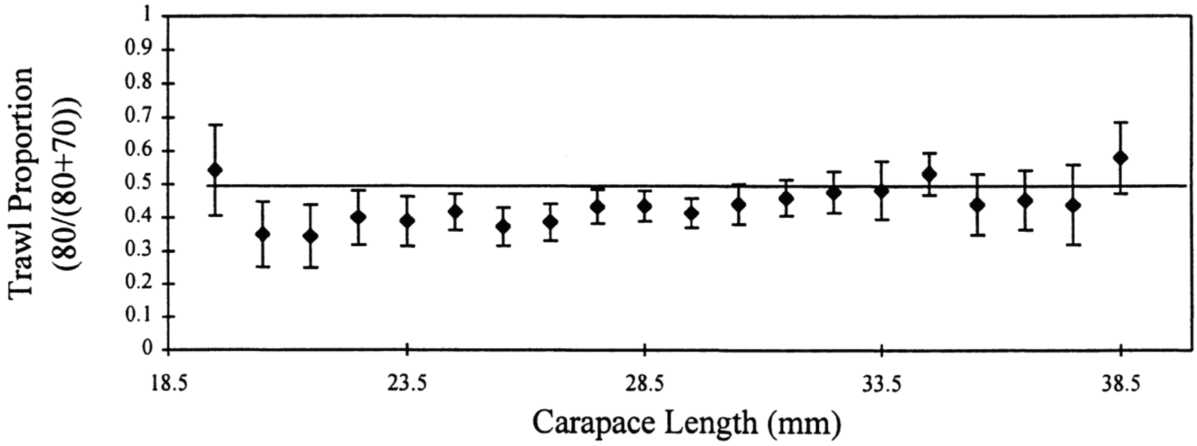

Figure 4. Proportions of *Nephrops* retained in 80 mm cod-ends from combined *Nephrops* catches in 70 and 80 mm cod-ends (P_{80}) by carapace length with standard error bars in (a) the current study, quad-rig vessel using 6 mm twine (b) parrallel tows using single-rigs with 6 mm twine in the Irish Sea in 1995 (reprinted from Briggs *et al.,* 1999 with permission from Elsevier)

Plots of the proportions of *Nephrops* retained in hauls with 80 mm compared with 70 mm cod-ends by carapace length demonstrate similar trends between the current study and Briggs *et al.* (1999) with the proportions of *Nephrops* retained by the 80 mm cod-end gradually decreasing in relation to CL The latter study demonstrated that P_{80} values continued to gradually decrease as CL decreased below the MLS of 20 mm CL (Fig. 4).

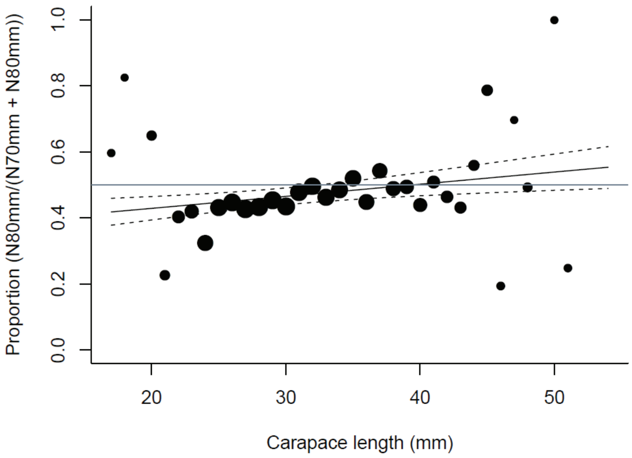

Figure 5. Predicted P_{80} values from a binomial GLMM with covariates. Note the proportional numbers of observations contributing to counts are indicated by marker size. In the predictions the bulk weights are set to their mean and the net positions to their proportional occurrence in the data

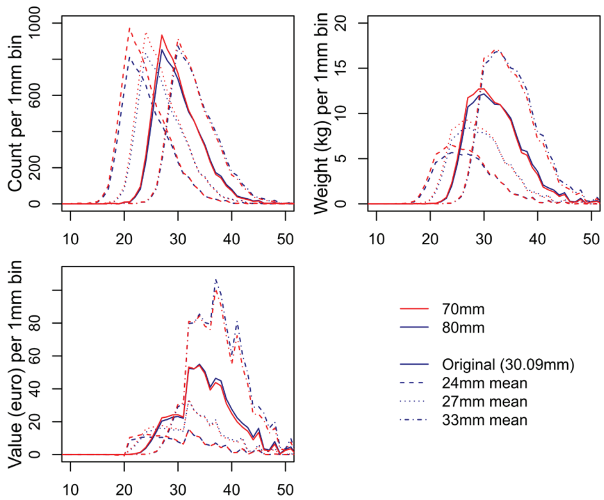

Figure 6. Simulated counts, weight and value by: length class, cod-end mesh size and simulated catch length composition scenario

Results of the GLMM in the current study showed that the relationship between P_{80} and CL was highly significant (P <0.01) (Fig. 5). A generalised additive mixed model (GAMM) using a spline smoother was conducted to examine a potential levelling out in P_{80} values in larger carapace lengths but this did not improve the model fit in terms of Akaike information criterion. The linear model was, therefore, employed as the basis of an economic assessment of differences in *Nephrops* catches between 70 and 80 mm mesh cod-ends for a range of simulated length distributions. The mean length of *Nephrops* catches during the current study (~ 30 mm CL) was larger than the mean length in historical catch composition data in the Western Irish Sea which was generally well below 30 mm CL (Fig. 1). Hence, mean carapace lengths of 33, 30, 27, and 24 mm were used in the simulated catch length compositions in order to model economic impacts on a range of catch length compositions more representative of a wider range of *Nephrops* length compositions associated with commercial catches (Fig. 6, Tables 3, 4, 5).

Economics

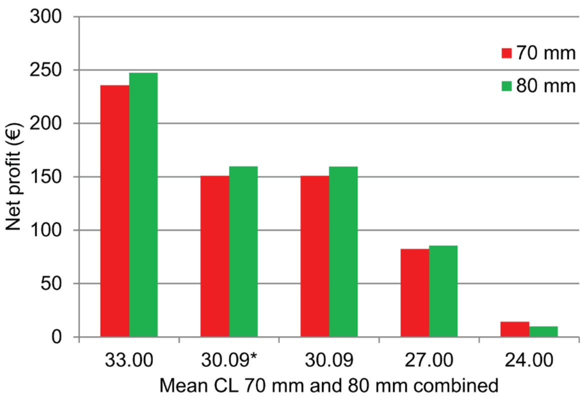

Figure 7. Modelled net profits in relation to 100 t of allowable catches in relation to a range of observed* and simulated *Nephrops* length compositions

Slightly higher catch weights were predicted to occur for the 33 mm mean CL scenario in the 80 mm cod-end due to the linear curve from the GLMM model which predicted higher catches of larger *Nephrops* in the 80 mm compared with the 70 mm mesh. This did not occur in the case of the observed data (30.09 mean CL). This highlights a potential limitation in the modelled relationship of P_{80} values to CL which appear to be more randomly dispersed for CL ~ > 31 CL (Fig. 4) as found by Briggs *et al.* (1999). Extrapolating profits and costs from trip level to a fixed quota of 100 t over the course of a season, gross profit was higher for the 80 mm cod-end in all scenarios given higher mean CL and higher associated prices kg^{-1}. However, with the exception of the 33 mm mean CL scenario which is a remnant from the limitation of the modelling approach, more trips were required to catch the 100 t using the 80 mm cod-end in all scenarios. This resulted in higher costs to catch the 100 t using the 80 mm cod-end in all scenarios. With the exception of the smallest CL scenario (24 mm), however, net profits over the course of the season using the 80 mm cod-end exceeded net profits using the 70 mm cod-end (Fig. 7). The proportional difference in profits between the 70 and 80 mm cod-ends was relatively similar in the case of the 33 and 30.09 (observed and predicted) scenarios, and slightly lower in the 27 mm mean CL scenario. The numeric difference of ~ €4000 in profits for the 24 mm mean CL was relatively small and the proportional difference in profits of ~ -31% was relatively large because of the low net profit figures of €14,000 for the 70 mm and €10,000 for the 80 mm cod-ends.

Table 3. *Nephrops* catches, economic values, mean price and gross profit at haul level in relation to a range of observed and simulated *Nephrops* length compostions

Cod-end mesh size (mm)	Mean CL 70 & 80 (mm)	Mean CL (mm)	Catch** < MCRS (kg)	Catch** ≥ MCRS (kg)	Total catch (kg)	Value < MCRS (€)	Value ≥ MCRS (€)	Mean Price (kg^{-1})	Gross profit (€)
70	33.00	32.96	0.00	802	802	0.00	4452	5.55	4452
70	30.09*	30.01	0.04	644	644	0.00	2614	4.06	2614
70	30.09	29.96	0.08	611	611	0.00	2515	4.11	2515
70	27.00	26.97	1.00	452	453	-0.20	1415	3.13	1415
70	24.00	23.97	13.84	310	324	-2.76	764	2.35	761
80	33.00	33.23	0.00	824	824	0.00	4749	5.76	4749
80	30.09*	30.34	0.10	565	565	-0.08	2474	4.38	2474
80	30.09	30.23	0.08	603	603	0.00	2592	4.30	2592
80	27.00	27.23	0.80	428	428	-0.16	1401	3.27	1401
80	24.00	24.24	11.12	283	294	-2.24	728	2.47	726

*Observed, **Extrapolated from 1 to 4 nets

Table 4. Economic projections at trip level in relation to a range of observed and simulated *Nephrops* length compostions

Cod-end mesh size (mm)	Mean CL 70 & 80 (mm)	Mean CL (mm)	Gross profit (€000)	Expenses (€000)	Wages (€000)	Total costs (€000)	Net profit (€000)
70	33.00	32.96	89.05	13.37	37.84	51.21	37.84
70	30.09*	30.01	52.28	13.37	19.46	32.83	19.46
70	30.09	29.96	50.30	13.37	18.47	31.84	18.47
70	27.00	26.97	28.29	13.37	7.46	20.83	7.46
70	24.00	23.97	15.22	13.37	0.93	14.29	0.93
80	33.00	33.23	94.99	13.37	40.81	54.18	40.81
80	30.09*	30.34	49.47	13.37	18.05	31.42	18.05
80	30.09	30.23	51.85	13.37	19.24	32.61	19.24
80	27.00	27.23	28.03	13.37	7.33	20.70	7.33
80	24.00	24.24	14.52	13.37	0.58	13.95	0.58

*Observed

Table 5. Economic projections in relation to 100 t of allowable catches over the course of a fishing season in relation to a range of observed and simulated *Nephrops* length compostions

Mesh size (mm)	Mean CL 70 & 80 (mm)	Mean CL (mm)	Gross profit (€000)	Hauls (No.)	Trips (No.)	Total costs (€000)	Net profit (€000)	Δ 70 profit (€000)	Δ 70 Profit (%)
70	33.00	32.96	555	125	6.23	319	236		
70	30.09*	30.01	406	155	7.76	255	151		
70	30.09	29.96	411	164	8.18	260	151		
70	27.00	26.97	313	221	11.05	230	82		
70	24.00	23.97	235	309	15.44	221	14		
80	33.00	33.23	576	121	6.07	329	248	12	4.98
80	30.09*	30.34	438	177	8.85	278	160	9	5.72
80	30.09	30.23	430	166	8.30	271	160	9	5.67
80	27.00	27.23	327	233	11.67	242	86	3	3.74
80	24.00	24.24	247	340	17.02	237	10	-4	-31.30

*Observed, Δ = Difference from

Fish

Total catch weights of the main commercial species caught during the trial are outlined in Table 6. Mixed flatfish which formed the highest component of the catch by weight consisted primarily of non-commercial species such as dabs and some undersized species such as plaice. Major reductions in catches of mixed flatfish occurred with increases in cod-end mesh size e.g. ~ 30% less mixed flatfish were caught in the 80 mm compared with the 70 mm cod-end.

Table 6. Quantities of fish species (kg) retained by cod-end mesh size (mm)

Cod-end mesh size (mm)	70	80	90	100	Total
Mixed flats	859	597	320	461	2236
Whiting	515	572	216	484	1787
Haddock	352	483	370	452	1657
Lesser spotted dogfish	202	362	353	312	1229
Mixed non-commercial round-fish	103	119	76	103	400
Cod	55	106	52	53	266
Monkfish	20	30	51	35	137
Thornback ray				18	18
Turbot		5			5
Blonde ray			4		4
Black sole		1	1	1	3
Brill		3			3
Plaice	2				2

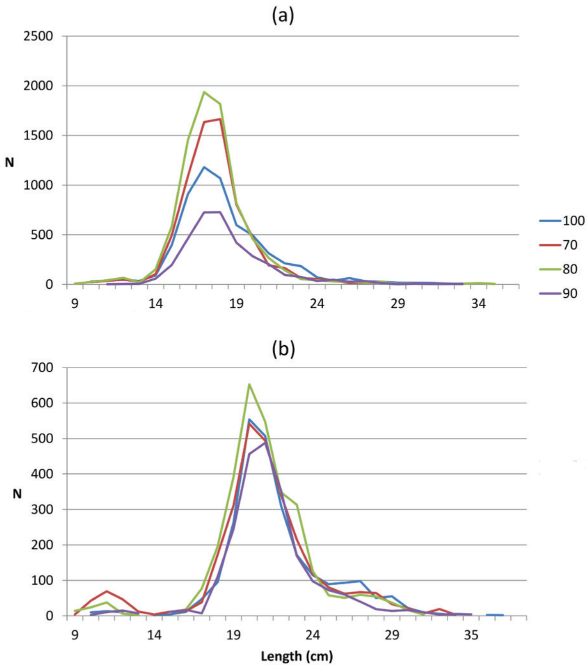

Figure 8. Whiting (a) and haddock (b) length frequency distributions in relation to cod-end mesh size (mm)

Catches of the principal whitefish species, whiting and haddock, were mainly below their respective MLS of 27 and 30 cm (Fig. 8). Little difference in catches of whiting occurred between the 70 and 80 mm cod-ends but reductions in whiting catches were observed in the larger meshed 90 and 100 mm cod-ends. Haddock catches differed little between cod-end mesh sizes while cod catches were generally > MLS of 35 cm but too sporadic to analyse in detail.

Discussion

Results of this study demonstrate the importance of incorporating economic information into assessment of potential technical measures in the context of the LO. For example, observed *Nephrops* catches in the 80 mm cod-end were reduced by ~ 17% by number, ~ 12% by weight but just ~ 5% by economic value compared with the 70 mm cod-end. When modelled over the course of a fishing season, reduced catches of small *Nephrops* afforded an extra opportunity to catch increased quantities of larger more valuable *Nephrops*, resulting in an increase in profitability in the 80 mm compared with the 70 mm cod-end. Additional costs associated with extra fishing effort to avail of this opportunity were outweighed by the benefits of having increased access to available resources. In the case of observed catches during the trial, this resulted in an increase in profitability of ~ 6% by increasing cod-end mesh size from 70 to 80 mm over the course of a fishing season.

The ultimate aim of the economic analysis was to derive proportional differences in profitability between cod-end mesh sizes. Hence, it is important to note that provided the same approach was adopted for both 70 and 80 mm cod-end data sets, that the size and representativeness of simulated *Nephrops* length distributions; empirical values for notional trip length, fixed annual catch limit, and expenses incurred; as well as the precise nature of the share system utilised, were likely to have minimal impact on proportional differences in profitability. Given a highly significant positive linear correlation between P_{80} and CL, variability in the length composition of *Nephrops* catches was likely to have a much greater impact on profitability, and simulating a range of *Nephrops* length compositions greatly assisted in dealing with this issue. Similarity in observed and modelled figures bode well for the accuracy of the model: No difference occurred in net profits and ~ < 0.1% in proportional difference in profitability occurred in observed and modelled figures in relation to the combined mean CL of 30.09 mm for 70 and 80 mm sizes. Modelled increases in proportional profits for mean CL values of 27, 30.09 and 33 mm suggest that an increase in cod-end mesh size would have benefits across a range of *Nephrops* length compositions caught in the Irish Sea. The scenario with a mean CL of 24 mm shows that a vessel reliant on such small *Nephrops* would in effect operate at just over breakeven point over the course of a season. *Nephrops* catches would predominantly consist of tails (≤ 31 mm CL) (Fig. 6). The labour intensive practice of tailing would likely result in additional costs which are not covered under the current study. Extra costs of this nature may result in a net loss over the course of a fishing season. Hence, although it's useful to model a range of values, the 24 mm mean CL scenario is probably not reflective of normal commercially viable fishing practices in the Irish Sea.

Results from the current study, Briggs *et al.* (1999) and Nikolic *et al.* (2015) demonstrate similar trends in *Nephrops* catches in a range of gear trials using different trawl-rig configurations and twine diameters with the larger 80 mm cod-end mesh retaining proportionally less small *Nephrops* in all cases. Furthermore, in the context of the LO, results suggest that an increase in cod-end mesh size may also be economically advantageous for twin and single-rig *Nephrops* vessels, and other *Nephrops* fishing grounds outside the Irish Sea. Briggs *et al.* (1999) conducted a total of 96 tows over a range of area, depths and tidal conditions encountered under normal commercial fishing operations, and using vessels typical of the fleet at that time which employed single and twin trawls. As twine diameter influences the selectivity of a cod-end (Herrmann and O'Neill, 2006; Lowry, 1995) we compared P_{80} values from the current study with P_{80} values derived from cod-ends with the same twine diameter in the earlier study. However, P_{80} values for twin trawls and single trawls using 4 mm twine derived by Briggs *et al.* (1999) also demonstrated similar trends, with P_{80} values decreasing in relation to carapace length.

Slightly lower P_{80} values at smaller carapace lengths apparent in the single trawl experiment with 6 mm twine compared with the current study (Fig. 4), are likely due to differences in mesh openings related to bulk catch volumes. Due to lower headline height and altered sweep arrangements, quad-rigs catch less gadoid fish species compared with twin or single rig trawls (BIM, 2014; Revill *et al.,* 2009). The opening of diamond mesh used in cod-ends is known to be affected by increased catch accumulation (Herrmann *et al.,* 2006; Robertson and Stewart, 1988). Hence, *Nephrops* are less likely to escape from a quad-rig cod-end compared with twin or single-rig cod-ends. An increase in mesh size would likely lead, therefore, to a slightly larger decrease in profitability for a single or twin-rig vessel compared with a quad-rig vessel at trip level. However, in the context of the LO, reduced catches of smaller *Nephrops* would again provide more opportunity to catch increased quantities of larger more valuable *Nephrops* probably leading to improved profitability over the course of a fishing season for such vessels.

The same principle is likely to apply in other *Nephrops* fishing grounds given demonstrated similarities in P_{80} to CL relationships across a broad range of gear trials, as well as relatively homogenous diamond mesh cod-end configurations used to target *Nephrops* in different areas. In addition, a larger MLS/MCRS of 25 mm CL, suggests that the 80 mm cod-end may be even more beneficial in reducing catches of < MCRS *Nephrops* in areas outside the Irish Sea. The total national value of Nephrops landings in 2014 was ~ €44.5m (source SFPA). Proportional differences in mean prices kg^{-1} for *Nephrops* caught in 70 and 80 mm cod-ends based on a variety of simulated and observed *Nephrops* length composition scenarios (Table 3) ranged from 3.8% to 7.8%. Let's assume similar prices and a similar national quota in 2016 when the LO will apply, and that ~ 90% of all Irish vessels are currently using 70 mm cod-ends. The total value of Irish *Nephrops* landings would potentially increase by between €1.53m and €3.14m if a minimum cod-end mesh size of 80 mm was adopted. Indeed, these figures can be considered as conservative as they do not take account of quota uplifts which are likely to result in further increases in the value of *Nephrops* landings

Additional potential benefits of an increase in cod-end mesh size include a major potential reduction in the gap between current *Nephrops* discard rates and the de minimus exemption of 7% of total *Nephrops* catches. For example ~ 45% less *Nephrops* by weight < 25 m CL, the size at which discarding commences in the Irish Sea, were retained in the 80 mm compared with the 70 mm cod-end in the current study. Assuming that the 90% of observed trips using 70 mm cod-ends corresponds to 90% of catches in the Irish Sea, a similar reduction in the current *Nephrops* discard rate (17%) would reduce the discard/MCRS rate to ~ 10%. Such catches would likely be composed of *Nephrops* > and < MCRS (20 mm CL). The 7% de minimis allowance could primarily be used to deal with *Nephrops* < MCRS which may not be sold for human consumption, while the remaining 3% may partially consist of *Nephrops* > MCRS, which can be tailed and sold for human consumption, thereby minimising the impact of the LO.

Increased exploitation of larger *Nephrops* and decreased exploitation of smaller *Nephrops* associated with a larger cod-end mesh size should, in addition, gradually lead to an increase in the mean length of *Nephrops* catches. This is likely to lead to reductions in fishing mortality and, *ceteris paribus*, improved stock status which may lead to further increases in catch allowances.

Moreover, *Nephrops* are known to escape throughout trawls with a greater propensity for smaller individuals to escape further up the trawl in areas such as the wings and trawl body compared with the cod-end (Hillis and Earley, 1982). Hence, an increase in minimum mesh size throughout trawls would likely result in even greater proportional reductions of smaller *Nephrops*, further boosting profitability over the course of a fishing season. A move to 80 mm minimum mesh size would also demonstrate a firm commitment to achieving improvements in selectivity and optimal use of available *Nephrops* resources. This should assist in justifying the case for continued de minimis exemptions in future years.

Increases in cod-end mesh size beyond 80 mm resulted in an approximate doubling of economic loss for relatively small gains in terms of reductions of catches of small *Nephrops*. In the short term, an increase to 90 or 100 mm mesh cod-end is unlikely to be economically feasible as a means of reducing catches of small *Nephrops*. However, demonstrated benefits of larger cod-end mesh sizes in reducing catches of whiting, suggest that increasing cod-end mesh size could, in the longer term, be an option for fishers to deal with this key Irish Sea choke species (Poseidon, 2013) when the LO applies. Given the low economic impact of increased cod-end mesh size beyond 80 mm on whole *Nephrops* (Fig. 3d), this option could be particularly relevant to vessels which primarily target larger whole *Nephrops* e.g. for the frozen market. Plaice is also likely to be a problematic species when the LO applies for this species in the Irish Sea. Corresponding to large differences in quotas and total catches, major bycatches of juvenile plaice are known to occur in *Nephrops* fisheries in the Irish Sea (MI, 2014). The 30% reduction in catch weight of mixed flatfish observed in the current study suggests that an increase in cod-end mesh size from 70 to 80 mm has major potential to improve plaice selectivity and reduce LO impacts in relation to this species.

Acknowledgements

We are grateful to the owners and crew of the participating vessel for their assistance during the trial. The vessel name has been excluded for reasons of confidentiality. We also thank Coilin Minto and Brian Burke from GMIT for assistance with statistical analysis, and Colm Lordan from the MI for information on Quad-rig vessel activity in the Irish Sea.

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