Fisheries Research Services Internal Report No 16/07

EFFECT OF INTRODUCING A SPECIES SELECTIVE TRAWL GEAR IN A SCOTTISH NEPHROPS FISHERY

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June 2007
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ABSTRACT

The mesh sizes used in many European Nephrops fisheries are poorly selective for the gadoid by-catch, resulting in the capture of many fish below the minimum legal landing size and high discard rates. The European programme NECESSITY aims to overcome this by designing new species selective Nephrops trawl gears. Fishing trials using both the standard net currently used by the Nephrops fleet in Scottish waters (80mm cod-end with a 90mm square mesh panel) and a '4-panel' net (80mm cod-end with a short inclined separator panel guiding fish towards a 100mm square mesh panel) were carried out on commercial fishing grounds on the West coast of Scotland (ICES division VIa). Selectivity data for haddock (Melanogrammus aeglefinus), whiting (Merlangius merlangus) and Nephrops (Nephrops norvegicus) were collected using the twin trawl method and analysed using a smoother-based method. The 4-panel net significantly improved whiting selection, but had no significant effect on haddock or Nephrops selection. The effect on the VIa whiting stock of switching the Nephrops fleet from the standard to the 4-panel net was investigated. Assuming no change in fishing effort or in the gear selectivity of other demersal fleets, the whiting yield of the Nephrops fleet and the whiting spawning stock biomass would both increase by about 45% in the long term. The implications for the fishing industry and the management of the fishery are discussed. However, the development of the 4-panel net is not finished and further work is suggested.

1. INTRODUCTION

Nephrops (Nephrops norvegicus), also known as Norway Lobster, is exploited throughout Europe from the Baltic Sea to the Mediterranean, and is one of the most valuable species landed in UK (Anon., 2004a) and Scottish waters. Nephrops are found on the same grounds as commercial finfish species such as whiting (Merlangius merlangus), haddock (Melanogrammus aeglefinus) and cod (Gadus morhua). Because Nephrops are smaller, the minimum mesh size in Nephrops trawls is smaller than in targeted gadoid fisheries, causing large discards of juvenile gadoids (Bergmann et al., 2001; Stratoudakis et al., 2001; ICES, 2004). In some Nephrops fisheries, however, the by-catch of marketable gadoids is an important economic component of the catch. There is a clear need to improve the sustainability of the gadoid stocks by changing aspects of the Nephrops fisheries.

One option is to separate fish from Nephrops during trawling so that a different or additional selection device can be applied to the fish. Several attempts have been made to do so in European Nephrops fisheries (Campos & Fonseca, 2004; Dunlin, 1999; Main & Sangster, 1985a). However, such modifications always risk losing some of the target species and the commercial by-catch (Tschernij, 2004; Anon., 2002a). The ideal solution would ensure that marketable fish and Nephrops are retained, non-marketable fish and Nephrops are released and survive, and the costs for modification and maintenance of the gear are acceptable. Potential benefits include reduced sorting time and hence increased efficiency of the fishing
operation, increased quality of the gadoid catch and hence a higher price and, crucially, healthier gadoid stocks.

The NECESSITY project, partly funded by the European Union, aims to reduce the non-commercial by-catch of Nephrops fisheries throughout Europe. Close collaboration with the fishing industry is a key element of the project. In Scotland, an initial liaison meeting agreed to trial a new gear, a ‘4-panel’ net, that has a short inclined separator panel guiding fish towards a 100mm square mesh panel (SMP). This study describes trials to compare the selection of the 4-panel net with that of the standard gear used by the Scottish Nephrops fleet. Selectivity data for haddock, whiting and Nephrops were obtained by the twin-trawl method (Wileman et al., 1996). The results are used to simulate the effects on the gadoid stocks of introducing the 4-panel net in the Nephrops fleet. The implications for the fishing industry and the management of the fishery are discussed.

2. MATERIALS AND METHODS

2.1. Boat, Fishing Ground and Gear

The 388kW commercial Nephrops twin trawler Ocean Trust with an overall length of 18.04m was chartered for the 16 days sea trials (23/05 to 08/06/2005). The trials were in the South Minch off the West coast of Scotland (ICES division VIa) where both Nephrops and gadoids are reasonably abundant.

The vessel’s own twin John Noble Nephrops Discer nets were used, each trawl having a fishing circle of 400 x 80mm diamond meshes (Figure 1). The trawls were of a 2-panel construction and had an overall ground gear length of 30m incorporating 300mm and 250mm hopper discs. The trawls were towed using a three-warp system with a 386kg chain centre clump and spread using Bison© No.5 otterboards. The trawls were fished using 36.6m single combination sweeps and 15.2m double bridles giving an overall sweepline length of 51.8m.

The trials compared the selectivity of two different net configurations. Both the standard and test gear incorporated a 22.5 mesh deep headline panel constructed from 160mm diamond mesh netting and SMPs positioned 14.3m-17.3m from the codline. The standard gear was rigged with a 3m long 90mm (nominal) SMP (Figure 2). The test gear incorporated a 3m long 100mm (nominal) SMP rigged into the top sheet of a 4-panel section with an inclined guiding panel and an horizontal separator panel rigged below the SMP inside the netting (Figure 3). The purpose of the guiding panel is to lead fish into the upper part of the net closer to the SMP. A gap under the inclined panel allows Nephrops to fall back under the panel, thus keeping the Nephrops in the lower part of the net leading directly to the cod-end. The guiding panel was inserted in a 4-panel netting section to allow for ease of rigging along a bar mesh and to give it stability since such a 4 panel section maintains a natural opening (Figure 4).

Both gears were fished using 80mm (nominal) diamond mesh cod-ends with 116 open meshes round the circumference. The cod-ends were rigged with 160mm diamond strengthening bags 12.5 mesh deep and constructed from 5mm double PE twine. All the cod-ends and SMPs were constructed from 4mm single PE twine. Video cameras were fitted inside and outside the 4-panel section to observe fish and net behaviour before the selectivity trials.
The twin trawl technique (Wileman et al., 1996) was used to assess the selective properties of the two test configurations. The 40mm (nominal) diamond mesh control cod-end was constructed from 1.6mm twisted PE twine with a stretched length of 7m. The control net did not have a diamond mesh headline panel or SMP, so the combined selectivity of all the devices (headline panel, SMP and cod-end) in the test gear was assessed.

2.2. Catch Handling

The test net was always attached to the starboard trawl to minimise the risk of wash out and fouling when the bag was brought alongside the vessel after each haul. Catch from the control and test nets were processed separately. Each catch was sorted by species. The total length of fish was measured to the nearest cm below. The Nephrops carapace length was measured to the nearest mm with an electronic calliper rule. Large catches were sub-sampled. The total catch of each species in each net was weighed on board.

2.3. Selectivity Analysis

The standard method of analysing twin trawl selection data is to assume a logistic selection curve and to use the SELECT methodology (Millar and Walsh, 1992). However, the model fitting procedure often failed to converge for the data reported here. This is a problem often encountered when large individuals are scarce. A more robust, non-parametric analysis based on smoothers (Fryer et al., 2003) was therefore used instead.

The method models the catch rate of the test net relative to the control net as a smooth function of length. A separate smoother was fitted to the data for each haul and a mean curve was then estimated by combining the smoothers across hauls. Differences between the mean relative catch rates of the 4-panel net and the standard net were assessed using a bootstrap significance test. Full theoretical details are in Fryer et al. (2003) and an application to twin trawl data is in O’Neill et al. (2006).

2.4. Stock Assessment

A stock prediction model (Diagram 1) was applied to the whiting stock in ICES area VIa to estimate the long term benefit of a change in gear selection by the Nephrops fleet. The whiting fishery was assumed to consist of two fleets: a Nephrops fleet using mesh sizes between 70 and 99mm, with a modal mesh size of 80mm, and a whitefish fleet using larger mesh sizes. The reference year was 2004 and the fishery was projected forward ten years. To focus on the effect of changes in selection in the Nephrops fleet, it was assumed that fishing effort was constant throughout and there was no change in selection in the whitefish fleet. Input data for Area VIa were obtained from FRS records (S Holmes, pers. comm.) and consisted of relative numbers of whiting at ages 1 to 6+ in 2004; fishing mortalities-at-age (F) by fleet obtained by partitioning total F in proportion to fleet landings and discards; weights-at-age of landings and discards by fleet; stock weights-at-age; and estimates of recruitment, natural mortality-at-age and maturity-at-age (Table 1). A stock assessment was not available for whiting in VIa in 2004, so the prediction was based on relative numbers-at-age obtained from fishery surveys, rather than absolute numbers-at-age. Recruitment for 2005 onwards was taken to be 3.77493, the geometric mean age 1 abundance for 1985-2004.

Two scenarios were considered. The first assumed that the Nephrops fleet continued to use the standard net over the 10 year period, so the fishing mortalities in the forecast years were the same as in the reference year. The second scenario assumed that the Nephrops fleet switched from the standard net to the 4-panel net in 2005. The fishing mortalities in the forecast years were then a function of the fishing mortalities in the reference year and the
Mean catch rate at age of the 4-panel net relative to the standard net. This catch rate was obtained from smoothers (Section 2.3) and a whiting length-age key.

The results (weight of landings, weight of discards, and spawning stock biomass) were expressed as the percentage difference from the status quo through the 10 year forecast period.

The methods described so far have assumed a constant fishing effort from 2004 onwards for all fleets in area VIa. However, the effect of a change in fishing effort can be considered by applying a multiplier to the fishing mortality. Projections to estimate the effect of changes in effort in the Nephrops fleet on long term whiting yield per recruit and SSB per recruit (YPR and SSBPR) were made. These projections were intended to assess optimal safe levels of effort for the whiting stock when fished with either the standard or 4-panel net.

3. RESULTS

3.1. Video Observations

To simplify the process of deploying the TV cameras during observation hauls the test net was shot as a single trawl. To enable the trawl to obtain the correct opening in a single trawl configuration the sweep length was extended from 37m to 91m. A total of 4 hauls were completed with the camera positioned inside the 4-panel section and 5 hauls with it positioned outside at the SMP. Haul duration varied from 43 to 55 minutes and water depth ranged between 13m-64m with no artificial light used in any haul. When positioned inside the 4-panel section the camera was orientated so that observations could be made of the leading edge of the inclined panel. When positioned outside, the camera was attached to the netting in the top sheet ahead of the SMP and aligned to look back along the panel.

The inclined panel was orientated correctly with the height of its leading edge just above the level of the sand cloud passing down the trawl. Due to the water flow the leading edge of the inclined panel curved back and upwards. The netting in the lower sheet of the 4-panel section sagged slightly, so the opening below the inclined panel was larger that expected. In the last observation haul, the rope rigged through the meshes at the panel’s leading edge was lengthened by 50mm and this appeared to reduce the sag in the lower sheet. The SMP was tensioned correctly with no observed distortion in the surrounding diamond mesh netting.

Few gadoids were encountered during the observation hauls and catches were composed mainly of pelagic species (sprat, herring and mackerel) and Nephrops. No conclusions could be drawn on the behaviour of haddock and whiting to the inclined panel and SMP.

Nephrops were observed only if they were out of the sand cloud, or if the sand cloud was sparse enough to see them inside. Nephrops seemed to be carried by the flow of water, and though they had flip-tail movements, their swimming and direction did not appear to be controlled. Only one sequence of 9 minutes presented a light sand cloud when Nephrops could be counted: 8 individuals (9.4%) went into the cod-end via the upper path and 77 via the lower path. In all other sequences, Nephrops were rarely observed in the lower path due to the sand cloud, but were observed in very small numbers in the upper path where the water was clearer. As Nephrops catches were large for most hauls, this suggests most Nephrops entered the cod-end via the lower path. No Nephrops were observed to escape through the SMP at either camera position.
Many pelagic fish escaped through the SMP, but some of the escapees kept swimming around the net and then actively attempted (many times successfully) to re-enter the net. At low densities, most fish were observed high in the 4-panel section, but at higher densities they filled all the available space down to the lower netting panel. Pelagic fish were also observed in the sand cloud, more so at high densities. When the sand cloud was sparse and fish density low, fish were observed to swim upward when they encountered the leading edge of the guiding panel. The contrast of the opening into the lower compartment was very dark which could possibly give a black tunnel effect and influence behaviour. Glass and Wardle (1995) found that for gadoids, a dark area such as this may trigger flight reaction from a predator’s mouth.

3.2. Selectivity Analysis

There were 8 valid hauls with the standard net and 11 with the 4-panel net (Table 2). Haul 1 was discounted because the net failed to fish properly but all other hauls were valid. Most of the by-catch was haddock, whiting, and sometimes dogfish (*Scyliorhinus stellaris*).

The individual-haul and mean relative catch rates for each species and net are shown in Figure 5. For haddock and *Nephrops*, the mean relative catch rates of the standard and 4-panel nets did not differ significantly (haddock: \( p = 0.80 \); *Nephrops*: \( p = 0.56 \)) and were around 100% for the largest individuals, as would be expected. For whiting, the mean relative catch rates of the two nets differed significantly (\( p = 0.004 \)), with the 4-panel net catching significantly fewer whiting than the standard net below about 30cm. The standard net showed no evidence of any length-dependence, and the relative catch of both nets was only around 65% for large whiting.

3.3. Stock Assessment

The stock projection showed that switching to the 4-panel net would initially reduce the whiting yield of the *Nephrops* fleet by 6.5% (compared to the case with no change in gear) but would then increase both whiting yield and SSB to give long-term increases of 45% and 43.5% respectively.(Figure 6).

In the long-term, the 4-panel net would increase the landings of whiting aged 3 years and above (e.g. 33% more age 3 whiting than the standard net) and reduce the discards of young whiting (e.g. 76% less whiting of age 1 and 26% less of age 2 than the standard net) (Figure 7). From these results, the 4-panel net would not cause any loss of whiting above commercial landing size (27cm which corresponds to whiting between 2 and 3 years old).

Projections to estimate the effect of changes in effort in the *Nephrops* fleet on long term whiting YPR and SSBPR are shown in Figure 8. Because of uncertainties in equilibrium YPR analysis, it is commonly recognized (Haddon, 2001) that the safe optimum fishing effort should be defined as that effort coinciding with the point on the YPR curve at which the slope is 10% of the slope at the origin \( (E_{0.1}) \). For the standard gear, the safe optimum effort is 18% below the 2004 level. For the 4-panel net, the safe optimum effort is 83% above the 2004 level. Thus, if the 4-panel net is adopted by the Nephrops fleet, the whiting stock will not be adversely affected unless the effort of that fleet increases by more than 83%.

For any fishing effort, the long-term whiting YPR would be higher using the 4-panel net than the standard net (Figure 8). The long-term catch per unit effort (CPUE) would also be higher using the 4-panel net than the standard net, but would decrease as fishing effort increased (Figure 9).
4. DISCUSSION

4.1. Video Observations and Net Rigging

It is generally recognised that in the forward part of the net, fish are able to swim energetically as a response to the visual stimulus of the net (Main and Sangster, 1981; Wardle, 1993; Kim and Wardle, 2003). Fish become tired as they swim in the path of the trawl and drop back in the net when they approach exhaustion (Main and Sangster, 1981). This suggests that fish would have more energy to make an active escape in the forward part of the net than further back. However, in any trawl net, the distance between the top and lower netting surfaces decreases toward the cod-end, so the further forward the SMP, the lower the probability that the fish will encounter the panel. Indeed, the selectivity performance has been shown to be better when the escape window is positioned further back in the net where the height is lower (O’Neill et al., 2006; Graham et al., 2003). However, the net configuration with a SMP too far back might not always be very selective due to the risk of net twisting (O’Neill et al., 2006), which makes it unpopular with the fishing industry. The 4-panel net design is intended to overcome these issues: the 4-panel section is positioned forward in the net, and given that fish can take the upper path, their probability of encountering the SMP should increase with the presence of the guiding panel.

The video evidence suggests modifications to the net that might improve species selection. The side panels in the initial design were too deep and therefore could be reduced by approximately 25%. This would increase the angle of the inclined panel but reduce its length. An increased angle would guide fish more quickly up towards the SMP and therefore improve the encounter probability (Figure 10). The length of the separator panel leading on from the top edge of the guiding panel would be increased, therefore keeping fish in contact with the SMP. To reduce the sag noted in the lower sheet of the 4-panel section the number of meshes across the top and lower netting panels could be reduced slightly. The height of the leading edge of the inclined panel is an important issue: its position should be tuned to guide as many Nephrops below and as many fish above the separator panel as possible. To enable a more accurate method of tuning, the opening into the lower compartment of the leading edge of the guiding panel could be cut up and in along the mesh bars giving an inverted ‘V’ opening (Figure 11).

Some Nephrops were observed above the separator panel. The intensity of the water flow in the net could explain the height at which Nephrops were seen. On the video, flick tail movements of Nephrops were observed but the direction of their swimming did not seem to be controlled. Briggs and Robertson (1993) also observed passive behaviour of Nephrops when passing below the SMP. Nephrops were not observed to escape through the SMP or to make upward active attempts of escape. Therefore, there is no evidence that significant numbers of Nephrops would escape during towing if the inclined panel were lower. A further experiment could test the effect of reducing the leading edge height to increase the proportion of fish in the upper path. However, the eventual escape of Nephrops, perhaps during the hauling process, is a major fear for fishermen intending to use such a net design and attention should be paid to this issue in further experiments.

The current legislation (in 2004) imposes a SMP at least 3m long (DEFRA, 2002). The upper path and SMP could be lengthened to increase the fish escape probability. Nevertheless, the benefit in reducing discards while retaining marketable individuals with a longer SMP and a separator panel should be demonstrated to encourage the fishing industry to use it on a voluntary basis.
Whether the inclined panel caused fish to rise was unclear from the video. Fish density and the sand cloud (Wardle, 1993) inside the net are likely to affect fish behaviour. Therefore, to improve net design further, work is required to understand the behaviour mechanisms of gadoids when confronted by the physical environment inside the 4-panel section during the capture process.

4.2. Selectivity

Though low selectivity for whiting has been reported in several studies (Zuur et al., 2001, Madsen et al., 1999), it is not always the case (Graham et al., 2003), and the lack of length-based selection observed here for whiting in the standard net was unexpected. Cod-end selectivity is known to depend on other factors as well as net design, such as water temperature and physiological condition of the fish (Özbilgin and Wardle, 2001, Breen et al., 2004, Ozbilgin et al., 2006) and on girth which, for a particular length, varies with season and maturity stage (Anon., 2004b). Such factors, studied in haddock, could explain these whiting results.

The mean relative catch rates for whiting suggest that both the 4-panel and standard nets failed to retain 100% of the largest whiting that entered the net (Figure 5). Madsen et al. (1999) also found a large reduction in whiting over minimum landing size (MLS) in the catch when a 90mm SMP was fitted to a conventional 70mm cod-end trawl. They suggested that larger whiting escape because they have better swimming capacity than smaller whiting, so can swim across the flow and out of the panel, or because they act as individuals whereas smaller whiting shoal and keep together. By looking at the length-girth relationship of whiting (Margetts, 1957), it appeared likely that large whiting could have escaped through the 80mm mesh used in the trials reported here. Note that, for both gears, 100% retention was achieved for haddock and Nephrops (Figure 5), suggesting that the fishing efficiencies of the experimental and control nets of the twin trawl system were similar.

There was no significant difference in Nephrops relative catch rate, and hence selection, between the two nets. Video observations supported this, since Nephrops did not appear to be affected by the inclined panel and no Nephrops was observed escaping through the SMP.

During the fishing process, tiring haddock and whiting tend to fall back and enter the net mouth by swimming upwards (Main and Sangster, 1985b). Whiting have been observed staying close to the top sheet and repeatedly trying to escape through a SMP (Briggs, 1992). Haddock, on the other hand, may not escape actively through a SMP (Main and Sangster, 1991). The 4-panel section aimed to increase the panel encounter probability, so these observations could explain why the 4-panel net improved whiting but not haddock selection. Unfortunately, the video observations could not support this hypothesis as few gadoids were caught during the observation hauls. Though haddock and whiting tend to fall back high in the net, density-dependent behaviour, whereby individuals tend to keep a certain minimum distance apart, could lead some fish to the cod-end via the lower path. In this case, the separator panel would have decreased their probability of encountering the SMP. There was a positive correlation between the total haddock catch size and the retention of juvenile haddock below 30cm (p < 0.05) which supports this assumption.

It is unclear whether the 4-panel section improved whiting selection because of the guiding panel, the increase in square mesh from 90 to 100mm, or both. Future experiments should be designed to test for the effect of the guiding and separator panels only.
4.3. Stock Assessment

The stock projections showed important long-term changes in the VIa whiting stock if the 4-panel net was introduced to the Nephrops fleet. However, these results should be regarded with caution for several reasons:

- The changes were partly because the standard net showed no length-related selection. The projections assumed that the selection patterns obtained from the NECESSITY trials would be repeated under commercial conditions over the forecast period (2005 to 2013), an assumption that is unlikely to be valid. For example, an experiment with the standard net on MFV Concorde (Anon, 2002b) showed length-related selection of whiting.

- The projection assumed that all whiting escaping from the test nets would survive but survival experiments have shown (e.g. Suuronen 2005) that this is not necessarily true under commercial fishing conditions.

This study shows that, for any level of fishing effort of the Nephrops fleet, the use of the 4-panel net instead of the standard net would benefit CPUE and YPR in the long term. An increase in fishing effort would lead to higher YPR but to lower CPUE and SSBPR (Figures 8 and 9). From a fishery management view point, an increase in effort would probably not be sustainable since whiting SSB is already very low (Bailey et al., 2005). The projection assumed a constant level of recruitment; however, SSB would decrease with increasing effort and this might lead to a reduction in recruitment and hence lower yield than predicted. From an industry view point, the economic benefit of an increase in yield must be balanced against the decrease in CPUE and the cost of increasing effort. An increase in effort might not be economically attractive. Therefore, the optimal YPR is likely to be lower than the one indicated by the YPR curve alone. The effect of increased effort on non-target species which may be retained should also be considered.

The stock projections assumed that all whiting were mature from age 2 each year (ICES, 2004). The projections showed that 26% more age 2 whiting would contribute to the SSB if the 4-panel net was used in area VIa. The 4-panel net would also release 76% more age 1 whiting than the standard net, thus reducing discards. At age 3, most whiting have reached the MLS and it is the major age class found in the landings. The quantity of age 3 fish caught would increase in the long term if the 4-panel net was used. Recruitment might also benefit because the fecundity of gadoids is known to increase with fish age, i.e. the number and quality of the eggs as well as their chance of successful development is higher with older genitors (Marteinsdóttir and Begg, 2001, Wright et al., 1999). The recruitment and SSB of whiting is currently low (Bailey et al., 2005), and the proportion and age of whiting currently released are probably not adequate to increase and maintain the stock biomass to a healthy level. Some large whiting seemed able to escape from both test nets (the mean relative catch rate for large whiting was about 0.65 (Figure 5)), but not more with the 4-panel net than with the standard net. Further study could investigate if the proportion and the age of the whiting released by the new gear would be sufficient to make the harvest of whiting by the Nephrops fleet sustainable.

For both nets, the retention of haddock was length-dependent with most age 3+ haddock being retained (Figure 5). It is assumed that none of age 1, 57% of age 2 and 100% of age 3+ haddock are mature (ICES, 2004), so relatively few mature haddock are released. The recruitment of haddock in 2005 was low (Bailey et al., 2005) and there is no evidence from this study that the number of mature haddock released by either net is sufficient to make the harvest of haddock at current levels sustainable.
5. CONCLUSION: FURTHER RESEARCH, RELEVANCE FOR THE INDUSTRY AND MANAGEMENT OF THE FISHERY

Results from this study showed an improvement in whiting selectivity when a 4-panel section with a separator panel and 100mm SMP was fitted to a standard Nephrops net. There was no evidence of an improvement in haddock selectivity or of any change in Nephrops catch rates. By comparison with other studies, it is unlikely that the significant improvement in whiting selectivity will be reproduced systematically under commercial fishing conditions. Therefore we should be cautious about claiming the 4-panel net is an improvement on the standard net and no major conclusion for the whole fishery can be drawn. The study showed how the 4-panel net should be tuned and that further research needs to be conducted under different commercial conditions (e.g. period of the year, area) to assess its overall selectivity performance.

If the pattern of selection for whiting observed in this study could be confirmed with further experiments, the use of the 4-panel net by the Nephrops fleets would lead to a long term increase in the yield of whiting of 45%. The catch of large whiting would increase (+33% whiting age 3) and of undersized whiting would decrease (-76% whiting age 1), reducing the sorting time needed by the crew on board. To be more realistic, the stock projections should also consider management measures on the demersal fleets harvesting the whiting stock (e.g. effort and selectivity changes) and the mortality rate of escapees.

Replacing the standard net by the 4-panel net would benefit the SSB of whiting (+43% in long term). However, to increase TSB and SSB to a healthy level, compared to the standard gear the 4-panel net should release a greater proportion of fish older than the age at first maturity. The legal MLS for whiting in Vla is 27cm (about 2 years old, generally the age of first sexual maturity), but it is not economically advantageous for fishermen to release fish larger than the MLS. If the MLS were increased, the selection of commercial fishing nets would have to be improved. This could be done by increasing the mesh size but, as Nephrops are smaller than whiting, the net design should seek to maximise the by-catch size selection whilst minimising the potential loss of Nephrops. This emphasises the key role of species separation in mixed fisheries and illustrates why further research should be carried out on separator panels and square mesh panels in Nephrops gears.

ACKNOWLEDGEMENTS

Thanks to the skipper and the crew of the Ocean Trust. The authors are most grateful to their colleagues Dave Bova and Martin Burns of FRS for valuable help during the cruise and in working up the data. This report is mainly based on a thesis submitted to Aberdeen University by Sonia Méhault in part fulfilment of her MSc in Marine and Fisheries Science (August 2005).

This study (Contract CT-2003-501605) was part financed by the European Commission’s Directorate General for Fisheries. This report does not necessarily reflect the views of the European Commission and in no way anticipates any future opinion of the Commission.
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TABLE 1

Input data for 2004 for stock predictions. Relative abundances estimated from survey data were used instead of numbers at age since a stock assessment was not available for 2004. Maturity at age was assumed to be knife edged with 100% maturity at age 2 (ICES, 2004).

Whiting in Area VIa

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<td>0.186566</td>
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<td>0.124319</td>
<td>1.699023</td>
<td>0.165758</td>
<td>0.02072</td>
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</table>

HC Human consumption catch
Dis Discards
NTR Nephrops trawl
Other All other fleets
## TABLE 2

Haul details. The * denotes that the mean gear performance variable differed significantly between the test and control net (Mann-Whitney test, p<0.05). NA = Non Available.

<table>
<thead>
<tr>
<th>Haul No</th>
<th>Starting position</th>
<th>Starboard net (test)</th>
<th>Port net (control)</th>
<th>Mean Speed (knots)</th>
<th>Water depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Start time (GMT)</td>
<td>Duration (Hours)</td>
<td>Mean headline height (m)</td>
<td>Mean wingend spread (m)</td>
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<tr>
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<td>3.3</td>
</tr>
<tr>
<td>2</td>
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<td>3.2</td>
</tr>
<tr>
<td>3</td>
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<tr>
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<td>3.2</td>
</tr>
<tr>
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<td>3:00</td>
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<td>3.3</td>
</tr>
<tr>
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<td>3:00</td>
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<tr>
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<tr>
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</tr>
</tbody>
</table>
Figure 1: Commercial net plan

John Noble Discer net
(Fishing circle 400 meshes x 80mm)
Figure 2: Test case: Standard net. SK = side knots, DBL = Double, PE = polyethylene.
**Figure 3:** Test case: 4-panel net

Note: All twine constructed from 4mm single PE (Drawing not to scale)
Figure 4: Diagram of experimental net with square mesh panel (black) with a guiding panel (blue) underneath. Most prawns pass under the guiding panel between its leading edge and the belly netting.
Figure 5: Individual-haul (thin lines) and mean (thick lines) relative catch rates for each species and net. The grey shaded areas are approximate pointwise 95% confidence bands on the mean relative catch rates. Relative catch rates are plotted on a log scale. Fish length is expressed in cm, Nephrops length in mm.
Figure 6. Percentage difference in whiting yield and SSB between standard and 4-panel net due to the adoption of the new gear.

Figure 7: Long term (2013) landings and discards of whiting by the *Nephrops* fleet in VIa assuming a constant fishing effort of all fleets from 2004. 4-panel Net (used from 2005), Standard Net (used from 2004). The population and hence landings and discards are expressed in terms of an abundance index obtained from fisheries surveys.
Figure 8: Long term relative whiting SSBPR and YPR in the *Nephrops* fleet in area VIa. Relative whiting SSB per recruit (SSBPR) a) - - - for 4-panel net, b) - - - - for standard net. Relative whiting yield per recruit (YPR) a) - - - for the 4-panel net, b) - - - - for standard net. Effort Multiplier of the *Nephrops* fleet relative to 2004 for the period studied (2005-2013). Selectivity and fishing effort of the other demersal fleets were assumed to be constant from 2004. The curves are based on the relative catch rate obtained from the mean smooth curves. Yield per recruit and SSB per recruit are based on abundance indices rather than absolute numbers at age.

Figure 9: Whiting Catch Per Unit Effort (CPUE) for the *Nephrops* fleet in the long term (2013) in area VIa, a) - - - using the 4-panel net, and b) - - - - using the standard net. Effort Multiplier of the *Nephrops* fleet is relative to 2004 for the period studied (2004-2013). The 2 curves are based on the relative catch rates obtained from the mean smooth curve. CPUEs are based on abundance indices rather than absolute numbers at age.
**Figure 10:** Possible modifications on the 4-panel section (side view).

**Figure 11:** Possible modifications on leading edge guiding panel
Diagram 1: Stock prediction process

4-panel Net

- Data, proportions retained
- Smooth Curves

Scenario 1:
- => Use of the standard net (2004-2013)
- E = 1
- S'/S = 1

Scenario 2:
- => Use of the 4-panel net (2005-2013)
- E can vary
- S'/S ≠ 1

Catch per component in 2004:
- Nephrops fleet Landing & Discards
- All other fleets Landings & Discards

Total SQ F (2004)

(known from stock assessment)

Standard Net

- Data, proportions retained
- Smooth Curves

Nephrops Fleet

- Smooth Curves

Pred F'

M

Pred F

1st year (2004)

Abundance 2004

% difference (NTR Discards)

Abundance'

% difference

Catch'

% difference

Yield'

% difference

TSB'

% difference

SSB'

% difference

2nd and following years

Square Foot per component

A_{a,y} = A_{a-1,y-1} \cdot e^{(-Z_{a-1,y-1})}

and for the oldest age(s) n :

A_{n,y} = A_{n-1,y-1} \cdot e^{(-Z_{n-1,y-1})} + A_{n,y-1} \cdot e^{(-Z_{n,y-1})}

C_{a,y} = F_{pred,a,y} \cdot A_{a,y} \cdot (1 - e^{-Z_{a,y}})

Y_{a,y} = W_a \cdot C_{a,y}

TSB_{a,y} = W_a \cdot A_{a,y}

SSB_{a,y} = TSB_{a,y} \cdot Mat_{a}

NB: Catch, Yield, Total Stock Biomass and Spawning Stock Biomass are relative to Abundance at age, i.e. they are not based on actual population numbers at age.