**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

~ 12% by weight and ~ 5% by value during the trial.

* 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 *Nephrops* length compositions showed a general increase in profitability over the course of a fishing season.
* 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* in the Irish Sea.



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**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.

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Fig 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).

However, annual length composition of catches and landed *Nephrops* from 1986 to 2013 presented in the Marine Institute stock book (Fig. 1) shows that most discarding predominantly occurs for *Nephrops* ~<= 25 mm to ~> 15mm CL in the Western Irish Sea (MI, 2014). The minimum landing size (MLS) in the Irish Sea is 20 mm carapace length (CL). 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. 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 (Pers. Comm. SFPA). Taking into account a potential deminimis exemption of 7% of *Nephrops* discards, ~ 10% of *Nephrops* catches which were formerly discarded, would have to be landed if a similar discard, or in the case of 2016 a similar MCRS rate, to previous years (17%) were to apply 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.

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 from an industry perspective. 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.

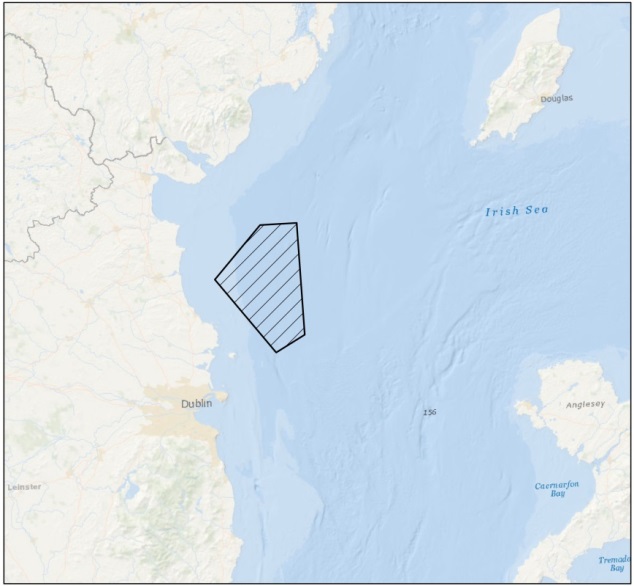


Fig. 2. Gear trial location (striped area)

For example, a recent study in the Bay of Biscay showed a 9% reduction in amounts of *Nephrops* discards (< 26 mm CL) and an increase in *Nephrops* landings by 9% 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 produce a reduction in total *Nephrops* catches of 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* that 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 fish. 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. The economics 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 |
| Cod-end nominal  mesh size (mm) | Cod-end measured  mesh size (mm) |
| 70 | 70.8 |
| 80 | 80.8 |
| 90 | 92.6 |
| 100 | 103.0 |

*Fishing operations*

The trial took place onboard 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 h, 3.1 knots and 48 m respectively. Fishing gear consisted of a Quad–rigged 18 fathom *Nephrops* trawls trawl set up using a triple warp and centre clump arrangement. Four test cod-ends with nominal mesh sizes of 70, 80, 90, and 100 mm diamond mesh cod-ends, with single 6 mm twine were towed simultaneously during the trial. 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 onboard *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 calipers 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 = 0.00032CL3.21 , 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. Compiled *Nephrops* sales note data in 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 length specific price information to *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) were similar to compiled average prices for the Irish Sea, whole (€6.39) and tailed *Nephrops* (€5.69). 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 per kg was assigned to catches of *Nephrops* bellows MCRS. The optimal 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 Nephops 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 quota 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 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 landing, or in the context of the LO, a fixed catch limit. 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 fuel during steaming, fuel during fishing, ice, net mending, duties and levies, port fees, insurance, transport of landings, repayments, ship maintenance and food. With the exception of fuel used during fishing none of these expenses were considered to vary between 70 and 80 mm mesh sizes. Based on communications with Industry, 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 cm 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 mesh sizes.

The proportional reduction in total value of *Nephrops* lost in the 80 mm cod-end was ~5% while the % loss in the 90 and 100 mm cod-end 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.

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Fig. 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 |
| Delta 70 mm (%) |  | 5.37 | 11.88 | 10.99 |  |
| >= 25 mm CL | 8395 | 7984 | 7430 | 7517 | 31327 |
| Delta 70 mm (%) |  | 4.90 | 11.50 | 10.46 |  |
| < 25mm CL | 100 | 55 | 56 | 46 | 257 |
| Delta 70 mm (%) |  | 45.20 | 43.98 | 54.61 |  |
| > 31 mm CL (whole) | 6434 | 6413 | 6107 | 6164 | 25118 |
| Delta 70 mm (%) |  | 0.34 | 5.10 | 4.20 |  |
| <= 31 mm CL (tails) | 2061 | 1627 | 1380 | 1398 | 6466 |
| Delta 70 mm (%) |  | 21.09 | 33.06 | 32.17 |  |

\* Δ = Difference from

(a)

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(b)

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Figure 4. Proportions of *Nephrops* retained in hauls with 80 mm compared with 70 mm cod-ends by carapace length (*P*80) 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 suggesting a correlation between the length composition of *Nephrops* catches and *P*80 (Fig. 4). Results of the GLMM showed that the relationship was highly significant (P <0.01).

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Fig. 4. 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

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Fig. 5. Simulated counts, weight and value by: length class, cod-end mesh size and simulated catch length composition scenario

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Figure 6. Modelled net profits in relation to 100 t of allowable catches in relation to a range of observed\* and simulated *Nephrops* length compositions

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 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 cm CL) was larger than the mean length in historical catch composition data in the Western Irish Sea which was generally well below 30 cm CL (Fig. 1). Hence, mean carapace lengths of 33, 30, 27, and 24 cm were used in the simulated catch length compositions in order to model economic impacts on a range of catch length compositions (Fig. 5, Tables 3,4,5).

*Economics*

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) similar to 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 results 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. The proportional difference in profits between the 70 and 80 mm cod-end was relatively similar in the case of the 33, 30.09 (observed and predicted) and 27 mm mean CL scenarios. The numeric difference of ~€4000 in profits for the 24 mm mean CL scenario is relatively small and the proportional difference in profits of ~ -31% is relatively large because of the low net profit figures of €14,000 for the 70 mm and €10,000 for the 80 mm cod-end.

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

\*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 (cm) | Mean CL (cm) | 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 | 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 |

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Fig. 7. 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 27cm and 30 cm (Fig. 7). Little difference in catches of whiting occurred between the 70 and 80 mm cod-ends but reductions 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% of 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 resulting in an increase in profitability in relation to observed *Nephrops* catches of ~ 6% by increasing cod-end mesh size from 70 to 80 mm.

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 representativeness of simulated size 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. Such a vessel would rely heavily on tails (Fig. 5) which would likely result in additional costs associated with the labour intensive practice of tailing, 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 mesh thicknesses 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 used single and twin trawls. As twine thickness 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 thickness 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 apparent in the single trawl experiment with 6 mm twine compared with the current study (Fig. 5) are likely due to lower fishing power of quad-rigs in relation to gadoid fish species compared with trawls with fewer rigs (BIM, 2014; Revill *et al.*, 2009). This is likely to result in less voluminous catches which may lead to smaller cod-end mesh openings and less escapement of small *Nephrops*. This would probably result in a slightly larger decrease in profitability between 70 and 80 mm cod-ends at trip level in single or twin-rigs compared to quad-rigs. 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* over the course of a fishing season. 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 in areas outside the Irish Sea suggests that the 80 mm cod-end may have additional benefits in reducing catches of small *Nephrops* which may not be sold for human consumption under the LO.

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. A similar reduction in the current *Nephrops* discard rate (17%) would reduce the discard/MCRS rate to ~10.5%. Such catches would likely be composed of *Nephrops* > and < MLS (20 mm CL) so the 7% allowance could primarily be used to deal with *Nephrops* < MLS which can’t be sold for human consumption, while the remaining 3.5% may to some extent consist of *Nephrops* > MLS, which can be tailed and sold for human consumption. 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 could lead to reductions in fishing mortality, and potentially contribute to improved stock status which could 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 which 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 *Nephrops* selectivity. In the short term, an increase to 90 or 100 mm cod-end mesh is unlikely to be economically feasible as 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 be an option to deal with this key choke 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. 3(d)) 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 a LO is introduced 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 catches 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.

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