The Methodical Introduction of High Strength Netting to the Prawn Trawling Industry in Queensland.

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Australian Government

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Sterling Trawl Gear Services

The Methodical Introduction of High Strength Netting to the Prawn Trawling Industry in Queensland.

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Table of Contents

2008/206 The Methodical Introduction of High Strength Netting to the Prawn Trawling Industry in Queensland

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OBJECTIVES:

1. For commercial netting of 50mm nominal mesh size, measure and compare the dimensional, mechanical and hydrodynamic characteristics:
    a. Measure the relative strength of various netting materials suitable for Qld prawn trawling.
    b. Assess the relative wear resistance of various netting material types.
    c. Conduct a detailed drag and flow study for various materials and trawl construction techniques, using the flume tank.
2. Compare the engineering and catching performance of prawn trawling systems in the field; each configured to be compatible ("optimal") respectively to the five netting types under investigation.

Nontechnical summary:

OUTCOMES ACHIEVED TO DATE

The superior strength features of high-performance netting were confirmed by quantitative load-to-failure tests; while wear resistance tests indicated that the rate of strength reduction during service is likely to be similar for high performance materials compared to traditional material. From the experimental data it is feasible that the tested dyneema netting would have about 2.5 times the service life of the standard PE netting.

Tow resistance tests in the flume tank indicated that large drag reductions occur commensurate with reduced twine diameter, while knot structure also plays a practically-significant role in determining drag. Although the removal of knots (knotless netting) has a relatively small effect of the transverse-projected-area of the netting, there is an emphasised effect on drag for prawn trawls, presumable because of the large effect "going knotless" has on the in-plane projected-area, or roughness, of the netting sheet. Crucially it was found that double-knots have a detrimental effect on drag as they effectively reduce the mesh size of the netting by restricting the lateral opening of the mesh. However , if due account is taken of this process in the selection of "mesh size", by aiming for equivalent selectivity or solidity, then most of the negative drag impact would be removed.

The field work highlighted the highly complex, diverse, and chaotic environment in which the prawn trawling industry operates and how this makes it challenging to introduce new technology. Substantial drag reduction (21%) was demonstrated in the field for the thinnest netting material (twisted Spectra) and the knotless dyneema trawl. It was concluded that a greater drag reduction could have been achieved if still smaller boards were used for the lowest drag trawls.

The catch of target prawns was strong for the low-drag trawls compared to the conventional trawl, and heavily biased towards larger prawns for the trawls made from soft flexible twine. High bycatch retention, particularly immobile benthic material, was a substantial problem for most of the low drag trawls. It is proposed that this was mainly due to the higher spread ratio, which would have occurred for those trawls, causing excessively

low fishing line tension and low fishing line height, and consequently reduced the height of the “trash gap” above the ground-chain. But given the contrasting clean catches for the Spectra trawl, which also happened to be a 4 seam trawl, it was identified in hindsight that this serious practical problem could have been remedied by the common industry practice of letting the headline back relative to the fishing line to increase the strain in the lower panel and fishing line and ensure there was a functional “trash gap”.

For the trawls constructed of soft material, much of the additional retained material became lodged in the netting such that the trawls became very labour intensive to keep operational and presumably increased drag significantly. Further targeted field trials are required to thoroughly understand/document the interactions between high-performance netting materials, the catch of benthic material and bycatch, and appropriate mitigation measures.

Introduction

A logical initiative for improving energy efficiency for prawn trawling is to use high strength netting with smaller diameter twine. A major impediment to this initiative is the substantially higher cost of high strength netting, which can be up to a factor of 8. In the long run though, given that twine diameter can be reduced by 30% with no reduction in twine strength, trawl-system drag and fuel consumption should be reduced substantially and provide a short pay-back period.

Tensile strength and wear resistance

Load-extension curves to failure were obtained for the 5 sellected netting materials across three mesh orientations; standard orientation, T90 orientation and square orientation.

Material type and mesh orientation had a significant effect on the strength of the netting samples. The average load-extension curve for each case, and grouped by mesh orientation, is plotted below in Figure 1.

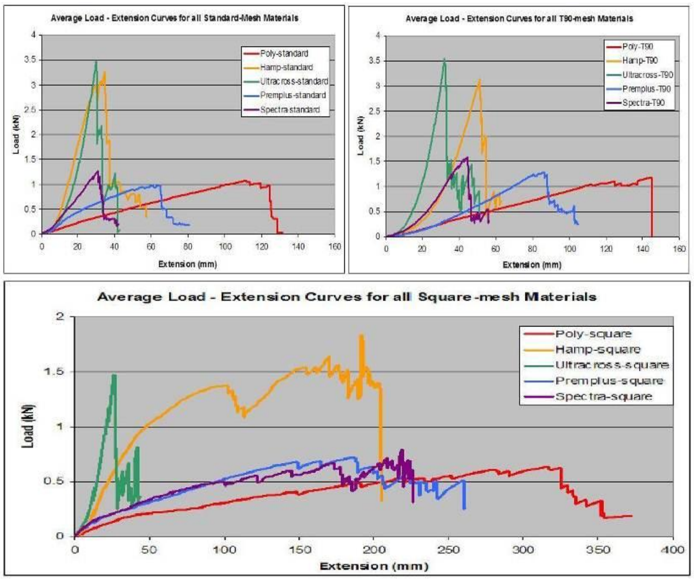

Figure 1: Load-extension curves obtained from various prawn netting materials and different mesh orientation.

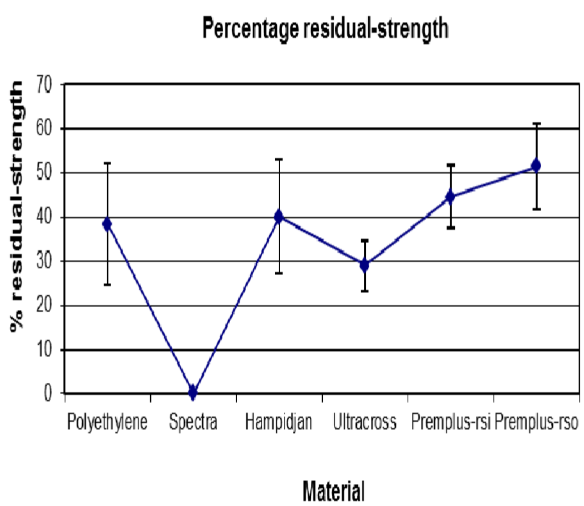

Figure 2: Residual strength after wear treatment as a percentage of original strength.

Despite the reduced twine diameter of the high performance materials, they all had similar or greater strength than the traditional polyethylene netting for the diamond-mesh samples (Standard-mesh and T90). For the Spectra and Euroline materials the strength was about the same as polyethylene, but the mesh strength of the two Dyneema materials (Dynex and Ultracross) were about 3 times higher.

Knot construction had a substantial effect on the strength of the square-mesh samples. The single-knot materials (Polyethylene, Euroline and Spectra) all had similar loading when the knots started to slip and substantial distortion of the meshes started to occur. The double-knotted material (Dynex) was substantially stronger and had a load at knot slippage that was about 3 times higher, while the failure load for Ultracross was 10 times higher than the single-knot cases. For the square-mesh Ultracross there was no distortion of the mesh what-so-ever and the ultimate failure was breakage at the gripping points of the tension machine.

The percentage residual strength for each material after wear treatment is plotted in Figure 2. The wear treatment produced an average strength reduction across the materials of about 60% (40% residual-strength), although the Van Beelen Spectra material, was effectively destroyed by the treatment and had zero residual strength. The Spectra material was supplied in the late 90's for the work by Lowe (1997) and has been replaced by a superior product.

There was little significant difference in % residual-strength for the five cases other than Spectra. Euroline Premium Plus appeared to have the greatest % residual-strength, while the Ultracross material had the lowest observed wear resistance. Despite the observed lower % residual-strength of the worn Ultracross material, it was still as strong as new polyethylene, in absolute terms, because of the very high initial strength of the Dyneema products.

Hydrodynamic drag

The tow resistance tests in the flume tank indicated that large drag reductions occur commensurate with reduced twine diameter, while knot structure also plays a practically-significant role in determining drag.

Compared to the standard industry material (24ply PE), all the trawls constructed of thinner high strength material had significantly less drag, except for the T90 Hampidjan Dynex case. The T90 Hampidjan test exhibited a 12% higher drag than the standard PE material, while the standard-mesh Hampidjan trawl had 18% less drag, the Ultracross trawl had 31% less drag and the Euroline trawl had 9% less drag.

Although the removal of knots (knotless netting) has a relatively small effect of the transverse-projected-area of the netting, there is an emphasised effect on drag for prawn trawls, presumable because of the large effect "going knotless" has on the in-plane projected-area, or roughness, of the netting sheet.

Crucially it was found that double-knots have a detrimental effect on drag as they effectively reduce the mesh size of the netting by restricting the lateral opening of the mesh. However , if due account is taken of this process in the selection of "mesh size", by aiming for equivalent area of mesh opening, then most of the negative drag impact would be removed.

There was no conclusive drag difference for Euroline Premium Plus trawls with a "Rough side out" knot arrangement as opposed to "Rough side in".

Field work outcomes

The assessment of high performance netting materials in the field involved collecting data from two rounds of field trials conducted with five highly standardised trawl-nets constructed from the netting materials under investigation.

Engineering performance

Trials to compare engineering performance (spread and drag) and obtain underwater video footage were undertaken over five days using a 15m commercial trawler. The five standardised trawls were streamed two at a time in double-rig configuration. Three pair of Kilfoil otter boards of three different sizes were used to spread the trawls.

The drag and spread results for the 15 trawl/otter-board combinations showed a clear consistent effect of netting type and otter board on drag. However, the effect of netting and otter board on spread was not clear, and this made it difficult to distinguish the interacting effects of the low drag trawls and otter board size on performance.

Figure 3 shows the predicted relative performance for selected combinations of trawls and boards such that spread was standardised as closely as possible, based on statistically determined trends in the data. The maximum demonstrated drag reduction was 22% for the Ultracross and Spectra trawls. However the spread of these trawls is still determined to be 2.5% higher than the PE trawl and a greater drag reduction would be feasible if smaller boards were used on the low drag trawls to give exactly matching spreads across all cases.

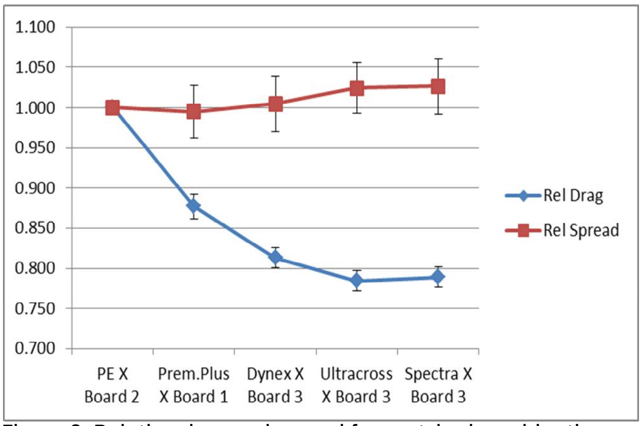

Figure 3: Relative drag and spread for matched combinations of gear.

Catching performance

Five-rig was used during catch trials so that all five test trawls could be towed simultaneously. The location of each trawl in the rig was randomly rearranged 8 times.

The high performance trawls , except the Spectra trawl, generally caught more prawn than the standard PE trawl. The prawn catch for Ultracross and Spectra trawls was also strongly biased towards larger prawns, presumably because the small twine diameter causes the size of the mesh opening to be somewhat larger, combined with the soft flexibility of the twine allowing small prawns to escape more freely. Less flow resistance could also promote the free movement of the trawl through the water and the associated reduced disturbance of the water might promote the capture of large fast swimming prawns.

The generally low prawn catching performance for the Spectra trawl is hypothesised to be due to its 4-seam construction and the relatively low number of meshes in the height of the wingend, which plausibly has caused it to have a higher fishing line height and possibly lighter ground chain contact, although this was not detected as a problem during the video observations.

The high performance trawls, other than Spectra, also generally caught disappointingly large amounts of unwanted fish, crabs, and benthic material compared to the PE trawl. It is hypothesised that this was due to very low fishing line tension caused by a higher operating spread ratio for those trawls, and that this could have been mitigated by increasing the length of the headline sweeps a few centimetres relative to the fishing line sweeps. For the Dynex trawl and the Ultracross trawl it is essential for commercial viability that this strategy delivers the intended reduction in bycatch as it was quite a burden to sort their catches. Additionally, the trawls with soft material were very difficult to clear of lodged benthic material, particularly starfish.

The unresolved question is how much the target prawn catch would be reduced in the process of letting the headline back to achieve cleaner catches. It is feasible that the target prawn catch might not be reduced substantially because it is more reactive to the trawl compared to the immobile benthic material, however the lower prawn catches observed for the spectra trawl does suggest that a strong negative affect on prawn catch is a possibility.

KEYWORDS: dyneema, spectra, netting, trawl, prawn, efficiency, Australia

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- Mike Soady for his valuable advice and assistance with the design and construction of trawls.
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- Rowan Frost and Giles Thomas for excellent service in managing the flexible availability of the flume tank for the project and to Alan Faulkner for his very capable preparation of the tank for the work, and the smooth operation of procedures during the tests.
- Cheslav Balash for his professional approach to data collection and management in the flume tank, and valuable assistance to the project by way of providing additional data from parallel AMC tank tests, expert input to various aspects of the analysis, and collaboration on the interpretation and description of the results.

The work conducted in the flume tank involved the utilisation of sophisticated facilities and a high standard of staff support to achieve results well beyond expectation. The tank's high technical standard is no doubt due to the large amount of work John Wakeford has applied to tank development over the last decade or so, and particularly since the damaging fire that occurred during 2008.

Finally the author would like to acknowledge and thank the owner/skipper (Tony Sterling) and crew of the Qld East coast trawler, FV Cking, for their dedicated input during the vessel charters and field work.

The project was supported by funding from the FRDC on behalf of the Australian Government.

Background

Prawn fisheries around Australia comprise fuel intensive enterprises currently stressed financially by rising diesel costs. An avenue for relieving the situation is to improve the energy efficiency of trawling by raising the productivity of fishing for each litre of fuel consumed.

The netting part of the prawn trawl is responsible on average for 2/3 of the total drag during a trawling operation, and hence retains a great potential for drag force reduction (Figure 1).

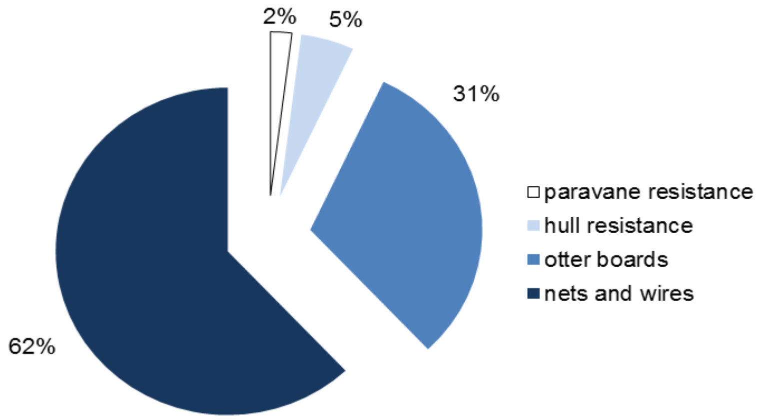


Figure 1: Resistance components of a 22m Success class trawler operating at 3 knots with double-rigged 16 fathom nets. (FRDC 2005)

High strength netting could provide a positive outcome in this area. Ultra High Molecular Weight Polyethylene (UHMWPE), Dyneema and Spectra, share very similar properties and end-use. Such twines have a higher breaking strength than that of steel wire of the same thickness, but have only one-tenth the weight. These twines have good UV, seawater, abrasion, cutting and fatigue resistances. With their low specific gravity, they also float. Netting made of this material has been specifically developed for use in trawling.

R&D to implement Spectra and Dyneema netting into trawls has been occurring around the world for more than two decades (LCES 1992, SECO 2010). In Australia some fishermen experimented early on with these materials but with little success and returned mixed responses. There appeared to be no argument regarding the material's strength and durability and its low drag nature when trawls are constructed of thinner twine (usually reduced by about 40% for this material). However, there were numerous anecdotal reports of very negative effects on the shooting performance of the connected otter boards, difficulties with the netting becoming fouled with bycatch, and unfavourable differences in the way the material "behaves". This negativity in conjunction with the high cost of the material (about 8 times more expensive) has resulted in very limited uptake throughout Australia at that time.

Since 2009 there has been increased adoption of a range of reduced diameter materials by the Australian prawn trawling industry. Success is now being experienced by quite a few fishermen.

The high initial cost of the material is a substantial barrier to industry adoption. To remove this barrier the industry needs to be clearly informed of the correct approach to utilising the material and successfully reassured that the outcomes will easily justify the initial additional expense.

Need

Australian commercial fishers are facing a very challenging future, with the prospect of further price rises in petroleum-based fuel, combined with a domestic oil deficit predicted to emerge past 2015, and a global need to reduce greenhouse gas emissions. The Australian fishing industry is seeking ways to improve the energy efficiency of its operations and to find viable alternative energy sources.

Fishing with trawl gear expends more fuel per kg of fish landed compared to passive methods such as longlining and trap fishing. In all cases however, rising fuel prices impinge on the profitability of the operations, and ultimately put their viability in jeopardy; this has reached a critical situation for many trawl operators in Australia.

This project to investigate implementation of high strength netting and demonstrate the positive outcomes for the prawn trawling industry has the intention of reducing the fuel used by fishing enterprises and shift the industry towards a more economically viable and environmentally sustainable position.

This project aims to cover the outstanding R&D challenges in the use of high strength netting through documenting the important knowledge that has been accumulated by fishers who have had success using these materials, conducting field trials with optimal gear to establish the maximum benefit for the industry, and perfect the procedures required for successful implementation of high strength netting into prawn trawling.

The principle initiative of the project was to achieve optimal matching of the otter boards to the low drag trawls, as this should control the most commonly reported problems, which are shooting away difficulties and little drag benefit.

This contributes to the R&D plans and strategies of all advisory bodies to the FRDC, since they contain high priority goals to achieve FRDC's planned outcome for Industry Development, that: "The commercial sector of the Australian fishing industry is profitable, internationally competitive and socially resilient".

Objectives

1. For commercial netting of 50mm nominal mesh size, measure and compare the dimensional, mechanical and hydrodynamic characteristics:
    a. Measure the relative strength of various netting materials suitable for Qld prawn trawling.
    b. Assess the relative wear resistance of various netting material types.
    c. Conduct a detailed drag and flow study for various materials and trawl construction techniques, using the flume tank.
2. Compare the engineering and catching performance of prawn trawling systems in the field; each configured to be compatible ("optimal") respectively to the five netting types under investigation.

Objective 1(a). The relative strength of various netting materials suitable for Qld prawn trawling

The first objective of the project is to quantitatively measure the tensile load bearing characteristics of relevant netting materials. This report-section covers the results of that task for 5 important netting types suitable for prawn trawling in Australia. Subsequent to the formal experimentation attention was drawn to a new material on the market. No doubt new entrants in the market will continue to occur, so a robust Tug-of War methodology was devised so that new materials can be qualitatively compared for strength with materials of known strength-performance. This methodology and some associated results are also reported in this section

The orientation of the netting used in a trawl involves a number of choices. Firstly, the netting can be either diamond or square-mesh orientation, but within diamond-mesh the netting can be either one of two different orientations that are 90 degrees apart; Standard-mesh or T90-mesh. Square mesh is a netting orientation at 45 degrees, or at the midpoint between Standard-mesh and T90. Given the wide variety of netting constructions, their relative performances may easily vary depending on mesh orientation. The wide scope of this study, which includes tensile load testing for all three orientations, allows a more detailed determination of these relative "performances" and helps define optimum use of each netting material.

Methodology

The netting materials tested for strength characteristics were:

1. Polyethylene twisted (control)
2. Van Beelen Spectra
3. Hampidjan Dynex
4. Ultracross Dyneema
5. Euroline Premium Plus

Figure 2 and Table 1 give the construction details and specifications of the materials.

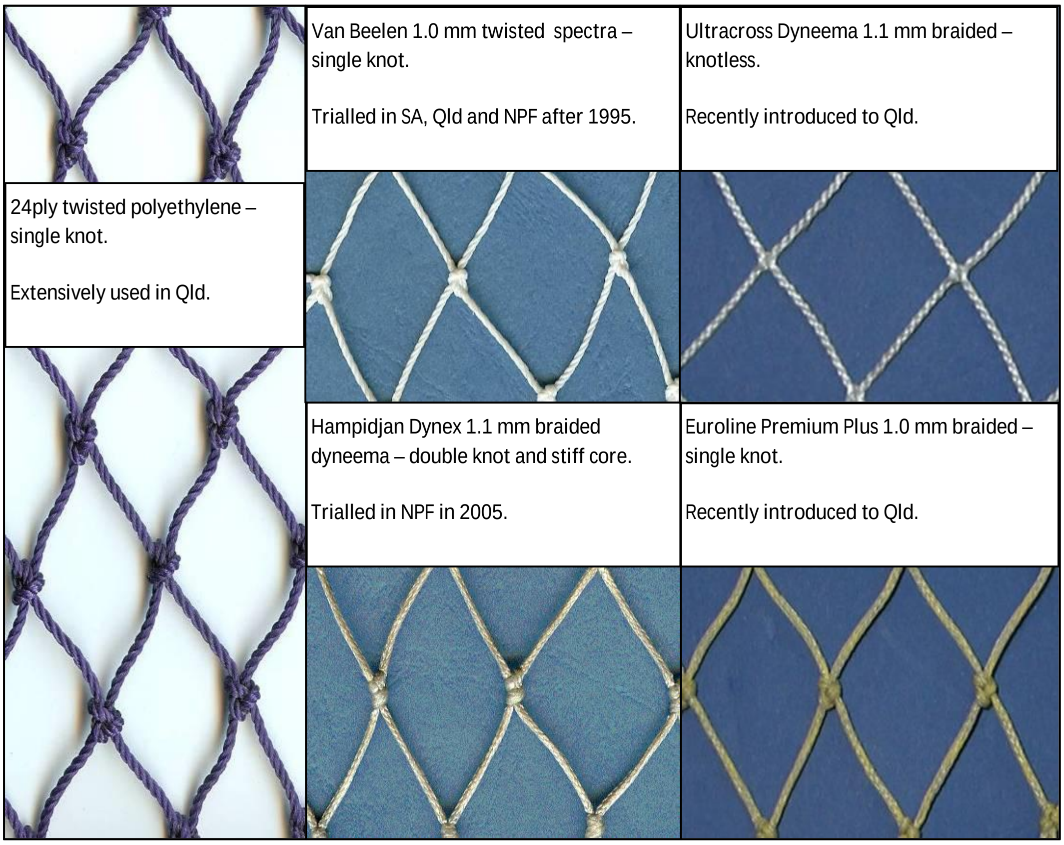


Figure 2: Pictures of the netting types tested – contemporary polyethylene (left) and high strength materials (centre and right).

Table 1: Description and specification of the netting types tested.

Retail name	Construction Labelled description	Measured twine diameter (mm)	Measured centre of knot stretched mesh size Longitudinal X lateral (mm)	Measured knot size Longitudinal X lateral (mm)	Comment
C.F.S. 24ply Polyethylene	400 denier twisted 24 ply single knot	1.68	51.0 X 49.7	6.8 X 5.1	Netting typically used by industry
Van Beelen Spectra	1.0mm twisted single knot	1.1	53.7 X 51.95	3.5 X 3.1	Trialled by Lowe and Moisel during 90's
Hampidjan Dynex	1.0mm braided double knotted	1.26	51.0 X 42.2	7.0 X 3.3	Latest product with double knot and stiffness core
Ultracross Dyneema	1.1mm braided knotless	1.28	51.0 X 51.0	0 X 0	Strong uptake promoted by Soady
Euroline Premium Plus	1.0mm braided single knot	1.40	52.5 X 49.5	6.6 X 4.4	Cheaper high strength netting

Testing covered three orientations of the netting mesh relative to the applied tension load:

1. Standard-mesh orientation
2. T90 orientation
3. Square-mesh orientation

For each orientation of meshes, all netting samples had the same shape and the same number of meshes within the sample. For Standard-mesh and T90 the samples had the same dimensions of 6 meshes by 6 points with necking down to 3 'meshes' at the midpoint as shown in Figure 3. The dimensions of the square-mesh samples was different, four bars by 12 bars with no necking, as also shown in Figure 3.

(a) Standard-mesh (b) T90 (c) Square-mesh

Figure 3: The shape of netting samples for the three mesh-orientations tested.

Three replicate tests were generally conducted for each case to give a more robust indication of material strength and its variability. Three were considered sufficient for the practical purposes of the investigation and further replicates could be undertaken if unanswered research questions required greater experimental resolution. All samples were soaked in salt water for 17hrs before tensile testing. The tensile testing machine used was an Instron 5584 controlled by a series IX automated materials testing system. This equipment was housed at the University of Queensland and operated by the staff of UQ Materials Performance. The equipment setup is shown in Figure 4. Each sample was stretched at a rate of 25mm/min to the point of parting, while load and extension measurements were logged at a sample rate of 10 readings/sec.

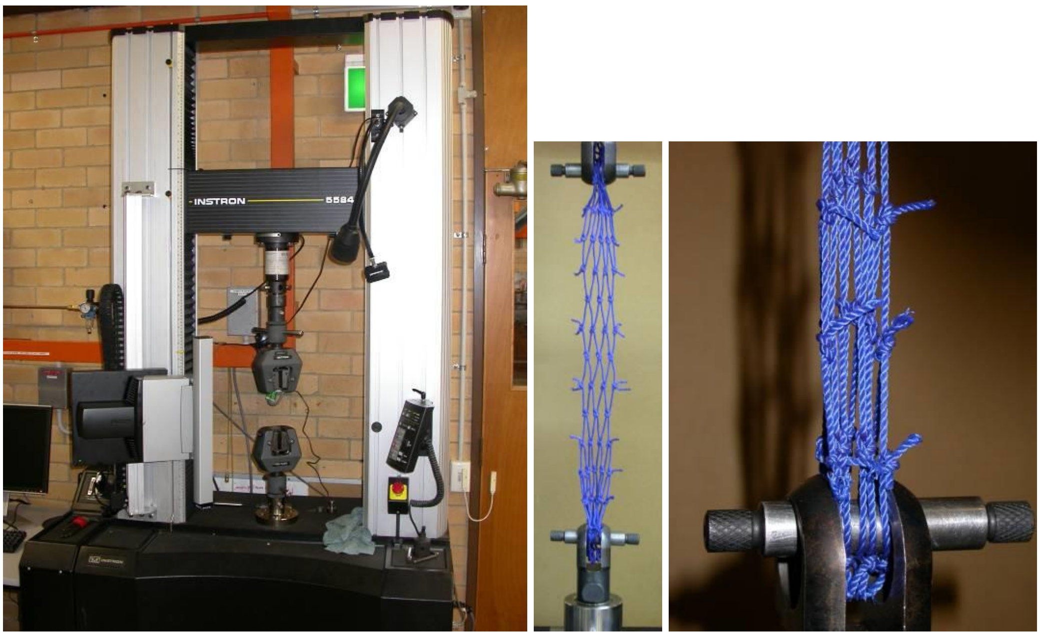


Figure 4: Pictures of the utilised Instron tensile testing machine and a polyethylene netting sample loaded for testing in the machine.

Analysis of the data comprised of calculating the average tension "resistance" across all samples in each case for each applied extension. Zero extension was set for all samples at the point where the load reached a standard value of 10N. A standardised load-extension curve was produced for each test and an average curve for each case.

The point of failure for each test was deemed the point where the sample was damaged such that it would no longer be functional within a trawl, according to the objective criteria outlined below. The load occurring at failure was recorded as the failure load. The median failure load across the samples in each case was recorded as the failure load performance indicator for each respective case.

For the Standard-mesh and T90-mesh samples, the failure load corresponded to the maximum load the samples sustained.

For the square-mesh samples, the failure load was not the maximum load the specimen sustained during the tension test because the maximum load occurred well after the sample had been effectively destroyed by gross mesh distortion. In these cases, a standardised measure of failure load was determined by a methodology based on inspecting the slope of the associated average load-extension curves. This was designed to indicate the load at which the knots in the square-mesh samples started to slip. Once knot slippage occurred the tension resistance of the samples still increased, but at a lesser rate. Figure 5 shows the standardised methodology applied to the 24ply polyethylene square-mesh case and Figure 6 shows polyethylene samples before and after being taken to this nominated failure condition. All knotted materials had the same load-extension characteristics for their square-mesh tests, which allowed the failure load methodology to be applied in a standard way across such cases.

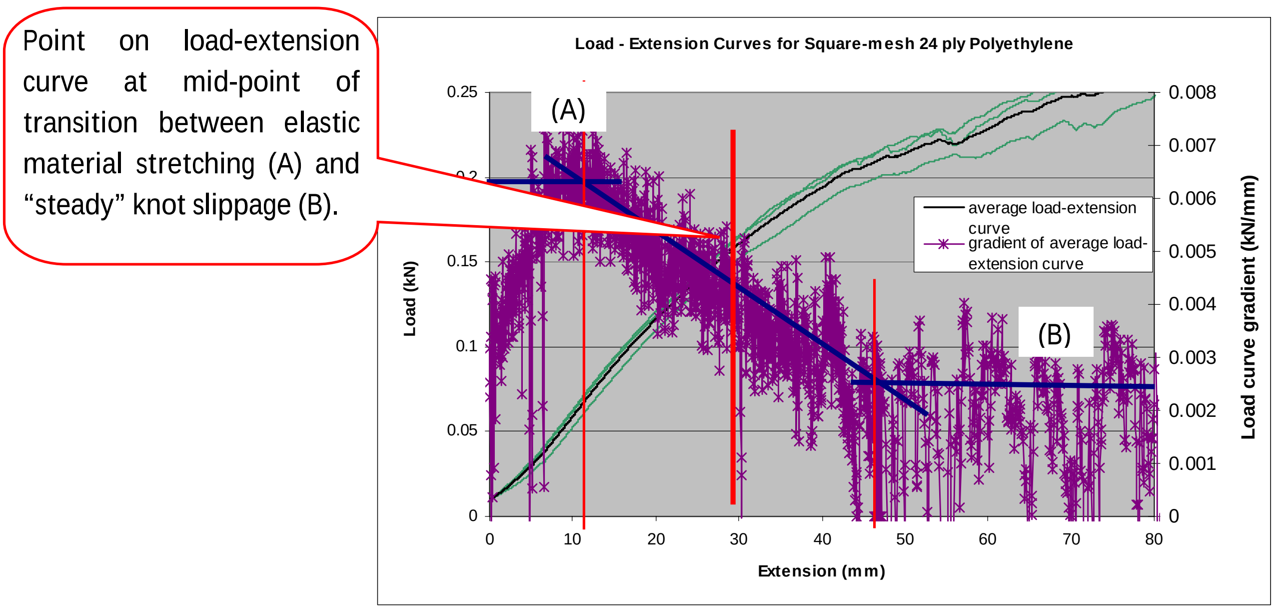


Figure 5: A graphical presentation of the methodology used to provide a standardised failure load for square-mesh cases. The failure load is deemed the load occurring at the midpoint in the transition between regions (A) and (B) of the extension curve. The regions of interest are best identified by graphing the gradient of the load extension curve.

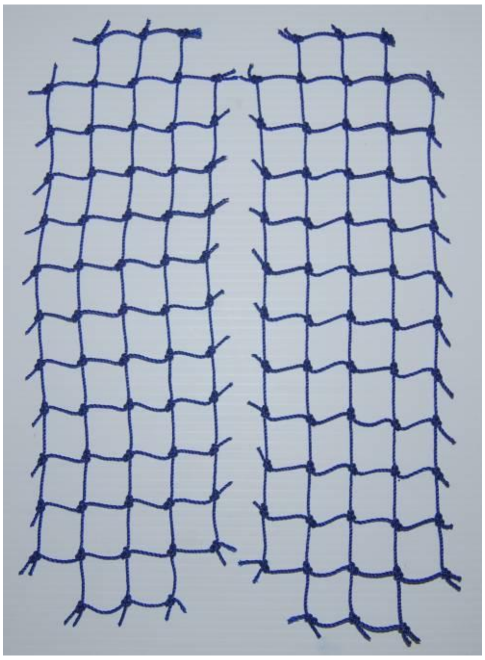


Figure 6: A picture showing samples of square mesh netting before (left) and after (right) being stretched to the nominated "failure" extension. The permanent distortion of the stretched netting sample is about 5mm over its entire length.

For the purposes of the investigation, it was not necessary to undertake significance testing of the conclusions. The equipment used in the tests provided measurements of load and extension at failure with an error far less than 10%, therefore easily indicating the minimum difference in material performance of practical relevance. The main source of variation in the results must come from inter-sample variation of material and construction properties. Manufacturing standards for the different materials are such that this should produce a variation in failure characteristics across samples of less than 10%. Differences in the performance of samples of greater than 10% are of practical significance to the fishing industry and are attributed to the specifications of the associated netting materials.

Results

The load-extension curve for each test is provided below, grouped by material-type X mesh-orientation (Figure 7 - Figure 11). For each material type, the respective figure also shows the average load extension curve for each mesh-orientation and these are also plotted on a summary graph.

Figure 12 provides a graphical summary covering all material types, with average load-extension curves for each case grouped by the three mesh-orientation conditions.

24ply Polyethylene

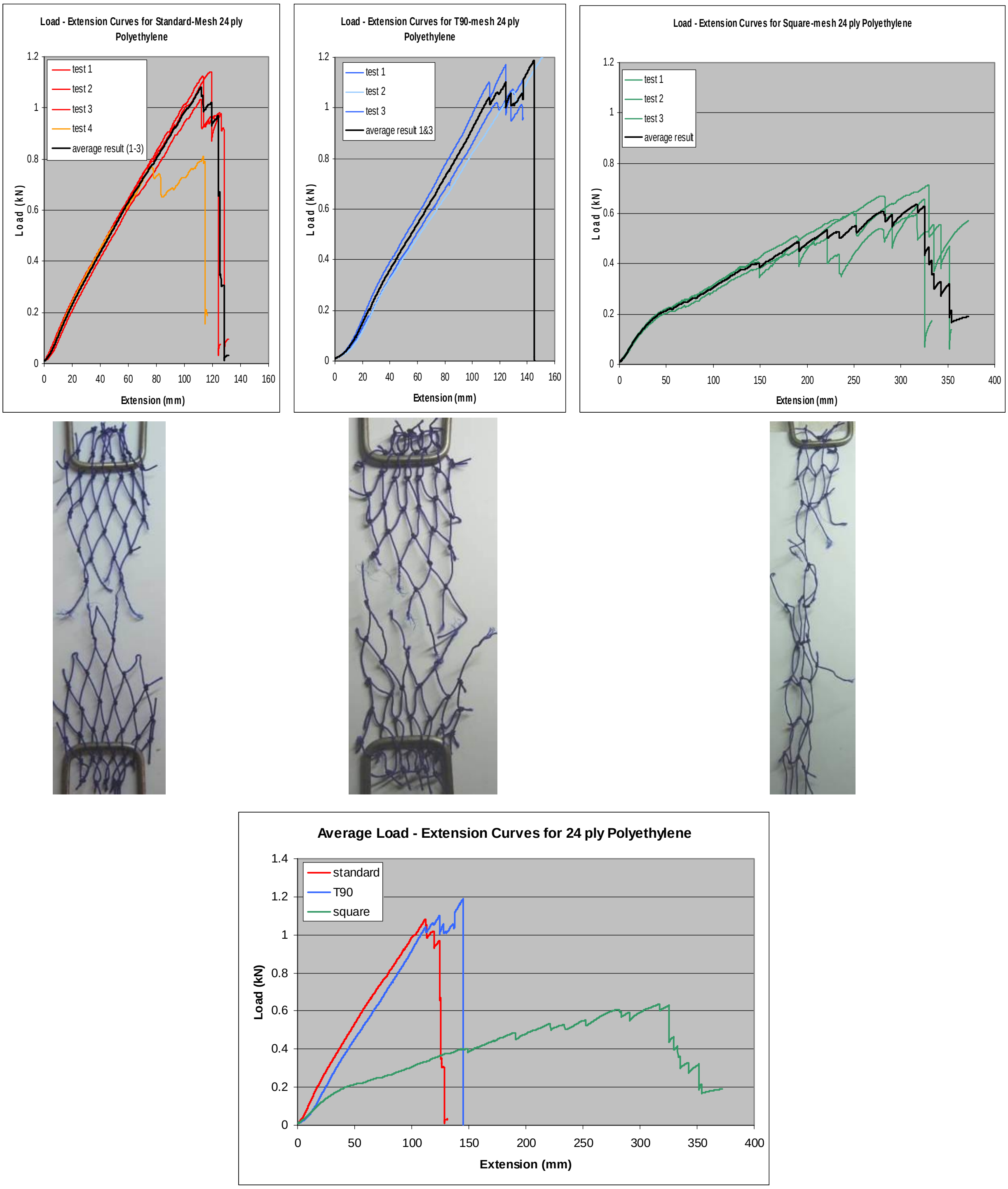


Figure 7: Measured and average load-extension curves for the tested Polyethylene samples and pictures of a typical failed specimen for each mesh-orientation.

Test 4 of the Standard-mesh case failed prematurely compared to the other 3 netting samples. The T90 samples seemed to have a “soft” start to their load-extension curves compared to Standard mesh and went on to support 5% higher load at 19% higher extension. The ultimate load supported by the square-mesh samples was only about half that of the diamond-mesh samples, but the load supported before significant mesh distortion occurred was only about 15% of the failure load for diamond-mesh.

Van Beelen Spectra

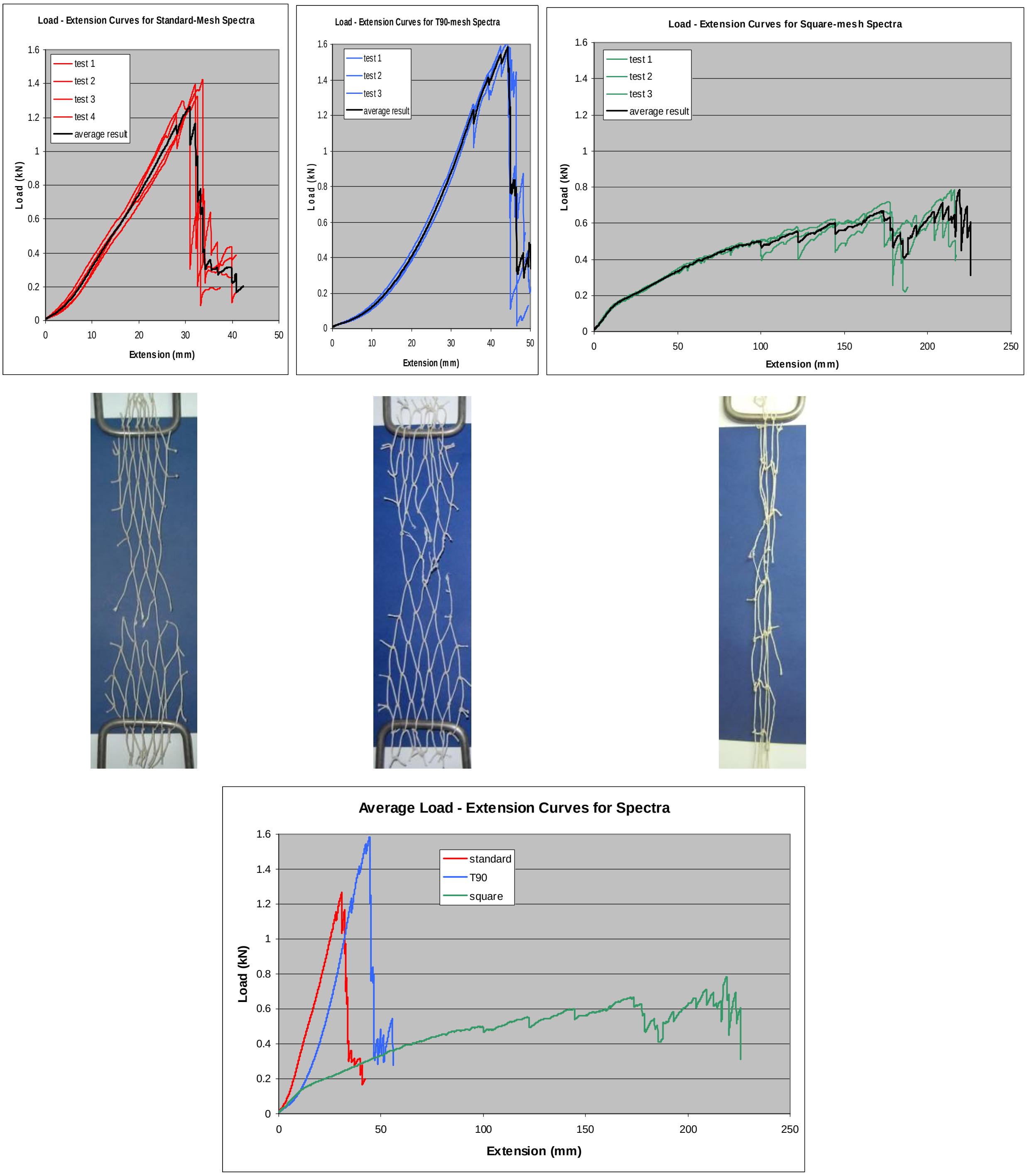


Figure 8: Measured and average load-extension curves for the Spectra samples and pictures of a typical failed specimen for each mesh-orientation.

The T90 samples had low resistance to extension (were soft) at the start of loading, but supported an 18% higher failure load than the Standard-mesh samples. The square-mesh samples failed, due to knot slippage, at about 10% of the failure load for the diamond-mesh cases.

Hampidjan Dynex

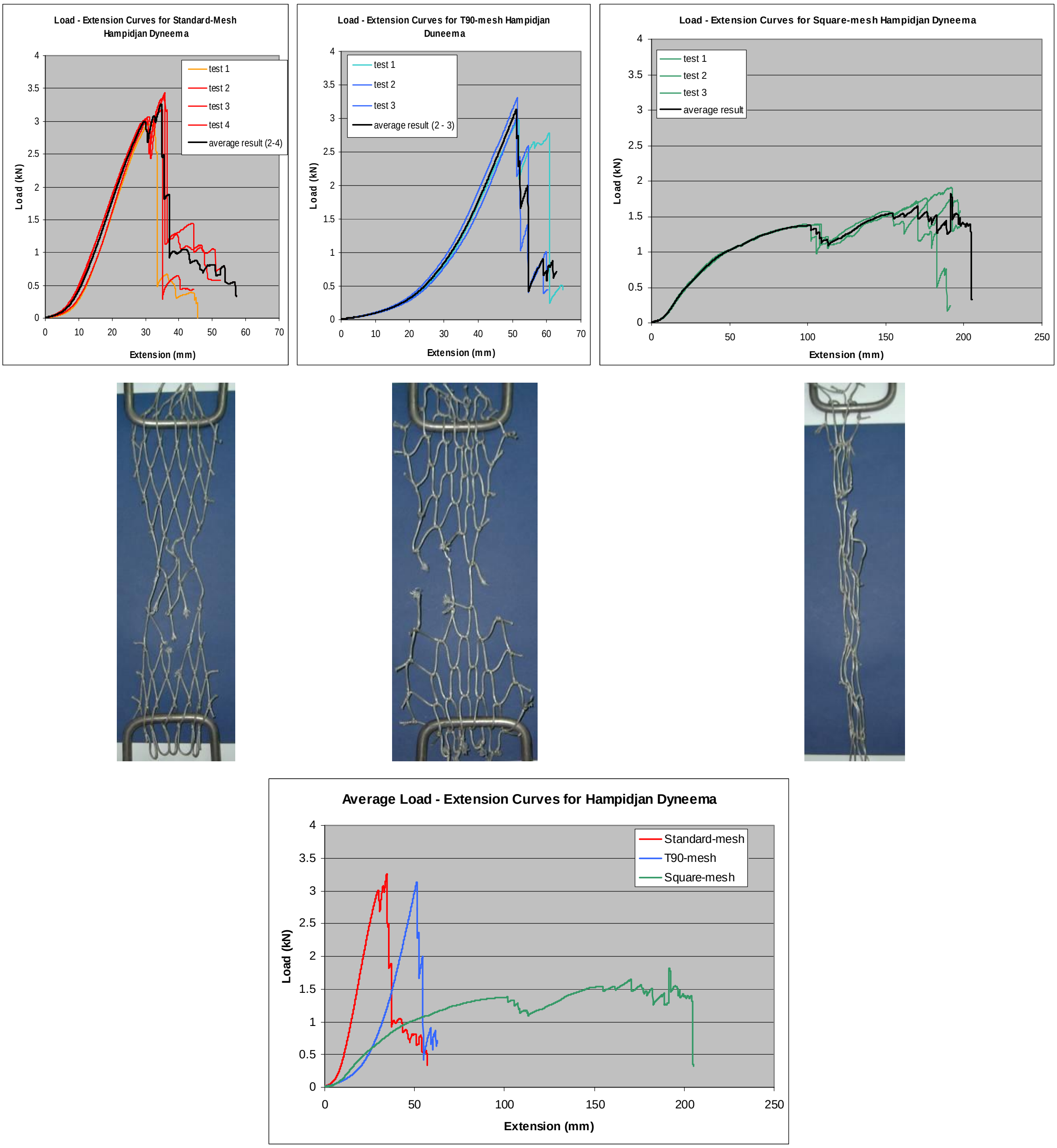


Figure 9: Measured and average load-extension curves for the Hampidjan Dynex samples and pictures of a typical failed specimen for each mesh-orientation.

All samples had a fairly soft start to their load-extension curves. For this material the T90 samples did not seem to have a higher failure load compared to Standard-mesh. Inspection of the Standard-mesh specimens after failure (example shown above) revealed that for the first time the bars down the edge of the specimen had not parted, presumably due to the higher resistance of double knots to knot slip. It seems that the existence of the double knot has changed the failure mechanism for the Standard-mesh samples of this material and most likely caused an increase in failure load. In absolute terms, the failure load for the square-mesh samples was about 3 times higher than for the previous knotted materials and the latter knotted materials below; all of which had single knots.

Ultracross Dyneema

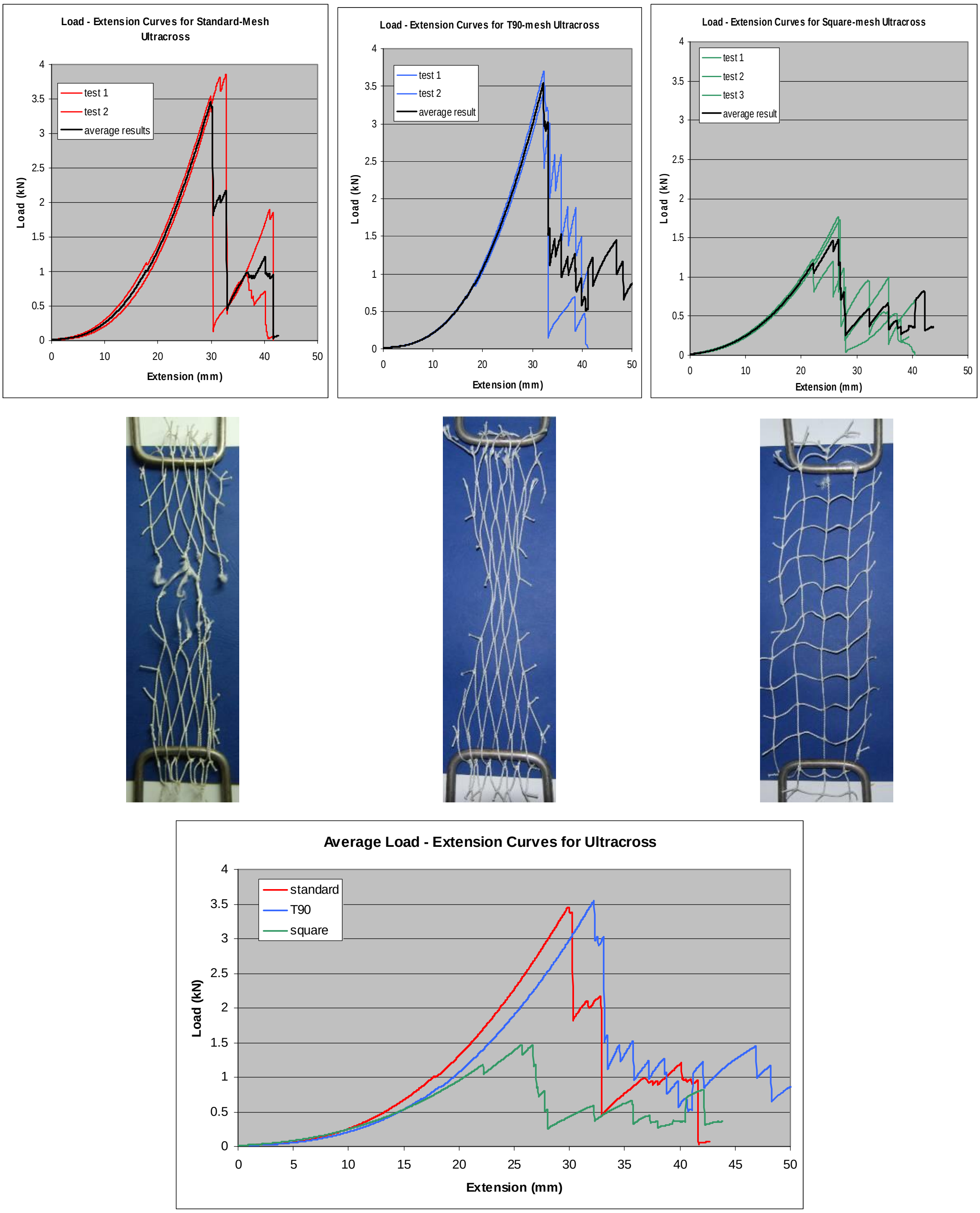


Figure 10: Measured and average load-extension curves for the Ultracross Dyneema samples and pictures of a typical failed specimen for each mesh-orientation.

Ultracross material has no knots. Due to the construction method, Standard-mesh and T90-mesh samples are identical in physical appearance and this carried across to their load extension curves, which are very similar. Without knots, the strength of the material does not suffer from stress concentration and associated weakness at knots. Six of the seven Ultracross test samples failed at the grip point rather than through the midpoint of the sample. The only sample that broke at the midpoint is shown above for the Standard-mesh result. The other Standard-mesh sample failed in the same manner as the two T90 samples, which was as pictured above for that case. The Square-mesh samples did not incur mesh distortion and failed at the grip at a very high load compared to the other Square-mesh cases, including the double-knotted Hampidjan case.

Euroline Premium Plus

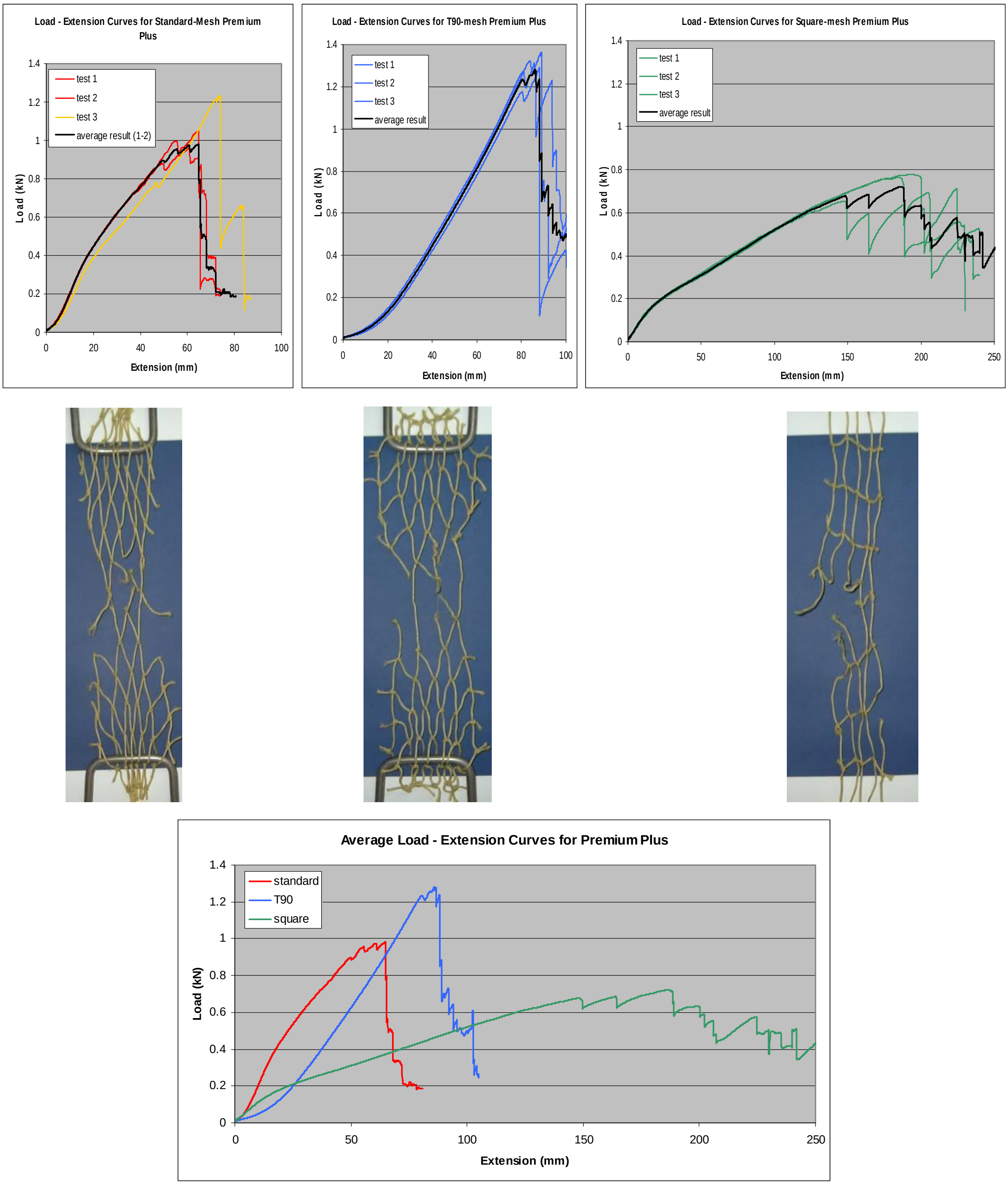
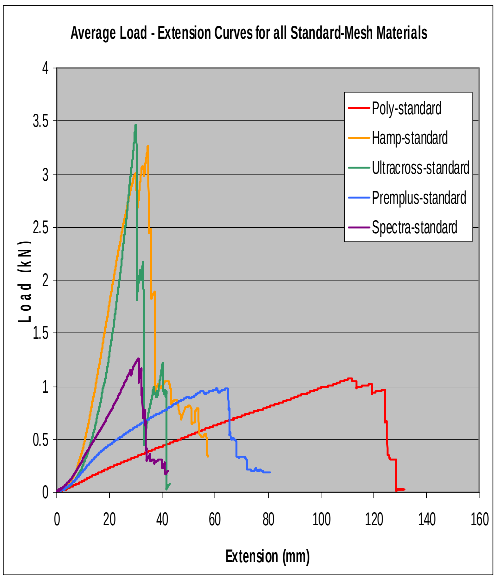


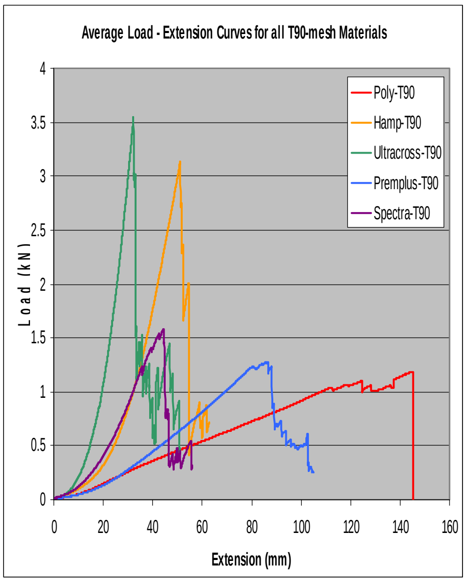
Figure 11: Measured and average load-extension curves for the Euroline Premium Plus samples and pictures of a typical failed specimen for each mesh-orientation.

The results for Euroline Premium Plus are typical of a single knot construction. The T90 samples had 30% greater failure load than Standard-mesh and the Square-mesh samples suffered large mesh distortion at low load. Test 3 of the Standard-mesh case displayed an outlying load-extension curve. On closer inspection it was found that the sample had been incorrectly cut such that it was reduced in width on one side only. The displayed curve has load scaled down inversely with the greater width of the failure cross-section, but nevertheless the maximum mesh loading is greater than for the standard samples. This reinforces the hypothesis that “necking” the Standard-mesh samples adversely weakens them by allowing a large amount of load induced mesh distortion at the failure cross-section and giving additional adverse load concentration for materials with low knot stability.

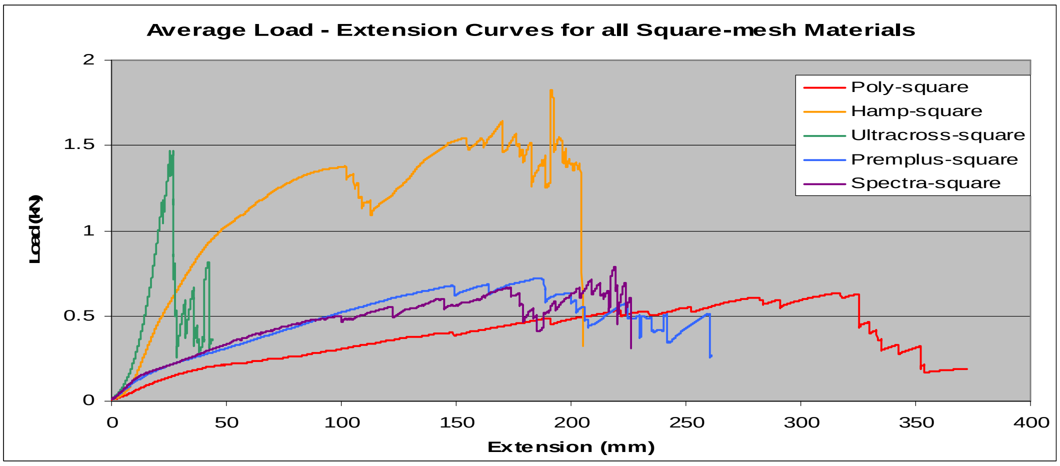
Relative performance between material types



(A)



(B)



(C)

Figure 12: Average load-extension curves obtained from the tested netting materials for three different mesh-orientations: (A) Standard-mesh, (B) T90-mesh, and (C) Square-mesh.

Despite the reduced twine diameter of the high performance materials, they all had similar or greater strength than the traditional polyethylene netting for the diamond-mesh samples (Standard-mesh and T90). For the Spectra and Euroline (Premplus) materials the strength was about the same as polyethylene (Poly), but the mesh strength of the two dyneema materials (Hamp and Ultracross) were still about 3 times higher.

Knot construction had a substantial effect on the strength of the Square-mesh cases. The single knot materials (Poly, Premplus and Spectra) all had similar load extension curves. The double-knotted material (Hamp) was substantially stronger and had a failure load (at knot slippage) that was about 3 times higher, while the failure load for the knotless Square-mesh material (Ultracross) was 10 times higher than the single-knot cases

Conclusions

The load-extension curves within each case had a low degree of variability (see Figure 7 - Figure 11). Of the 46 netting samples tested to destruction, only four gave results that were considered outliers. Those load extension curves are included in the displayed results, but were not used in the calculation of the “average” curves for the respective cases.

There was a large degree of variation in the average load–extension curves between cases, clearly indicating that both material type and mesh orientation had a significant effect on the strength of the netting samples. Table 2 summarises the median failure load and extension for the different cases. The results for the high performance materials are also expressed as a percentage of the respective 24ply polyethylene result.

Table 2: Median failure load and extension for the different cases

Netting Type Commercial brand	Standard-mesh Failure Load (kN)	Standard-mesh Extension at Failure (mm)	T90 Failure Load (kN)	T90 Extension at Failure (mm)	Square-mesh Failure Load (kN)	Square-mesh Extension at failure (mm)
C.F.S. Polyethylene 400den 24ply	1.12	113	1.18	135	0.155	29
Van Beelen Spectra 1.0mm	1.34 (120%)	32 (28%)	1.58 (134%)	45 (33%)	0.14 (90%)	11 (38%)
Hampidjan Dynex 1.0mm	3.39 (303%)	35 (31%)	3.13 (265%)	51 (38%)	0.45 (290%)	20 (69%)
Ultracross Dyneema 1.1mm	3.7 (330%)	32 (28%)	3.55 (301%)	32 (24%)	1.47 (948%)	26 (90%)
Euroline Premium Plus 1.0mm	1.00 (89%)	63 (56%)	1.31 (111%)	86 (64%)	0.15 (97%)	15 (52%)

The major factor driving the diversity of strength results is the relative yield stress associated with the different twine materials. Despite the reduced twine diameter of the high performance materials, they all still maintained similar or greater netting strength than the traditional polyethylene netting for the diamond-mesh samples. For the Spectra and Euroline materials, the displayed netting strength was about the same as for polyethylene, but the netting strength of the two dyneema materials was about 3 times higher. The Ultracross dyneema samples were particularly strong considering that the results might not have displayed fully their ultimate load carrying capacity because most of the samples failed due to load concentration at the grips. Close inspection of the samples however did indicate that strength at the edges of the samples heavily relied on well-executed (sealed) hot knife cuts - edges cut with scissors would come apart very easily.

Knot construction also had a significant effect on the measured strength characteristics of the samples. This was particularly the case for the Square-mesh cases, where the single-knot materials failed at very low load. The double-knot material fared somewhat better (3 X the failure load), and the Ultracross knotless Dyneema was by far the strongest (10 X higher). The Ultracross material had no distortion of the meshes whatsoever and failure occurred prematurely at the grips before the samples displayed their true maximum load carrying capacity.

It is apparent that knot construction also had an effect on the displayed strength of the Standard-mesh samples. The failure mechanism for the single-knotted Standard-mesh samples was one where distortion along the all bar edges of the samples caused further concentration of the load onto the centre mesh of the sample and a somewhat premature failure at that point. For the double-knotted Hampidjan samples, the edges offered more resistance to sample extension and presumably raised the failure load to be somewhat similar to the T90 case. The same was the situation for the knotless samples, where there was no distortion at all along the bars and the strain distribution within the Standard-mesh samples became identical to the T90 samples.

Given the confounding effect of knot stability on the load carrying capacity of the Standard-mesh samples, it can be concluded that the best indication of the practical strength of the different materials for use in the body of trawls is the T90 results, irrespective of the intended diamond-mesh orientation. It is not possible to conclude, for the single-knotted materials tested, that the netting is stronger in T90-mesh orientation compared to Standard-mesh orientation. It is quite likely that the apparent difference in strength shown in the results is due to the poor performance of the test specimen to hold a uniform distribution of applied load across the failure cross-section. Unfortunately, it appears to vary depending on the knot stability of the material. This is not the case for the T90 samples, where the distortion of the test specimen under load does not affect the distribution of load across the failure cross-section.

The square-mesh results give a good indication of the strength of the different materials with respect to applications where the bars are aligned with the principle stress direction. This occurs for square mesh codends, trawls that are hung on the bar (e.g. Siebenhausen), or trawls with “dog ears” (e.g. WA Flat trawl). As mentioned above the double-knot material showed a marked increase in knot slip resistance, but this was dwarfed by the mesh stability and overall strength of the knotless material in this mode of use.

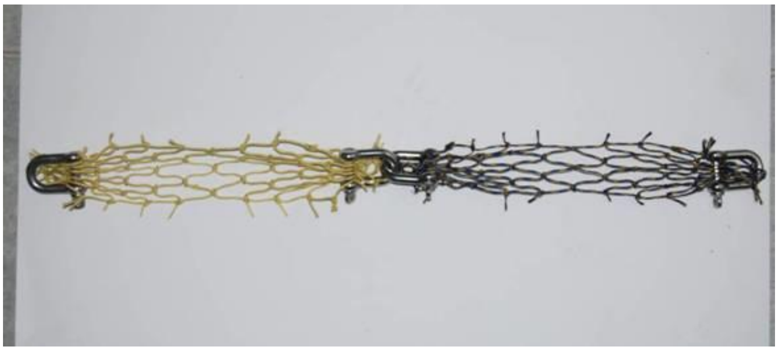
Tug-of-War methodology and relative strength results for Sapphire **V** Euroline Premium Plus

As part of the project enquiries were continually being made to netting suppliers for information on new netting products entering the market. This was to ensure the project covered the full range of opportunities for the Australian prawn trawling industry to utilise high performance netting materials to cost effectively increase fuel efficiency. Enquiries made to a leading netting supplier in the USA produced a range of samples for material that were becoming popular, because of good results, in prawn fisheries in North and South America. The netting samples supplied were a “Sapphire” brand and were knotted-braid materials specified as 1.0mm and 1.2mm twine diameter. The measured twine diameter of the 1.0mm sapphire material was about 0.1mm thinner than the 1.0mm Euroline Premium Plus and the published specs indicated that for a given spec diameter, Sapphire is about 15-20% stronger.

To establish whether the Sapphire brand material was a superior product to Euroline Premium Plus and if it should be fully assessed by the project’s material assessment program, the samples were subjected to a simplified strength comparison with the 1.0mm Euroline Premium Plus material.

The devised methodology was to connect a T90 sample of each material in series and stretch them until one or the other broke as per the apparatus shown in Figure 13. This methodology was basically a Tug-of-War test.

Test setup



Two connected T90 samples

Figure 13: Experimental setup for simplified strength comparison between competing materials.

The results of 4 comparisons are shown in Table 3 and photos taken after sample breakage for tests 2, 3, and 4 are provided in Figure 14.

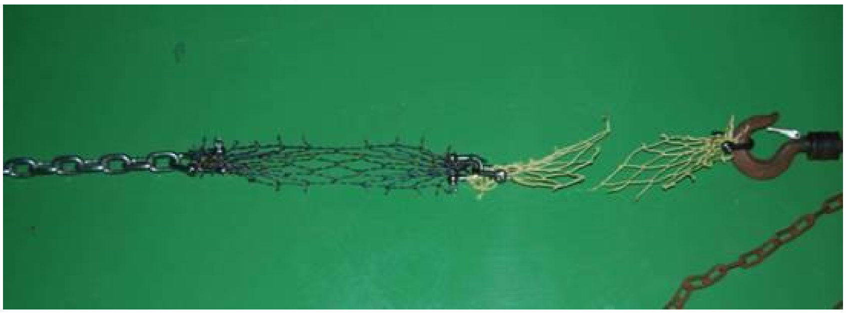
Table 3: The results of 4 simplified strength tests.

	Sample 1	*Sample 2*	*Broke sample*
Test 1	1.0mm Sapphire	1.0mm Euro Prem Plus	1.0mm Sapphire
Test 2	1.0mm Sapphire	1.0mm Euro Prem Plus	1.0mm Sapphire
Test 3	1.0mm Sapphire	1.0mm Euro Prem Plus	1.0mm Sapphire
Test 4	1.2mm Sapphire	1.0mm Euro Prem Plus	1.0mm Euro Prem Plus

The bottom line is that the two materials seem to have about the same strength. The 1.0mm Sapphire is about 0.1mm thinner than the 1.0mm Euro Prem Plus and is not as strong. The 1.2mm Sapphire material is stronger than the 1.0mm Euro Prem Plus and is also slightly thicker.

1.0mm Euro Prem Plus and 1.0mm Sapphire

1.0mm Sapphire and 1.0mm Euro Prem Plus



1.2mm Sapphire and 1.0mm Euro Prem Plus

Figure 14: Sample breakage for tests 2, 3, and 4. Euro Prem Plus is yellow and the Sapphire brand material is blue.

Objective 1(b). Relative wear resistance of various 50mm prawn-trawl netting materials

The last section provided the results of the measurement of the tensile load bearing characteristics of 5 selected netting types suitable for prawn trawling in Australia. This section describes the results of experimentally estimating the relative wear resistance of the same selected netting materials.

With use, trawl netting degrades and loses strength. Chemical breakdown of the material can occur due to the effect of UV light. It is common for material that has been exposed to a long period of intense sunlight to loose substantial strength. Anecdotally, this occurs more readily for cheap low quality materials that do not have a good UV protection system. This factor is important, but adequate UV protection is assumed for all subject materials of this investigation, such that other aging processes are more relevant to the comparison of practical performance.

In contemporary contexts, mechanical wear of the material is by far the dominant process that limits the service life of netting materials. In the field, it is observed that failure of netting due to wear is characterized by the knots 'falling apart'. Usually the most protruding part of the knot can be seen to acquire the most significant signs of abrasion and eventually 'lets-go' under load to form a crows-foot hole in the net. Ultracross netting has no knots and therefore its manufacturer claims a high level of wear resistance for netting made using the 'ultra-cross' construction process.

Abrasion of trawl netting occurs in a variety of circumstances ranging from on board handling, sliding against the seabed and associated obstacles, or from the movement of catch (including bycatch and debris) within the trawl. Surprisingly, if a well-tuned trawl does not meet any unfortunate circumstances, like accumulating a heavy catch or collecting a heavy object that causes the net to make contact with the seabed, it is abrasion wear on the inside of the net that gradually weakens the material and eventually causes the end of its service life. This wear occurs usually in the extension and codend and along the inside of the wings. It appears to be the protruding part of the knot, the loop of the sheet bend, which attracts the most intense abrasion damage.

For all knotted material, the knots in each successive row of knots have a different orientation to the previous row. For most netting, including all the knotted netting tested here, except Euroline Premium Plus, the protruding part of the knot is on each side of the netting sheet in successive rows. For Euroline netting though, the protruding part of the knots is always on the same side of the netting sheet for all rows of knots. This physical characteristic gives rise to claims that the netting will produce superior abrasion resistance if the protruding parts of the knots are organised to be on the outside of the trawl (rough side out). The other feature of this construction feature, for Euroline netting, is that the lateral hydrodynamic forces generated by successive rows of knots are in opposite directions and therefore produce no nett lateral force for the sheet of netting as a whole. For the other knotted netting materials, the lateral hydrodynamic forces are in the same direction for all rows of knots and causes a nett lateral force on the netting sheet as it is towed through the water at low angle of attack.

The specific objective here is to compare the wear resistance of the 5 netting materials tested for strength in section 1. In addition, it is hoped to provide an insight into the effect of knot orientation on wear resistance, when the wearing process is biased to one side of the netting sheet.

There is no clearly established methodology for the standardised application of wear treatments to netting and assessment of the effect on netting strength. A practical methodology for the task was established through considering the specific objectives of the task, budget constraints, the equipment and resources readily available, and the broad experience of the task team, which included a range of professional staff at UQ Materials Performance.

Methodology

The netting materials assessed for relative wear resistance were:

1. Polyethylene twisted
2. Van Beelen Spectra
3. Hampidjan Dynex
4. Ultracross Dyneema
5. Euroline Premium Plus; i) Rough side in, ii) Rough side out

The wear-application wheel shown in Figure 15 was constructed to simultaneously subject 6 pieces of netting to an equal treatment of abrasion wear. The diameter of the wheel was 490mm. Each piece of netting mounted in the wear-application wheel was nominally 7 points long X 27 meshes deep. For the Hampidjan netting, the piece of netting was 32 meshes deep because it's lateral mesh size was significantly smaller than for the other materials (see Table 1). The smaller lateral mesh size is caused by the double knot used in the Hampidjan material, which restricts the lateral expansion of the netting. Increasing the depth of the netting piece for the Hampidjan material to 32 meshes ensures that the hanging ratio of the netting is similar to the other tested materials when mounted in the wear-application wheel and the wear-treatment is applied.

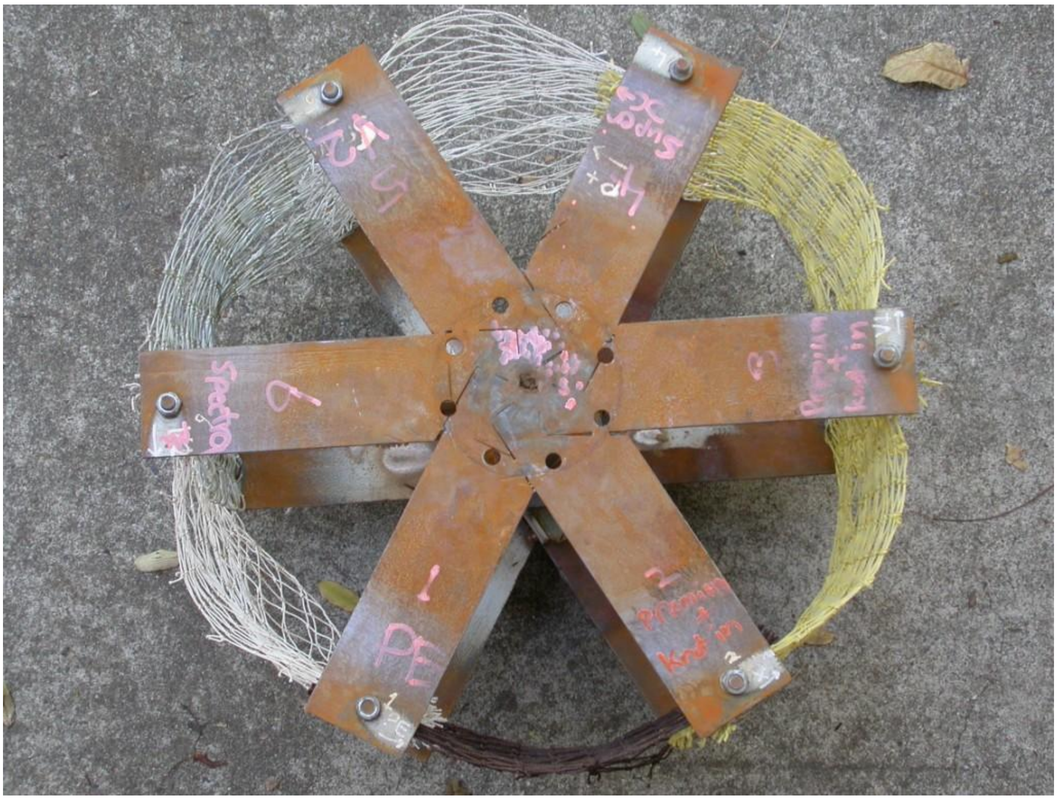


Figure 15: Netting samples positioned in the wear-application wheel.

The wear-application wheel was fixed to the drive shaft of a Steinel drilling machine (Figure 16(a)). The machine was able to lower the wear-application wheel into a stationary drum holding enough grit-slurry to fully submerge the wheel (Figure 16(c) and Figure 16(d)).

During the wear application, the wheel was rotated at 265 RPM for a duration of 40 minutes. The grit-slurry in the drum consisted of 90L of fresh water and 13L of abrasive. The abrasive used was 3mm coarse crushed silica (high particle angularity) as per Figure 16(e).

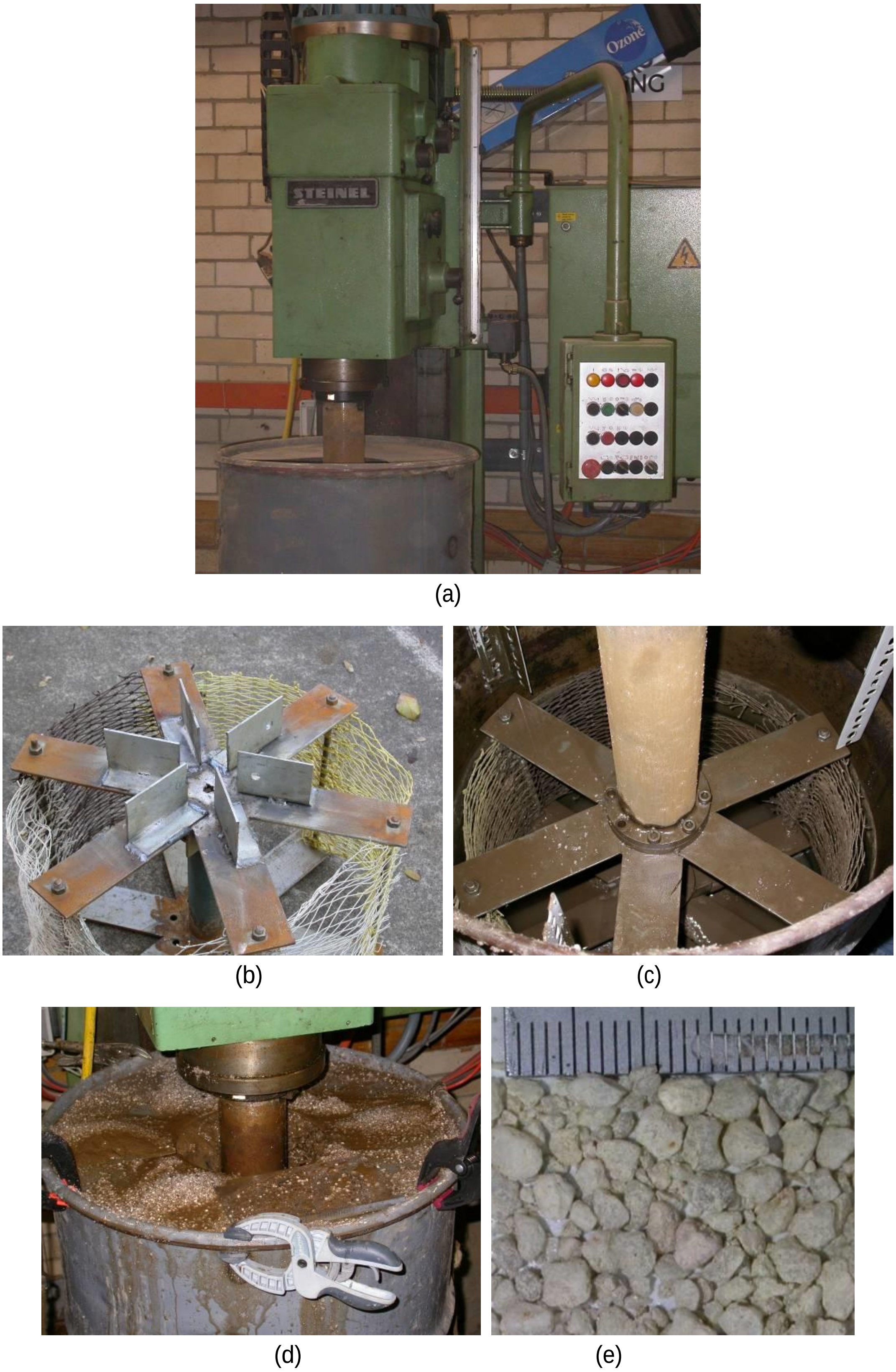


Figure 16: Pictures of the utilised wear application process. (a) Steinel drilling machine for turning the wear-application wheel, (b) Underside of the wear-application wheel showing grit agitators. (c) The application wheel in position inside the stationary grit-slurry holding container. (d) The wear application in progress. (e) Size and shape of grit used in grit-slurry.

From each piece of 'worn' netting produced, residual-strength samples as per Figure 3(b) were obtained. Each residual-strength sample had dimensions of 6 meshes by 6 points with necking down to 3 points at the mid-point.

The location and orientation of four residual-strength samples in relation to the original netting piece to be abraded was as shown in Figure 17. Residual-strength measurement involved T90 orientation of the netting mesh relative to the applied tension load. T90, as opposed to standard-mesh orientation, was selected for the residual-strength measurements because of the non-ideal load bearing characteristics of test samples having standard-mesh orientation; as discovered by the material-strength tests of Section 1.

Four replicate residual-strength tests were conducted for each case to give a more robust indication of the residual material strength and its variability. These were numbered according to their location relative to the top of the wear-application wheel and the number used as a covariate in the statistical analysis so that results could be standardised for any systematic variation in wear intensity that might occur with vertical location on the wear-application wheel.

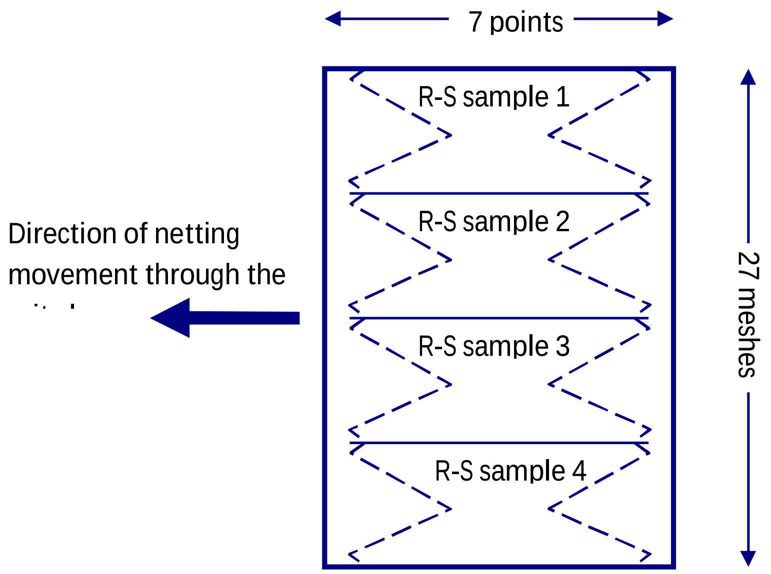


Figure 17: Dimensions of netting pieces to receive wear treatment with the location of future residual-strength (R-S) samples shown. Note. For the Hampidjan material the depth of the netting piece was 32 meshes.

For the residual-strength measurements, the tensile testing machine used was an Instron 5584 controlled by a series IX automated materials testing system. This equipment was housed at the University of Queensland and operated by the staff of UQ Materials Performance. This equipment is shown in Figure 4. Each sample was stretched at a rate of 25mm/min to the point of parting, while load and extension measurements were logged at a sample rate of 10 readings/sec.

Results and discussion

Figure 18 shows the wear-application wheel and the 6 fitted netting pieces after the wear application. The Spectra netting was effectively destroyed by the process. For the other cases, the netting was fundamentally intact but significant abrasion damage was apparent.

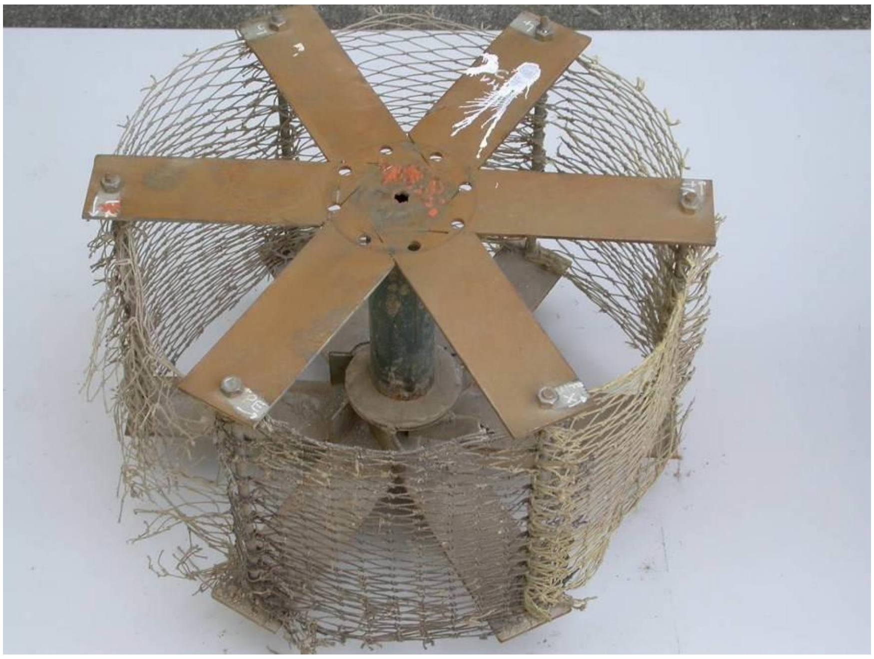
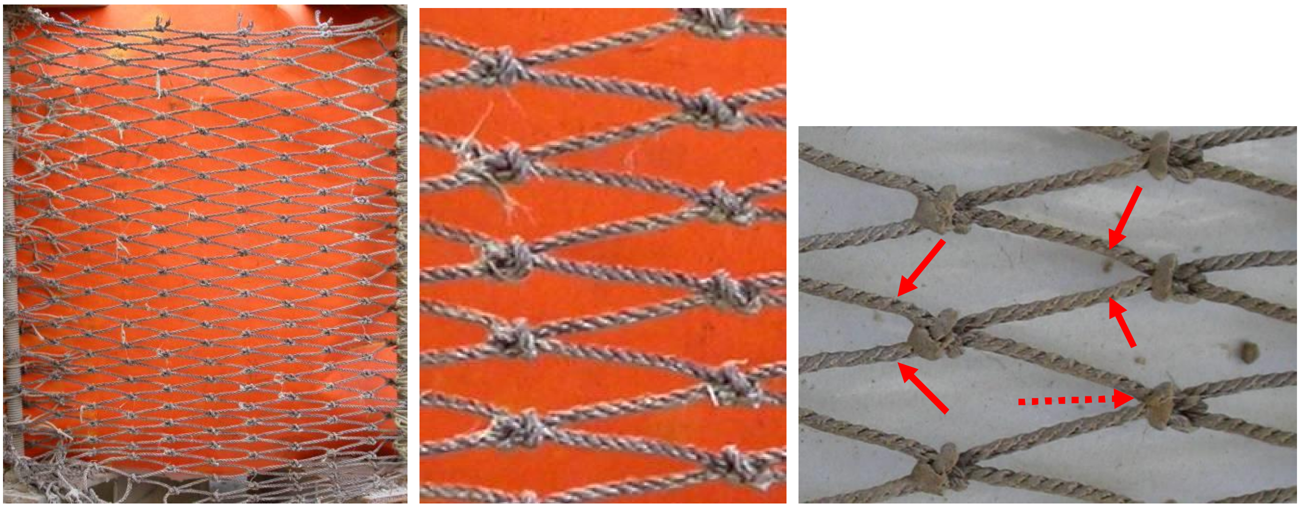


Figure 18: Wear-application wheel and mounted netting pieces after the wear treatment was applied.

Figure 19 to Figure 29 show in detail the condition of the netting for each case.

Table 4 gives the residual strength of the 4 test samples taken from each piece of worn netting. In some instances, a test sample was not available due to the extent of netting damage. In these instances, the residual strength was recorded as zero.

24ply Polyethylene



(a) (b) (c)

Figure 19: Three views of the Polyethylene netting after the wear treatment. (a) Whole piece from outside (b) Close-up of knots from outside. (c) Close-up of knots from inside.

For the polyethylene case the inside of the knots showed significant abrasion wear compared to the outside of the knots (Figure 19(c) versus Figure 19(b)), suggesting strongly that the wear process applied to the netting was more intense on the inside of the wear-application wheel than on the outside.

The inside of the knots had a ‘bruised’ appearance suggesting that the grit used might need to be ‘sharper’ to achieve the ‘rasped’ appearance of some of the abrasion observed in used trawl gear. In practice, the wearing mechanism would include contact with a wide variety of spikes and sharp edges existing on the animals and objects interacting with the trawl netting. No specific part of the netting knots visually appeared to be particularly affected by the wearing process. The action appeared to be non-discriminately applied to the fore part of the knots and on the inner side of the application wheel.

Failure of the worn polyethylene test pieces in the tension machine (example shown in Figure 20) tended to be on the bar elements near the leading edge of the knots, as marked by the solid red arrows in Figure 19(c). In the few instances where knots failed in the residual-strength samples, it was usually for the knots and at the point corresponding to that marked by the dashed red arrow.

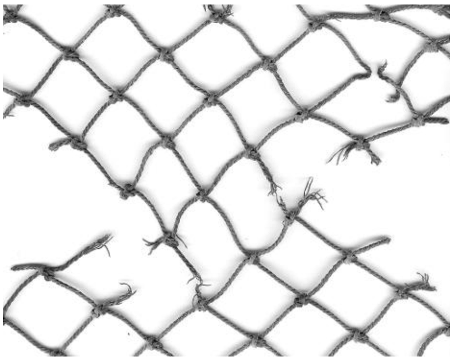
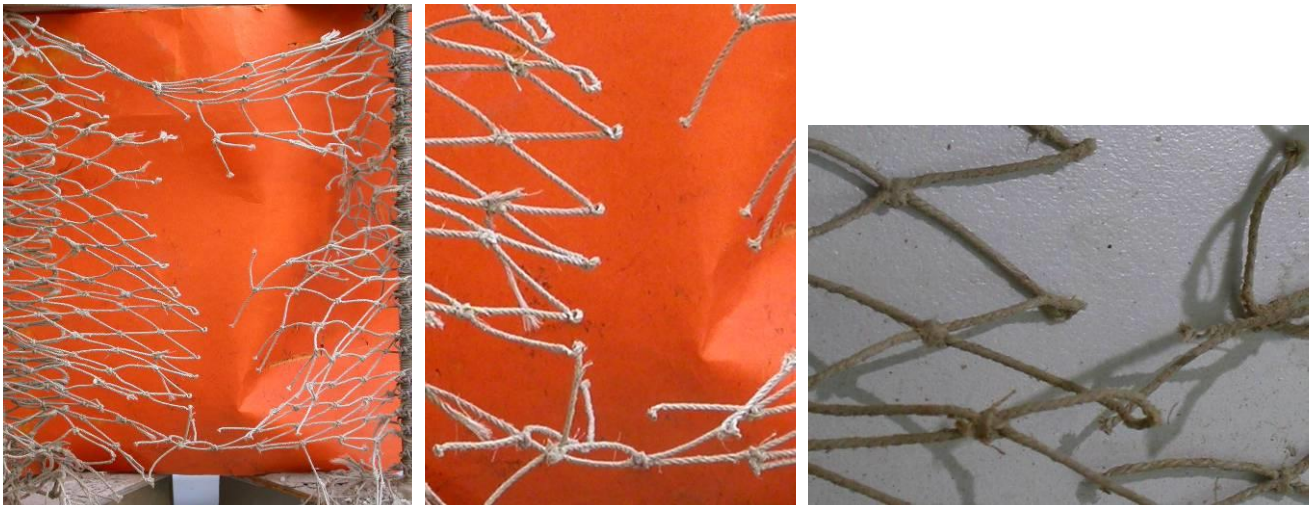


Figure 20: Failed residual-strength test-piece taken from the section of 24ply polyethylene netting subjected to wear treatment.

Van Beelen Spectra



(a) (b) (c)

Figure 21: Three views of the Spectra netting after the wear treatment. (a) Whole piece from outside (b) Close-up of knots from outside. (c) Close-up of knots from inside.

The Van Beelen Spectra netting appeared to be particularly susceptible to the applied abrasion since it was the only material where knots 'let-go' on a large scale during the wear-application process. It was apparent that the parted knots generally came from the same vertical row of meshes that were located down the centre of the piece of netting. Further inspection of the worn netting indicated that every second row of meshes had become quite weak by the abrasion process. The red arrows in Figure 22 show the vulnerable points of the spectra knots and the direction of impact by grit particles in the slurry. The green arrows show the point on the knots that were weakened in the polyethylene case described above, and was thought to be vulnerable to abrasion from industry observations. The spectra knots corresponding to those marked by the green arrows appeared to have reasonable residual strength.

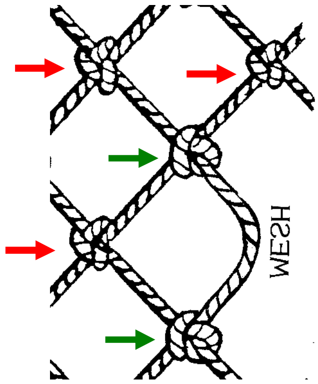
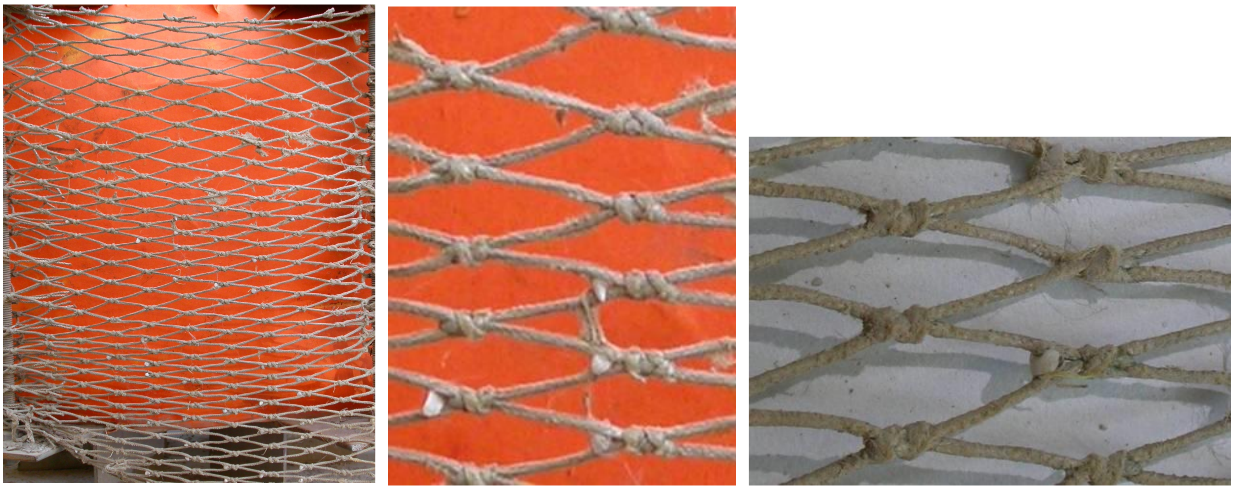


Figure 22: Netting structure with indication of differences between alternative rows. Red arrows indicate high wear and Green arrows indicate lower wear for the spectra case.

It could be that the abrasion process applied in the lab is fundamentally different from that occurring at times in practice, or the characteristics of the spectra twine makes it vulnerable to grit wear in a different way to the polyethylene netting usually used in the field.

Hampidjan Dynex



(a) (b) (c)

Figure 23: Three views of the Hampidjan netting after the wear treatment. (a) Whole piece from outside (b) Close-up of knots from outside. (c) Close-up of knots from inside.

The Hampidjan netting also had a 'bruised' appearance, particularly on the inside of the application wheel and held grit particles trapped against knots in a number of it's meshes. Failure of the worn netting in the tension machine (Figure 24) always occurred at the bar elements with no consistent sign of weakness occurring near the knots.

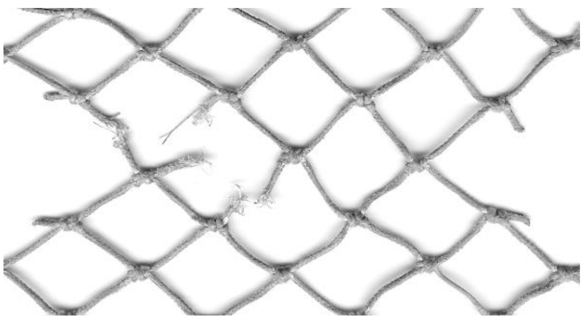
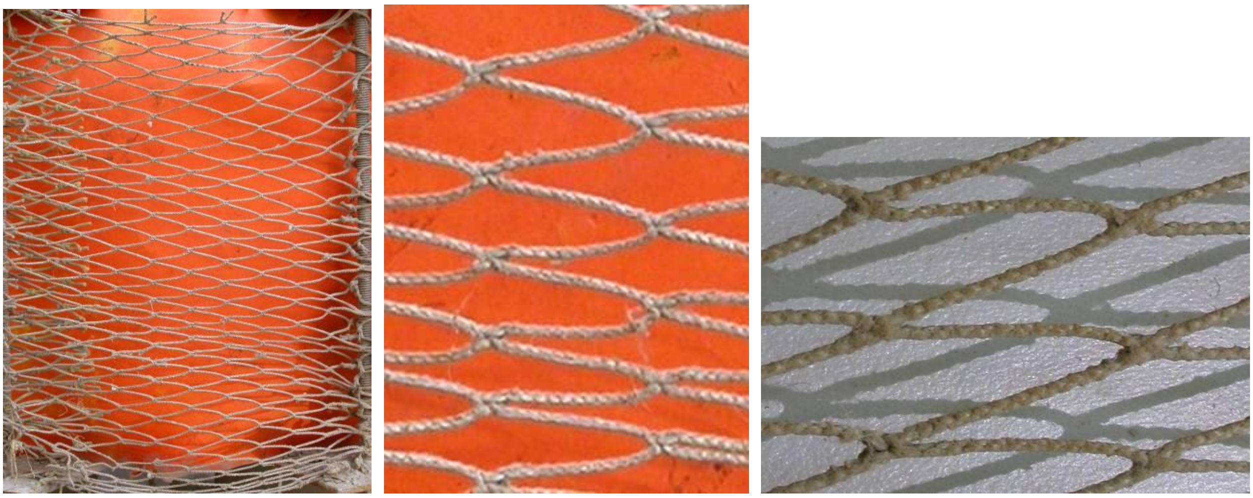


Figure 24: Failed residual-strength test-piece taken from the section of Hampidjan Dynex netting subjected to wear treatment.

Ultracross Dyneema



(a) (b) (c)

Figure 25: Three views of the Ultracross netting after the wear treatment. (a) Whole piece from outside (b) Close-up of knots from outside. (c) Close-up of knots from inside.

As shown in Figure 26, failure of the worn Ultracross netting in the tension machine seemed to occur mostly close to the mesh nodes. It appears that the grit was able to work itself in very close to the node and cause intensified abrasion damage compared to other parts of the netting

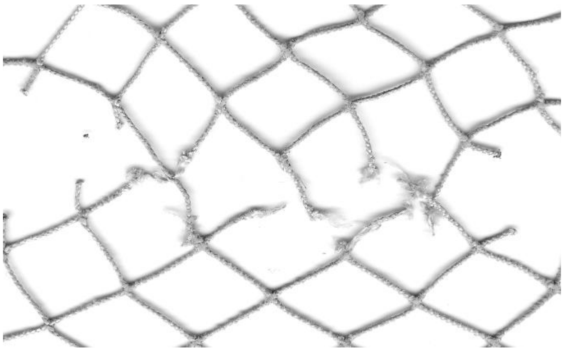
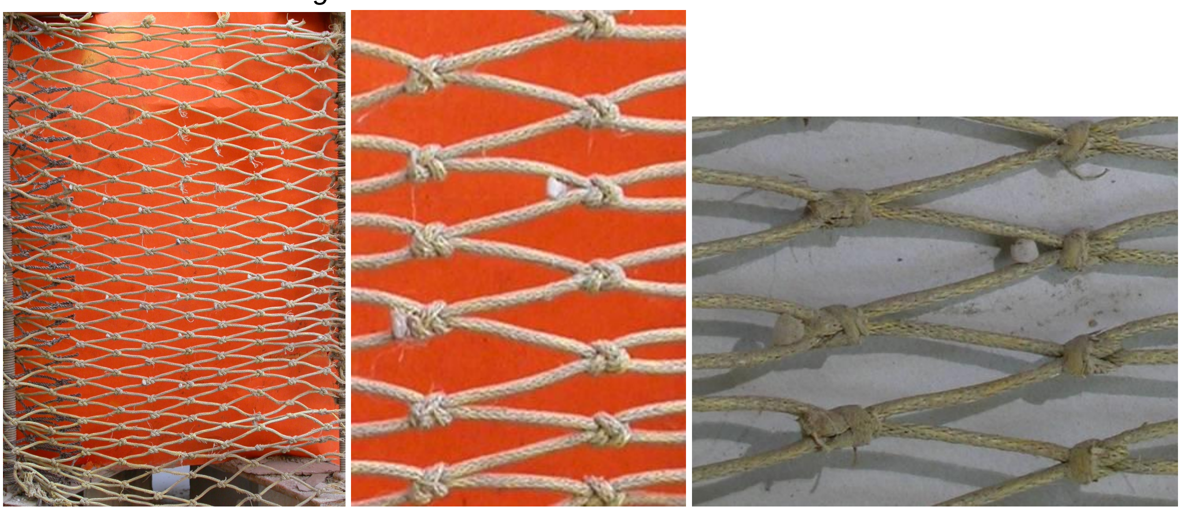


Figure 26: Failed residual-strength test-piece taken from the section of Ultracross Dyneema netting subjected to wear treatment.

Euroline Premium Plus – Rough side in



(a) (b) (c)

Figure 27: Three views of the Euroline (RSI) netting after the wear treatment. (a) Whole piece from outside (b) Close-up of knots from outside. (c) Close-up of knots from inside.

For the Euroline netting (RSI) failure of the worn netting in the tension machine occurred only within the bar elements. Parting of the bars tended to occur close to the knots as shown in Figure 28. There was no sign that the high points of the knots, which were on the inside of the application wheel (rough side in), had become the weak point of the netting's structure.

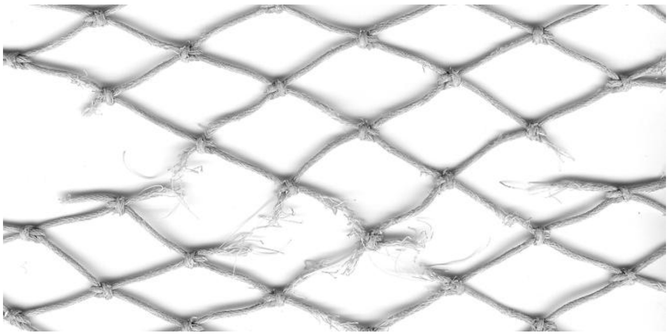
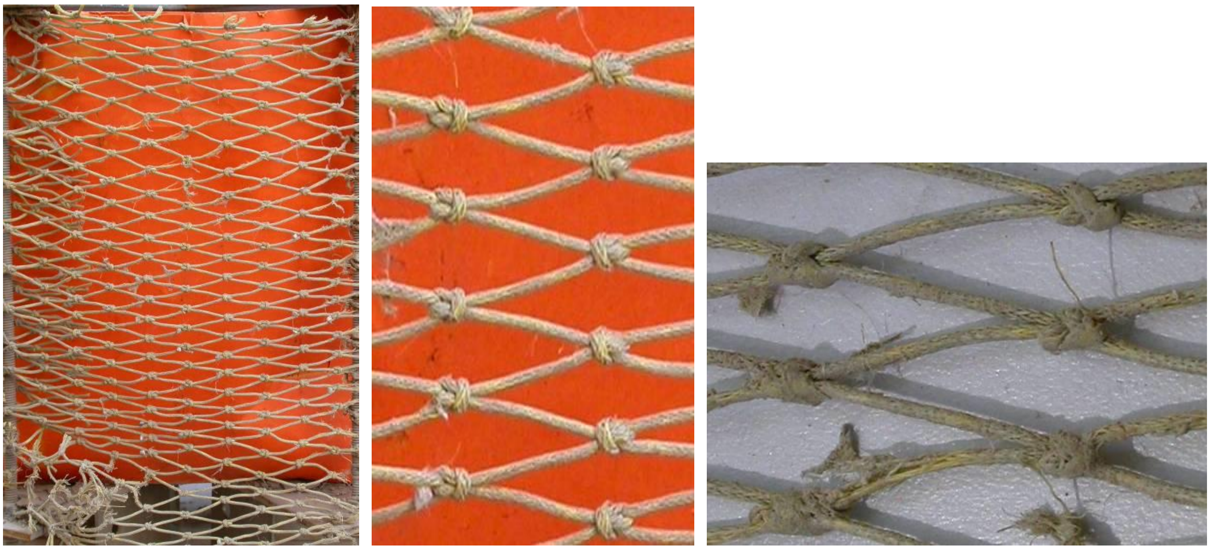


Figure 28: Failed residual-strength test-piece taken from the section of Euroline Premium Plus (Rough side in) netting subjected to wear treatment.

Euroline Premium Plus – Rough side out



(a) (b) (c)

Figure 29: Three views of the Euroline (RSO) netting after the wear treatment. (a) Whole piece from outside (b) Close-up of knots from outside. (c) Close-up of knots from inside.

The wear damage and weakening of the Euroline netting with the 'rough-side-out' appeared to be the same as for the 'rough-side-in' case reported above. Failure of the worn netting in the tension machine occurred in the bar elements close to the knots, as shown in Figure 30.

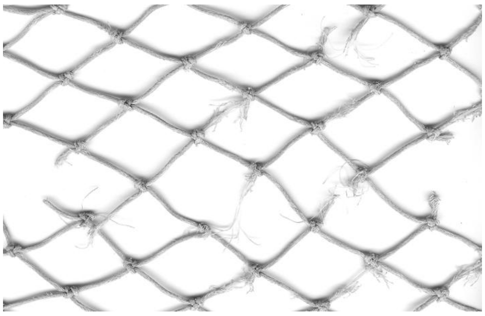


Figure 30: Failed residual-strength test-piece taken from the section of Euroline Premium Plus (Rough side out) netting subjected to wear treatment.

Relative performance between material types

Table 4 shows the original and residual strength of the tested materials. There is considerable variation in residual strength for the samples of a given case, and there was not a highly consistent variation in residual strength between sample number (location of the sample). More replicates would be required to assess differences between materials and sample location with a high degree of precision. The objectives of the current investigation however was not to achieve high precision, but rather to establish whether there were any substantial differences in wear resistance between the materials of interest, and also establish coarse information on the validity of the testing methodology. Based on the residual-strength results of the single run of the methodology, it appears that the Van Beelen Spectra netting was very susceptible to the wear process set up by the experiment. It also appears that the intensity of the wear process is strong at the bottom of the wear-application wheel compared to higher up in the grit-slurry container, given the relatively low residual strength of the majority of 4th samples of the worn materials. The 4th Hampidjan Dynex sample held a comparable residual strength to samples higher up the application-wheel, while it was not possible to obtain a 4th sample from the worn polyethylene netting because that part of the piece was no longer intact. A simple view of the data can be obtained by ignoring the 4th sample, which contains complications due to the raised intensity of the wearing process at that level. With this in mind, Table 4 provides the average and 90% confidence range of the residual-strength results, calculated across the first three samples for the 6 cases. These simple summary statistics are plotted in Figure 31.

Table 4: Breaking loads in Newtons for T90 test-samples taken from new and worn prawn trawling netting.

	Polyethylene	Spectra	Hampidjan	Ultracross	Premplus-rsi	Premplus-rso
New T90 failure load	1180	1580	3130	3550	1310	1310
Worn sample 1	623	0	1150	930	575	912
Worn sample 2	540	0	1316	1351	643	648
Worn sample 3	644	0	1272	1430	637	809
Worn sample 4	0	0	1274	395	479	324
Average (samples 1-3)	602.3	0	1246	1237	618.3	789.7
90% conf. range	63.5	0	99.3	310	43.5	154

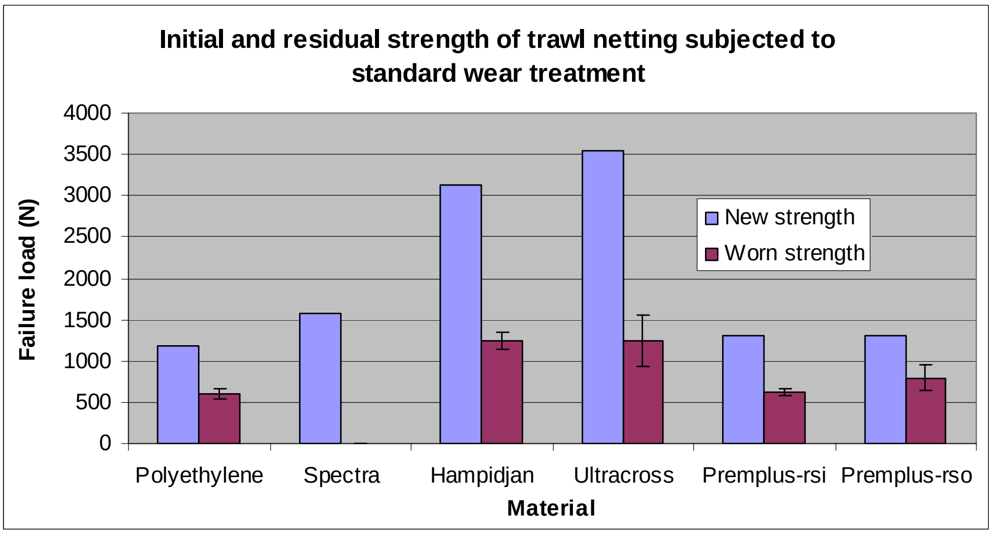


Figure 31: Initial and average residual strength of the materials tested for relative wear resistance. The average and 90% confidence interval shown for the residual strength results are based on the first 3 samples only.

Table 5 shows the same residual strength data, but expressed as a proportion of each material's initial unworn strength. The average calculated across all 4 samples for each material is also shown in Table 5 and plotted in Figure 32. The 90% confidence interval shown in Figure 32 was derived after the residual strength data was standardised for the differing wearing intensity occurring at different levels of the application wheel. In this presentation of the data, all the available information is included and the variation between replicates within each material was processed to estimate a realistic 90% confidence interval for the results.

Table 5: Residual-strength data expressed as a proportion of the original strength of the materials. The average proportional residual strength is calculated across the four replicates. The 90% confidence range is based on the random variation between samples within each material after the average variations between corresponding samples were removed.

	Polyethylene	Spectra	Hampidjan	Ultracross	Premplus-rsi	Premplus-rso
Sample 1	0.528	0.000	0.367	0.262	0.439	0.696
Sample 2	0.458	0.000	0.420	0.381	0.491	0.495
Sample 3	0.546	0.000	0.406	0.403	0.486	0.618
Sample 4	0.000	0.000	0.407	0.111	0.366	0.247
Average	0.383	0.000	0.400	0.289	0.445	0.514
90% conf. range	0.138	0.121	0.128	0.056	0.072	0.098

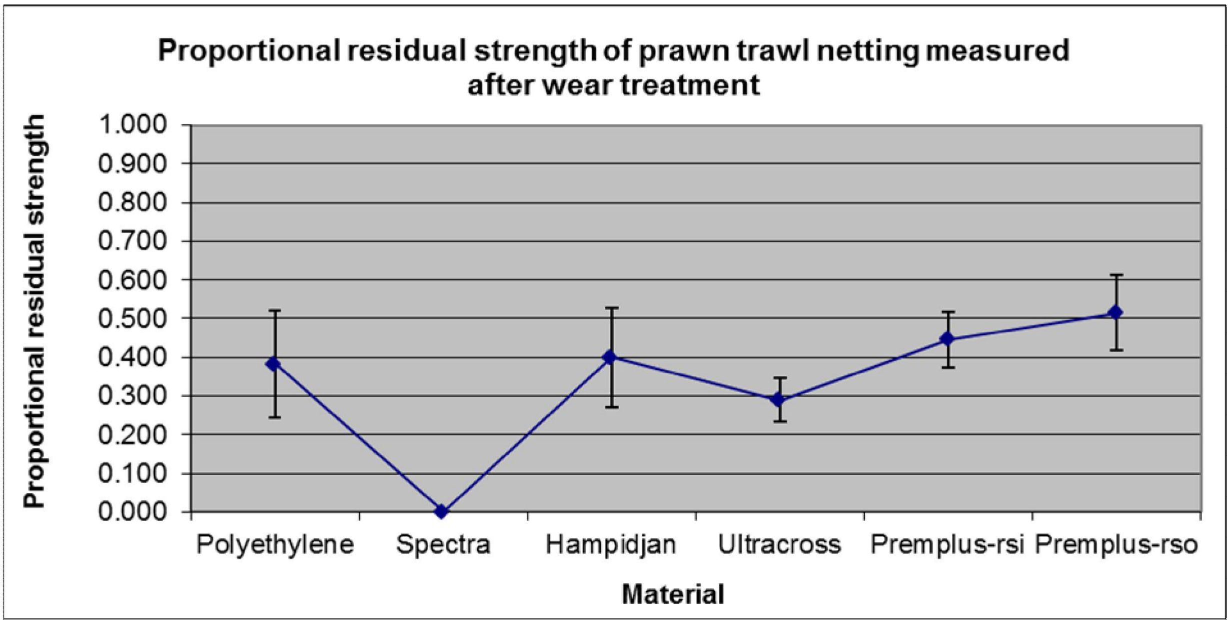


Figure 32: Proportion of initial strength apparent after the wear treatment for various prawn trawl materials. Error bars show the 90% confidence interval for each result.

The results show that the Van Beelen Spectra had a substantially lower wear resistance compared to all the other materials tested. As discussed above, this appeared to be due to the knots being quite vulnerable when oriented in a specific way to the oncoming grit particles. The twisted spectra twine has low bending stiffness and may have allowed the grit particles to wedge in against these knots and eventually cut through the exposed twine segment over the duration of the wear process.

Figure 32 shows that there was no scientifically significant difference in wear resistance for any of the other 'high performance' materials compared to polyethylene. The results do indicate though that the Euroline Premium Plus material has a higher wear resistance than the Ultracross Dyneema material. Although the reduction in strength due to wear appeared to be greater for the Ultracross Dyneema material compared to the Euroline material, in absolute terms the residual strength of the Ultracross Dyneema was still as high as the Euroline material in its new condition (see Figure 31).

For the Euroline material there was no proven advantage of keeping the rough side of the knots on the outside of the application wheel and away from the more intense wearing process occurring on the inside.

Conclusions

The methodology developed to assess the relative wear resistance of trawl netting was practical and efficient in terms of time and resources.

A single run provided some degree of replication of results for a rudimentary appraisal of experimental error. Additional runs of the methodology can be undertaken with a high degree of repeatability, and would conceivably increase the precision of the comparisons to a high level.

It appears from the visual signs of wear damage to the netting that the wear treatment is more intense to the inside surface of the netting in the wear-application wheel, and to the leading edge of netting components, as one would expect for the relative motion of the netting and the grit occurring during the wearing treatment. These features of the wear treatment correspond well to known wear processes in the field.

The appearance of the wear damage achieved in the laboratory was 'bruised' compared to a 'rasped' appearance often observed in the field. It is recommended that future trials of the methodology investigate the use of 'sharper' grit and larger grit particles.

A wear treatment duration of 40 minutes produced an average strength reduction across the materials of about 60% (40% residual strength), although the Van Beelen Spectra material was effectively destroyed by the treatment and had zero residual strength.

For the single run of the methodology involving the 6 material cases under investigation, there was no substantial difference in wear resistance, when expressed as proportional residual strength, for the five cases other than Spectra. Euroline Premium Plus appeared to have the greatest wear resistance and was significantly better than Ultracross Dyneema. None of the materials, apart from the spectra was significantly different from traditional polyethylene in terms of the determined wear resistance measure.

More replicates are required to increase the precision of the experiment such that more of the relatively small differences in wear resistance might be deemed statistically significant.

There was some indication in the results that the Euroline Premium material might have better wear resistance if the rough side of the material is opposite to the side experiencing the more intense wear treatment. But the result was not statistically significant at a 90% level of confidence.

There was also a suggestion, which cannot be proved by the current results, that the Ultracross material has a lower wear resistance than standard knotted Polyethylene. Despite the lower proportional residual-strength of the worn Ultracross material compared to worn polyethylene, it was still as strong as new polyethylene in absolute terms because of the very high initial strength of the Dyneema products.

Objective 1(c). Drag and flow study for various materials and trawl construction techniques, using the flume tank.

The previous sections provides the results of the measurement of the tensile load bearing characteristics and experimentally determined relative wear resistance of 5 selected netting types suitable for prawn trawling in Australia. This section relates to the hydrodynamic drag characteristics of the netting, based on model trawls in the Flume Tank.

Methodology

Drag measurements

Trawl-net scenarios

Generally, the netting materials tested were the same as those tested for strength and wear in previous sections, however the 1.0mm Van Beelen Spectra (circa 1995) was not included in the flume tank testing because it has been extensively studied previously (Low, 1997) and no additional information would be obtained for that material by further testing in this stage of the project. Interacting with material type, a number of knot-orientation variations were investigated in terms of their effect on trawl drag because they are options in the construction of trawls giving rise to likely performance variations. Table 6 is a definitive list of the material by knot-orientation combinations that were drag tested:

Table 6: Structure of drag tests conducted in the Flume tank on 5 different model trawls with Tier 1 designating fundamental drag measurements and Tier 2 designating drag sensitivity tests for second order factors.

Tier 1 tests	Tier 2 tests
1. 24ply 400 den PE – standard-mesh orientation	
i) Knot forces out – with struts	ii) Knot forces in – with struts iii) Knot forces out – without struts iv) Knot forces in – without struts
2. 1.0mm Ultracross dyneema	
3. 1.0mm Hampidjan Dynex Standard-mesh orientation – knot forces out	
4. 1.0mm Hampidjan Dynex T90	
5. 1.0mm Euroline Premium Plus – standard-mesh orientation	
i) Rough side out	ii) Rough side in iii) Rough side out – net stretched longitudinally iv) Rough side out – net stretched laterally

Eleven model trawl-net scenarios were tested in total, involving 5 model trawls and 4 material types. Two trawl-net scenarios, 5(i) and 5(ii), were replicated at a later date to increase the statistical-power of the results. All trawl-net scenarios were tested with standard 60ply codends (knots forces out), and the detailed specifications of the 4 materials considered are shown in Table 1.

The tests were divided into two tiers. Tier 1 tests, listed on the left in Table 6, provided data to determine an operational drag parameter for each of the 5 trawl-net materials[1]. Tier 2 tests (listed on the right in Table 6), relate to the exploration of intersecting drag issues and produced data that did not contribute to the fundamental assessment of relative drag between material types, but rather provided sensitivity tests to

[1] Hampidjan T90 is treated as a different material type to Hampidjan standard-mesh.

indicate the degree of drag variation that might exist in practise due to commonly-applied net design and rigging factors.

Figure 33 shows the plan of the standard trawl utilised for the drag tests. The design is a “simplified” prawn trawl in that the trawl does not have any leadahead (the top is identical to the bottom) and the frameline tapers are simple, but representative, of Australian prawn trawls. The design style of the model-trawl was fundamentally a “Flyer” and its proportions approximately depict an 8 fathom trawl at ¼ scale, given that the mesh size for all models were nominally 51mm.

The two Hampidjan Dynex model trawls (3. Standard–mesh and 4. T90) depart somewhat from the standard trawl plan because although the stretched-mesh length is similar to the other materials (specified as 50mm), the stretched width of the mesh is 16% less than the other materials (see Table 1). This occurs because the Dynex material is constructed with a double knot. The double knot does not allow the mesh to stretch laterally as wide as expected and it must be hung on the frameline of the model trawl at a lower hanging ratio that suits the situation. In order to obtain a model trawl for the Dynex material that is the same overall size as the other model trawls more meshes have to be included in the bosom of the standard-mesh Dynex trawl (11 meshes instead of 9). In addition, the side taper needs to be steeper so that the trawl still has the same length as the other trawls despite having more meshes across the mouth. For the aft part of the trawl the side-taper was increased to 1Point5Bar. Initially this model trawl was constructed with more bars in the wings and more 1M3B tapers on the framelines, with matching 16% reductions in hanging lengths for those sections of the frameline (ie the same corrections as made for the bosom meshes). It was instantly obvious that the netting along the framelines, outboard of the bosom, was too slack so the trawl in these areas was adjusted back to the standard pattern. The resulting Hampidjan standard-mesh model appeared to work correctly during the flume tank tests, however subsequent consideration of the netting geometry concludes that a 7% ”correction” should have been applied to the Bars at the wings and a 8% ”correction” applied for the 1Mesh3Bar frameline tapers. If this had been applied there would be additional meshes across the mouth of the trawl, increasing the twine area and presumable producing more drag.

Because of the identified complication of using the Hampidjan Dynex material, due to the double knot, part of the drag advantage of using Dynex, with its thinner twine, is offset by the need to include more meshes into a trawl of a given size. A way of potentially avoiding putting extra meshes into the trawl is to use the netting in T90 orientation so that the lateral mesh dimensions of the trawl are now maintained at 50mm and the standard net plan can be used, in terms of the lateral dimensions. However, with a T90 orientation the length of the trawl will now be shorter than the other models. To overcome this, a less-steep side taper was selected (1Point2Bar instead of 1Point3Bar) for the Dynex T90 model trawl.

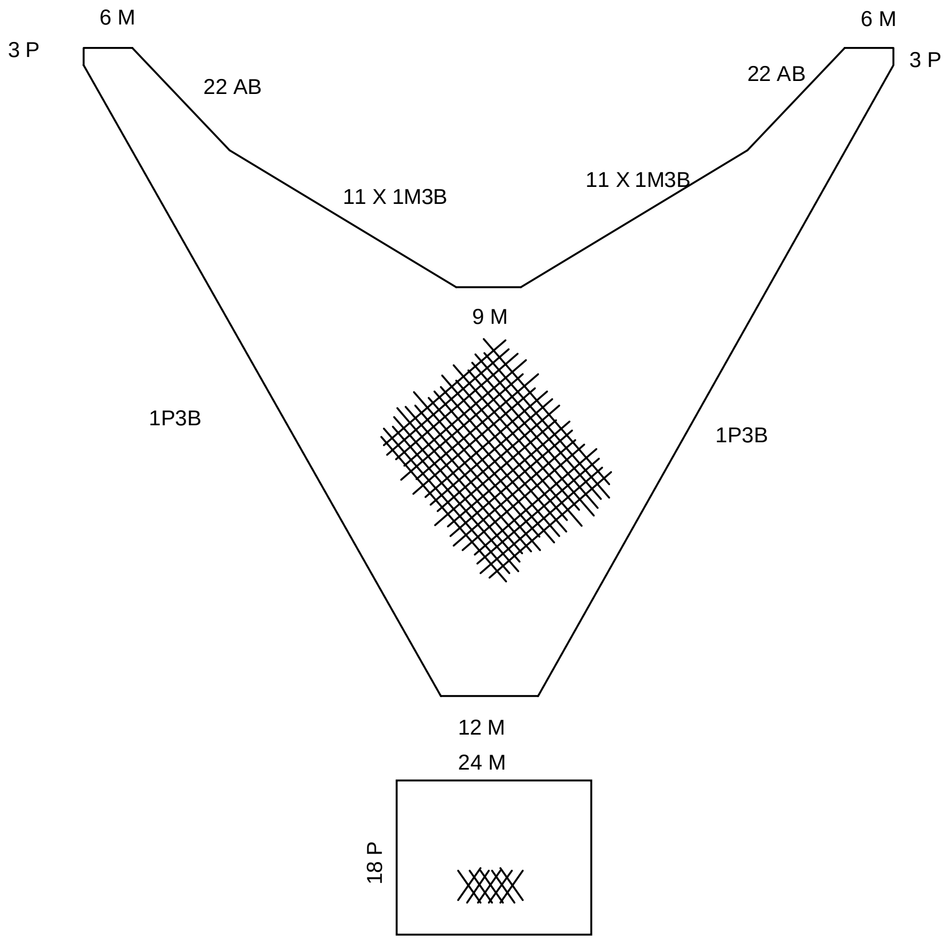


Figure 33: The standard net plan for the model nets to be drag tested in the flume tank.

Data collection

For each case the subject model-trawl was fitted to the back of the Trawl Evaluation Rig (TER) such that it was spread to 80% (see Figure 34), and drag measurements recorded over a range of speeds to get a statistical measure of the drag coefficient. The frameline separation at the TER was set at 226mm, and this was fixed around the trawl by four equally spaced thin (4mm), centreline struts (see Figure 35).

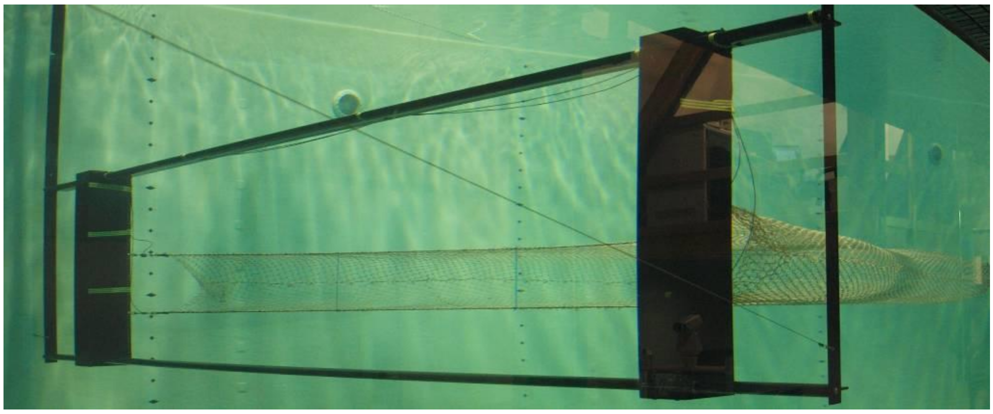


Figure 34: Model trawl connected to the Trawl Evaluation Rig at 80% spread ratio.

The flow velocity was recorded with an electro-magnetic probe located 7 m upstream of the model, 1.25 m below the free surface and on the centre line of the tested trawl models. The model tension was measured with four load cells of 20kgf capacity each and ± 0.05 kgf accuracy.

The performance data collected was tension from 4 wingend load-cells of 20kgf capacity each and a wingend divergence angle for each side of the trawl (see Figure 35 for the location of the 4 load –cells at the wingends of the trawl). The two wingend angles are theoretically the same and should not change with speed and material type. The 4 load-cell readings are in theory the same and should all change together with speed and material type.

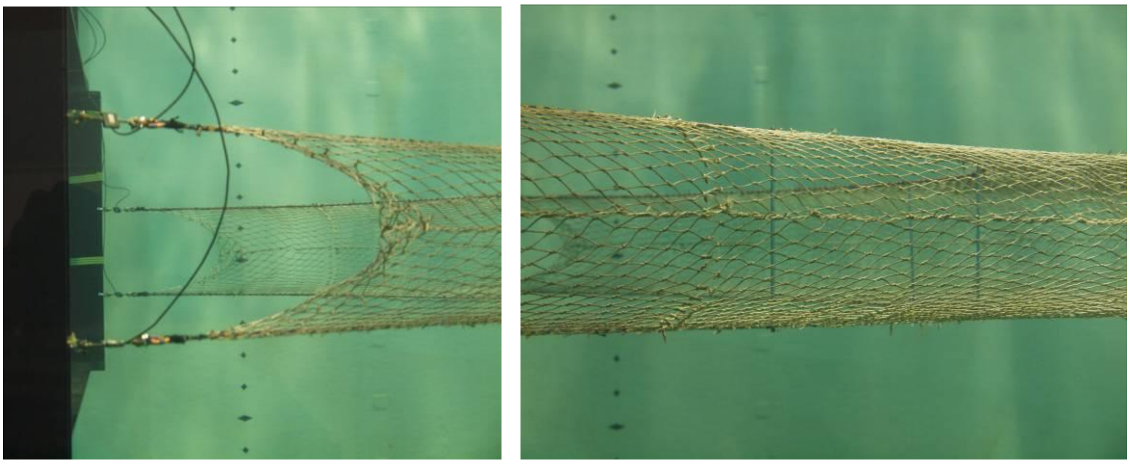


Figure 35: Model trawl connected to Trawl Evaluation Rig with 226mm headline height, which was fixed around the frameline by four equally spaced thin (4mm) vertical struts.

For each trawl-net scenario the flume tank propellers were set sequentially to 4 highly-repeatable operating conditions; 90, 120, 150, and 180rpm[2]. While for the whole duration, water speed and tension acting at the 4 trawl connection points were recorded at a rate of 50hz using the flume tank's data acquisition system. For each flume tank setting, port and starboard wingend angles were measured and recorded manually using a purpose-built optical protractor.

Analysis

All connection-point tension measurements were converted to drag components by multiplication with the drag directional cosine, cos(wingend angle). The wingend angle used in all instances was the average of all measurements taken. A single average value was used because the accuracy of the angle measuring system is quite low. Using the average stabilises the error structure, rather than add unnecessary noise into the data by applying local measurements of the wingend angle to respective tension measurements. This is justified by the fact that there is no expectation that wingend angles should vary between trawl-net scenarios and any such variation, if it did exist, would be far too small to be detected by the measurement system used.

The hydrodynamic-drag parameter for each trawl-net scenario was estimated by applying a proportional regression (linear regression with intercept set to zero) to the sum of the drag components of the 4 connection-point tensions against the square of water speed. Figure 36(a) shows an example of such a regression applied to all the drag data collected for trawl-net scenario 1 i), 24ply PE – knot forces out (PE-KFO). Figure 36(b) shows a plot of the residuals from the regression, which has a significant linear trend and was found to exist similarly for all scenarios. This situation produces a risk of variable bias in the estimation of drag parameters if the drag data in each scenario is not uniformly, or consistently, distributed along the range of examined water speed. To ensure a consistent distribution of data and a standardised process for drag parameter estimation, a single-point average of trawl drag and water speed was determined for each of the 4 flume tank settings, and these were solely used in the regression to estimate the drag parameter. Figure 36(c) shows the application of a proportional regression to the 24ply PE-KFO case after the drag data was collapsed to 4 single-point indications of the relationship between drag and water speed.

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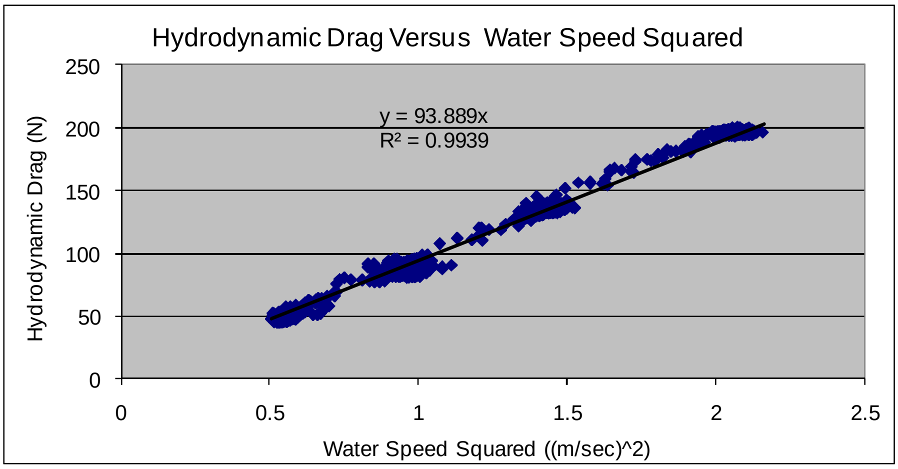
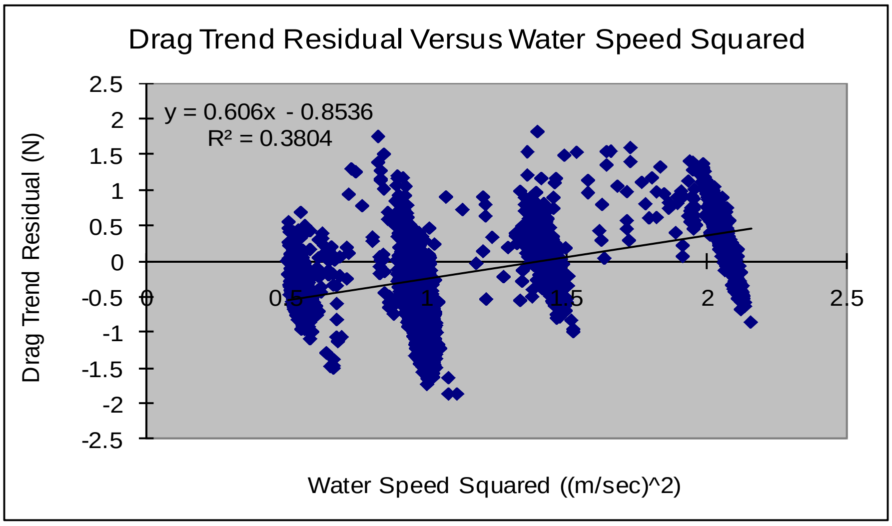
[2] The propellers operating at 180 rpm produce flow of about 1.425 m/s.

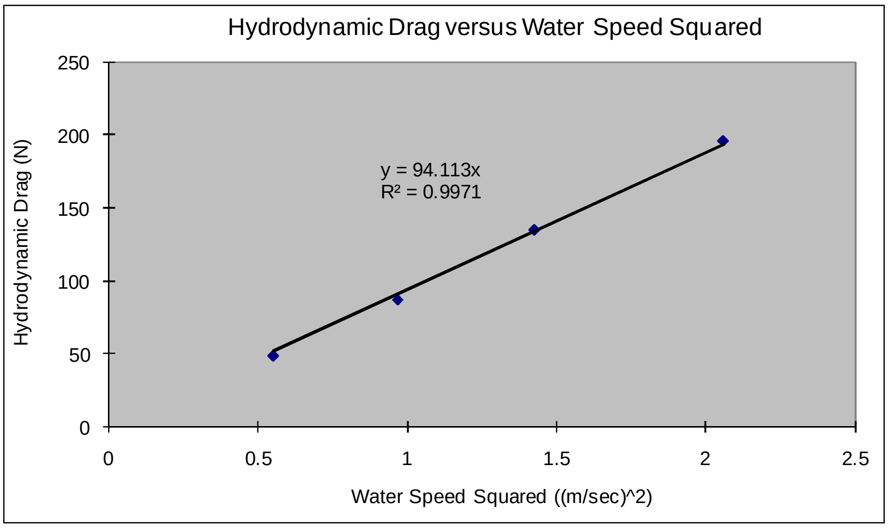
95% confidence intervals for the estimated drag parameters were determined based on the Standard Error determined for the complete data set.



(a)



(b)



(c)

Figure 36: Derivation of an unbiased hydrodynamic-drag parameter for the standard polyethylene trawl.

Centre-line velocity pattern

For 3 cases the velocity at various points down the centre line of the trawl were compared to the reference velocity. The water speed at these locations was also determined when no trawl was in position, to normalise the data. Two speed logs were used, one at the reference point and a mobile unit for water-speed measurements down the centreline of the trawl. The 3 model trawl cases investigated in this way were:

1. Standard 24ply 400 den PE – standard-mesh orientation, Knot forces out, standard codend
2. 1.0mm Ultacross dyneema, standard codend
3. 1.0mm Ultacross dyneema, Dynex T90 codend

Results and discussion

Drag measurements

Overview

45,500 drag records were produced by the tests, with each record containing readings from the speed log and 4 load-cells. On average this was 3,500 records per trawl-net test. All the collected drag data is plotted in the three scatter-graphs below. Figure 37 shows all the Tier 1 data, while Figure 39 shows the Tier 1 and Tier 2 data for 24ply PE and Figure 41 shows the Tier 1 and Tier 2 data for Euroline Premium Plus. To quickly compare the data between cases a power regression has been applied and the graph legends, with regression results, have been ordered in terms of highest to lowest coefficient. In Appendix 1 there is a photo gallery where side-elevation and overhead photos taken during testing of the trawls are shown.

In all cases the exponent of the power regression is slightly higher than 2, showing that hydrodynamic drag is increasing slightly more rapidly with speed than simple hydrodynamic theory predicts. This is either due to Reynolds number effects, where the drag coefficient of key netting elements is increasing with speed, or there are subtle shape changes in the trawls with speed. One possibility is that the nets are generally “inflating” with speed, due to the bending resistance of the mesh elements, producing increasing exposure of netting elements to the flow.

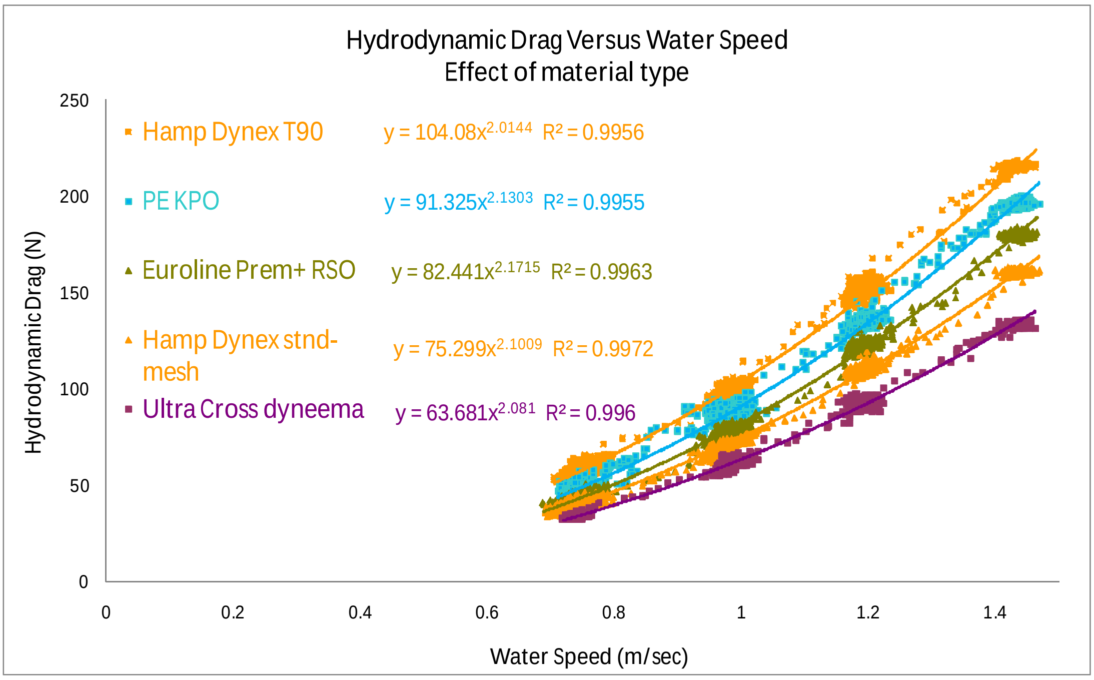
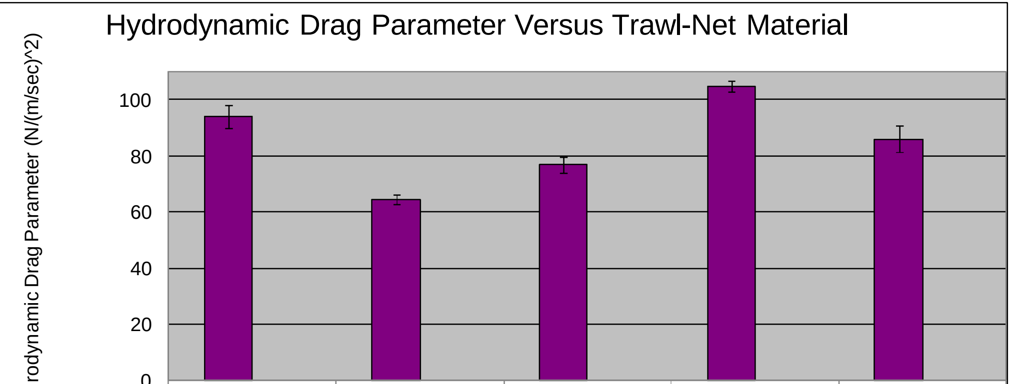


Figure 37: Raw drag data for Tier 1 tests.

Tier 1 results

Figure 38 shows the drag parameters estimated from the data in Figure 37 for the 5 trawl-nets tested in their conventional mode. The T90 mesh configuration for the Dynex material had a large increase in drag (approximately + 36%) compared to standard-mesh Dynex. Most of this drag increase is explained by twine area, since the T90 net has 34% more twine area due to its less-steep side taper. The T90 trawl is the same length physically as the standard trawl, but it is has more meshes between the bosom and the codend.



	24ply PE KPO	Ultracross dyneema	Hamp Dynex stnd-mesh	Hamp Dynex T90	Euroline prem+ RSO
Drag Parameter	94.1	64.6	77.1	105.0	86.0
Drag shift from PE	0%	-31%	-18%	12%	-9%

Figure 38: Estimated hydrodynamic drag parameters for the investigated trawl-net materials.

Of the standard-mesh orientation trawls, 24ply PE had the highest drag. Compared to the PE netting the Euroline Premium Plus material had approximately 9% less drag, the standard-mesh Dynex trawl had about 18% less drag, and Ultracross dyneema had about 31% less drag.

Table 7 gives a summary of the results including the result of twine area calculations for each model. For each model the table also provides the relative twine diameter, with reference to 24ply PE, and the relative size of the knots in the materials. These physical factors along with the size of the mesh and the details of the trawl pattern give rise to the relative twine area for the models. In all cases the drag reduction falls short of the reduction in twine area caused in the main by variation in twine diameter. This failure for drag to reflect twine area was mainly evident for the Hampidjan Dynex trawls. For the standard-mesh Hampidjan trawl there was a healthy 18% reduction in drag, but this was well short of the calculated 30% lower twine area for that trawl compared to 24ply PE. The Euroline Premium plus and more so the Ultracross Dyneema trawl did more reasonably reflect the reduction in twine area.

It is proposed that the variation in drag result with respect to twine area is due to three effects that interact to varying degrees for each of the cases:

1. PE being the only twisted twine may have an effective “hydrodynamic” twine diameter somewhat smaller than the measured overall diameter. This may be particularly significant here because all the other materials tested at this time are braided and have a more definite cylindrical shape. The twisted twine may allow water to pass around the twine relatively more easily than braided twine of the same nominal diameter, and therefore have slightly less drag. A small correction to the diameter of the PE twine to allow for this effect would easily bring twine area calculations and drag results into line for Ultracross and Euroline Premium plus compared to PE.
2. When a correction for twisted twine is applied to the twine diameter of the PE trawl, as outlined above, the drag reduction for Ultracross easily exceeds that which would be predicted by twine area. This is possibly due to Ultracross being the only knotless material tested. A tentative conclusion is that the effect of knots on drag is significant and not well captured by using twine area as a predicator of drag. A vast amount of netting in a prawn trawl is at a low angle of attack where much of the drag is generated by an accumulation of skin friction over the netting rather than form drag from flow around mesh elements. Therefore, for these areas of netting in the

trawl, the thickness of the twine has a relatively diminished effect on drag[3]. However the knots of the mesh provide bumps in the surface of the netting that would to a certain extent cause form drag and produce a significant contribution to drag over the vast area of netting involved. Since the effect of knots on drag is considered in the twine area calculation only in terms of their area compared to the area of the twine, when the knots in netting are removed it only has a relatively small effect on the twine area calculation, while plausibly quite a large relative effect on the drag of a prawn trawl.

3. The Hampidjan netting seems to be out on its own in terms of the overall drag/twine-area relationship. Within the Hampidjan Dynex cases the proportional drag/twine-area relationship is reasonably upheld, given that the drag of the T90 trawl was higher than the standard-mesh trawl by an amount expected by the relative increase in twine area, however that relationship breaks down when comparing drag and twine area with any of the other material types, even after rationalising into the situation the effects of issues 1 and 2 above. The unique characteristic of the Hampidjan Dynex material compared to the others is its double-knot. This knot is not markedly different in shape or relative size such that the drag situation can be explained by issue 2. Instead one views with interest the effect the double-knot has on the ability of the mesh to open. Much about this has been mentioned already, because it has caused necessary amendments to the construction of the Hampidjan trawls to accommodate the situation, and caused increases in drag through the necessary increases in twine area. It appears that the detrimental effect on drag by the double-knot has been greater than that caused by the associated need for more meshes in the Hampidjan trawls, and the resulting increase in twine area. This is due to the fact that when more meshes are included in a given area of netting the mesh opening (effective hanging ratio) is reduced. This is known to adversely affect the drag coefficient for flow through netting panels by increasing the solidity ratio; that fraction of the hung netting area that is covered by the netting twine. The less thrifty the hanging ratio, the bigger is the solidity ratio and the greater is the hydrodynamic drag per unit of twine area (Fridman, 1986).

From a performance perspective there appears to be very little to be gained from using a double-knot in the Hampidjan Dynex netting (greater knot stability of questionable benefit – see results of Objective 1(a)) and a lot of negative consequences in terms of drag as outlined above.

Table 7: Tier 1 drag results for the various netting materials tested, compared with relevant netting factors.

	Drag Parameter N/(m/sec)^2	*Twine diameter mm*	*Knot area mm^2*	*Twine area mm^2*
24 ply 400 den PE	94.1	1.68	34.7	1.094
Ultracross Dyneema 1.1mm	64.6 (69%)	1.28 (76%)	0 (0%)	0.718 (66%)
Hampidjan Dynex 1.0mm Standard-mesh	77.1 (82%)	1.26 (75%)	23.1 (67%)	0.761 (70%)
Hampidjan Dynex T90	105.0 (112%)	1.26 (75%)	23.1 (67%)	1.018 (93%)
Euroline Premium plus	86.0 (91%)	1.4 (83%)	29.0 (84%)	0.943 (86%)

[3] Fridman (1986) states that for a plane netting panel set parallel to the flow the solidity (eg. twine diameter for a given mesh size) has little effect on drag.

Sensitivity tests for 24ply PE

Figure 40 shows the drag parameters estimated from the data in Figure 39 for the four configurations of the 24ply PE trawl tested. Turning the trawl inside out to cause the knot forces to push-in had a very small effect on drag. Although the trawl outline can be seen in the gallery photos (in Appendix 1) to inflate and deflate with the change in direction of the knot forces, the distance between the headline and footline was fixed by the vertical struts in the first two tests, and the extent of trawl shape change therefore restricted. Somewhat surprisingly, the drag increased slightly (0.7%) when the trawl had the deflated appearance (knots-pushing-in). This was contrary to the effect on drag of turning the trawl inside out in the last two tests, when the vertical struts were not applied. For the later comparison, the drag was lower for the deflated case by nearly 7%.

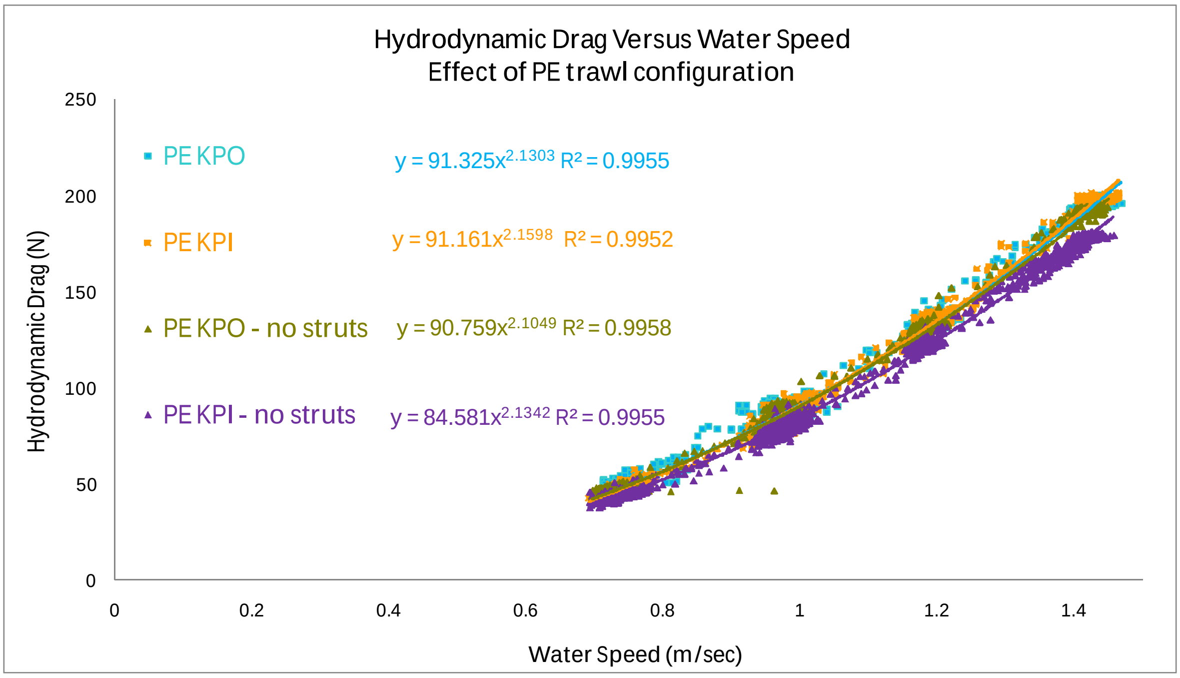
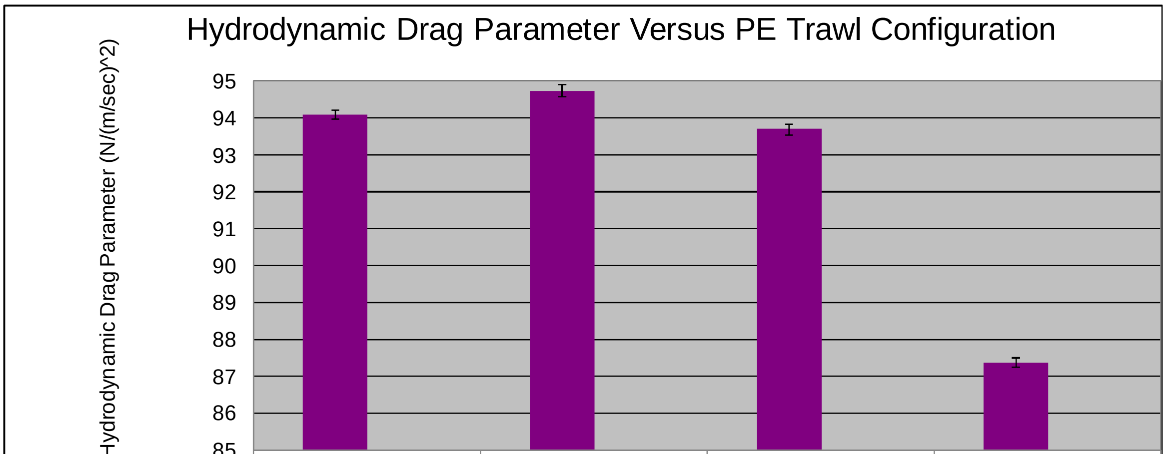


Figure 39: Raw drag data for the24ply PE trawl Tier 2 tests.



	24ply PE KPO	24ply PE KPI	24ply PE KPO no struts	24ply PE KPI no struts
Drag Parameter	94.11	94.75	93.71	87.39
Drag shift from stnd config	0.0%	0.7%	-0.4%	-7.1%

Figure 40: Estimated hydrodynamic drag parameters for various configurations of the 24ply PE trawl.

Close inspection of the associated photos provides a plausible explanation for the results, in that the application of vertical struts causes a slight increase in headline height in the bosom of the trawl for the knots-pushing-out (KPO) mode. Therefore for the case of no-struts the drag was slightly lower (0.4%), and the drag reduced further when the trawl was turned inside out (knots-pushing-in, KPI) as the trawl deflated and the headline height reduced further. In the case of deflation with the headline height fixed by the struts, the deflation appeared to cause the top and bottom panels to attain a small angle of attack to the flow, and could be why the drag for this case was the highest of all cases. The complex hypothesis described here proposes an "explanation" for some very small drag variations, which alternatively could be due to unknown systematic errors. Replicate tests are required to tests the veracity of the suggested explanations.

It is of practical interest to estimate from the experimental results what the effect of turning a full-scale PE trawl inside out would be in the field. Due to the fact that a real trawl effectively has the bottom frameline pinned to the ground by the weight of the ground chain, yet the headline is free to move vertically according to the balance of forces acting on it, it seems reasonable that the drag of a real trawl with knots pushing out would be represented by half of the drag from Test 1 plus half of the drag from Test 3, while for the case of knots pushing in, the drag would be reflected by half the drag of Test 2 plus half the drag of test 4. This gives 93.91 for KPO and 91.07 for KPI, and indicates a 3% reduction in drag when the knots are pushing in compared to when the knots are pushing out. The disadvantage of this "low drag" mode of operation is the lower headline height, which is estimated to be about 5% from the associated photos in Appendix 1. In practice the most popular knot orientations are KPO or a combination of KPO in the top panel and KPI on the bottom panel to keep the netting away from the seabed and also ensure that the fishing line is off the bottom and the trawl fishes cleanly. It is quite popular among quad-rigged boats though to have KPO on the bottom panel. This is because quad-rigged boats tow the gear quite quickly and KPO on the bottom panel helps the trawl hold ground contact.

Sensitivity tests for Euroline Premium Plus

Figure 42 shows the drag parameters estimated from the data in Figure 41 for the six configurations of the Euroline trawl tested. Turning that trawl inside out produced a measureable drag increase (3.0%).

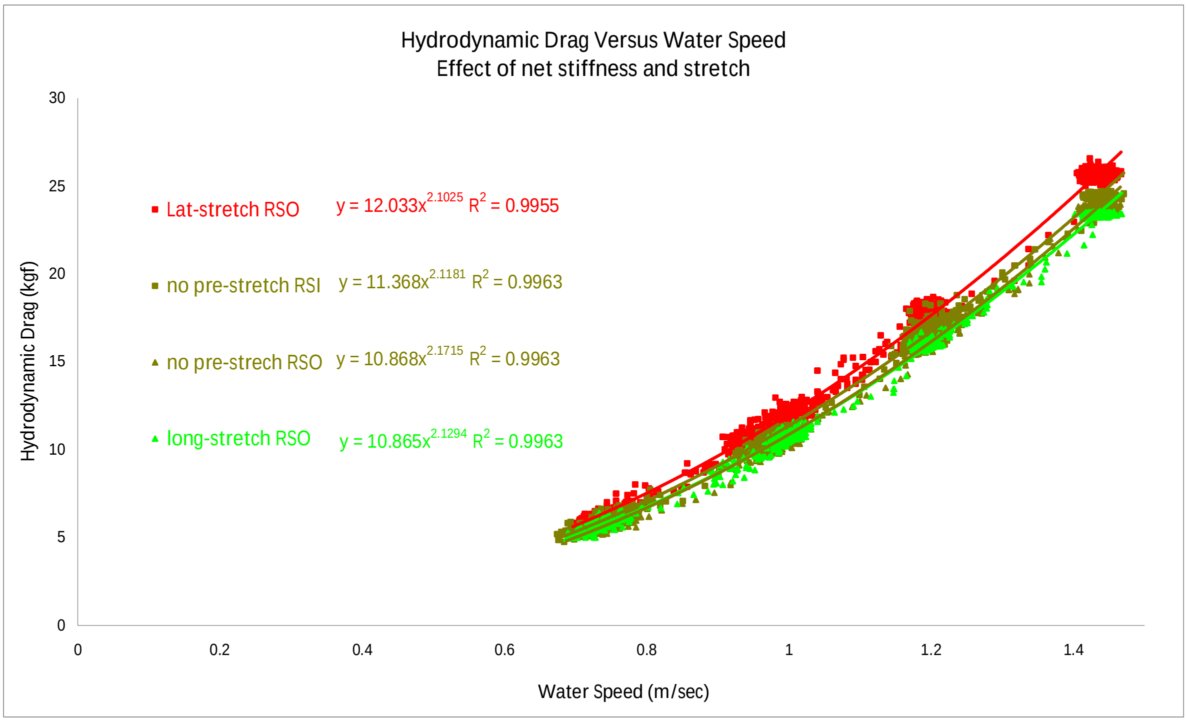
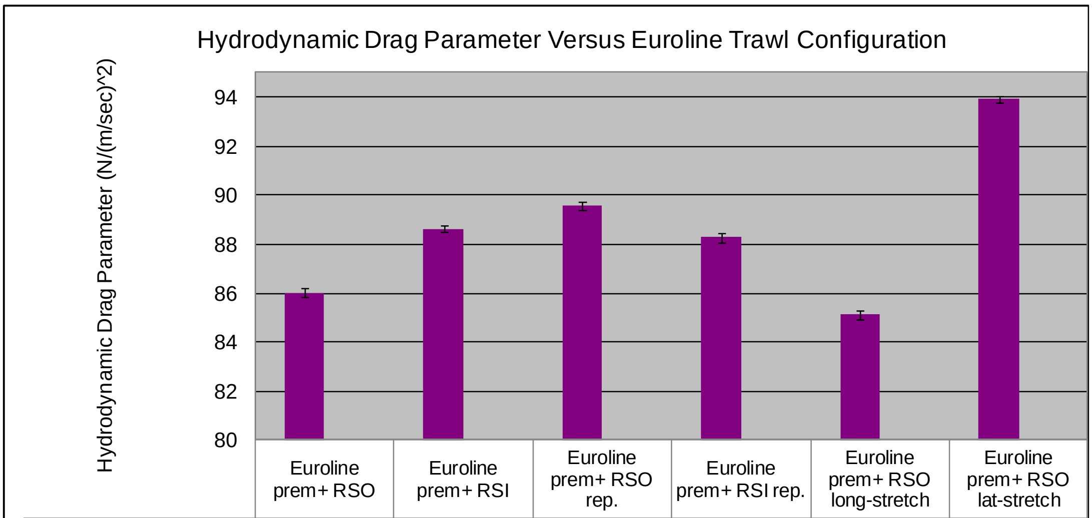


Figure 41: Raw drag data for the Euroline-trawl Tier 2 tests.



	Euroline prem+ RSO	Euroline prem+ RSI	Euroline prem+ RSO rep.	Euroline prem+ RSI rep.	Euroline prem+ RSO long-stretch	Euroline prem+ RSO lat-stretch
Drag Parameter	86.03	88.64	89.58	88.27	85.14	93.92
Drag shift from stnd config	0.0%	3.0%	4.1%	2.6%	-1.0%	9.2%

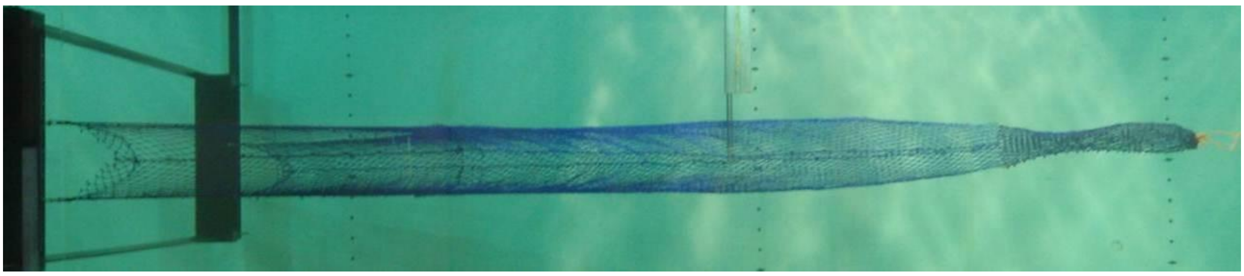
Figure 42: Estimated hydrodynamic drag parameters for various configurations of the Euroline trawl-net.

The above drag results show that deliberate stretching of the meshes in the model-trawl has a drag effect three times larger than that observed for the knot orientation test (difference between last two tests and first two tests in Figure 42). It is therefore not possible to exclude the possibility that the drag effect observed from turning the trawl inside out was not actually due to differences in the initial set of the meshes for this very stiff Euroline material; as the methodology did not include a standardised stretching of the trawls before testing.

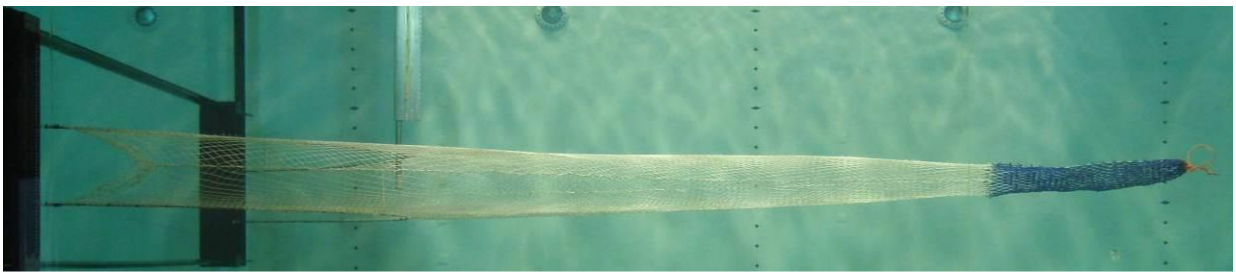
For the middle two tests of Figure 42 the first two tests were repeated, but an attempt was made to apply a standard stretch to the trawl before testing. For this pair of tests the effect of turning the net inside out was to slightly reduce the drag by about 1.5% rather than, as was previously evident, increase it by 3%. The final conclusion drawn by the tests conducted to date is that there was no statistically significant drag difference between RSO and RSI for the Euroline Premium plus netting.

Flow pattern tests

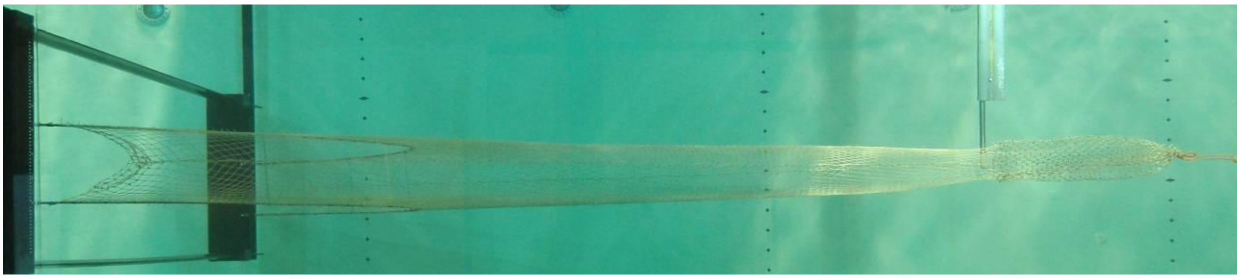
Figure 43 shows photos taken during the measurement of water speed down the centreline of three trawl netting scenarios.



a) 24ply PE (knot forces out) with standard codend.



b) Ultracross dyneema, with standard codend.



c) Ultracross dyneema with Dynex T90 codend.

Figure 43: The three trawl net scenarios being investigated in terms of centreline flow speed.

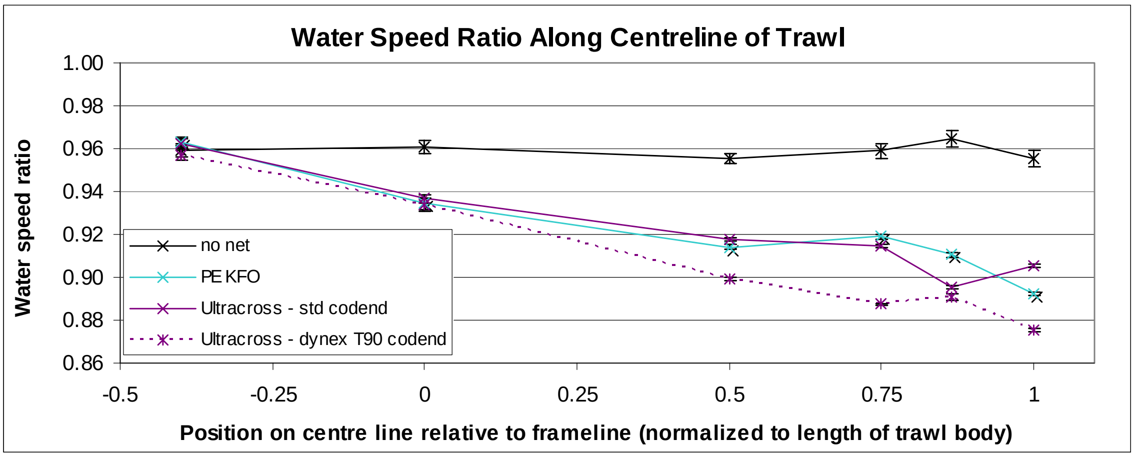


Figure 44: Residual water speed along the centre line of three model-trawl cases compared to water speed at the same location with no trawl being streamed.

Figure 44 presents the measurements of water flow down the centreline of the 24ply PE trawl and the Ultracross dyneema trawl. These two trawls provide the greatest contrast possible in terms of net blockage to test the hypothesis that as the netting in the trawl body gets thinner the centreline flow will reduce because of the relatively high blockage of the codend. There appeared to be no additional reduction in centreline flow for the Ultracross dyneema trawl compared to the 24ply PE netting. The utilisation of a 1.0mm Dynex T90 codend, which was designed to improve the centreline flow of the trawl, appeared to further slow rather than improve the centreline flow of the Ultracross trawl. Below (Figure 45) are close-up photos of the rear part of the Ultracross trawl for the two different codends that were used. These show no marked difference in the shape of the trawl between the two codend cases. The results seem to comprehensively disprove the hypotheses behind the tests and provide very baffling input to the question of optimal codends for low drag trawls. Based on the data there seems to be no need to worry about the relative blockage of the codend in the optimal design of a low drag trawl. The drag of the Ultracross dyneema trawl with the T90 Dynex codend was not measured. It was presumed that this small alteration to the trawl would have no measurable effect on overall drag. There are however anecdotal reports from the field that codend changes, for example the utilisation of square-mesh codends, do have a practically significant effect on overall drag. It may be that not testing a hypothesis that the utilisation of a T90 thin-twine codend reduces the overall drag was an oversight and may have provided clarifying input to the question raised in these tests.

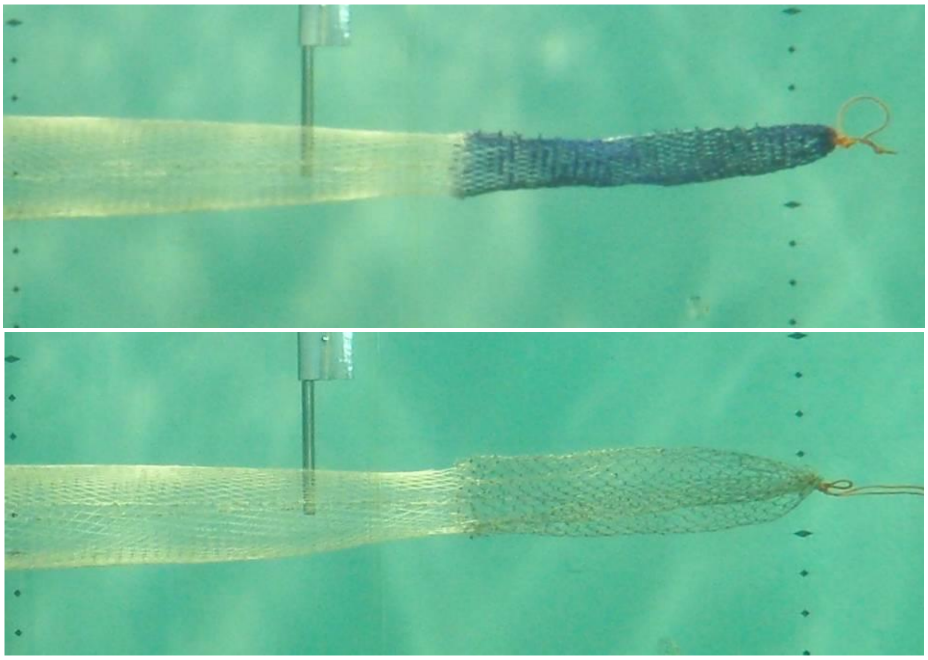


Figure 45: Close-up photos of the rear part of the Ultracross trawl with standard codend (upper photo) and Dynex T90 codend (lower photo).

Other valuable input data may have come from an expanded methodology whereby water flow measurements are obtained for a vertical transect at each of the test points in the trawl rather than just at the presumed “centre line”.

Conclusions and recommendations

For all test cases the drag-speed relationship was one where drag increased with water speed slightly more rapidly than proportional to speed squared. No firm conclusion can be drawn as to why this occurred, although it is suspected that the trawls may generally inflate slightly as internal forces build up and overcome bending stiffness of the of the twine elements in the mesh structure.

Compared to the standard industry material, 24ply PE, all the trawl constructed of thinner high strength materials displayed significantly less drag except for the T90 configured Hampidjan Dynex case. The T90 Hampidjan test exhibited a 12 % higher drag than the standard PE material, while the standard-mesh Hampidjan trawl had 18% less drag, the Ultracross trawl had 31% less drag and the Euroline trawl had 9% less drag.

Table 8 displays the reduction in drag for the tested high-strength materials compared to 24ply PE. For comparison Table 8 shows the reduction in twine area for the model trawls due to the use of thinner twine etc. Also presented in Table 8 is a result for Van Beleen spectra estimated from the data previously obtained by Low (1997).

Generally speaking, the drag reduction achieved does not reflect the reduction in twine area and there is quite a variation in agreence. It is believed that it is reasonable to assume that the effective diameter of the PE material is a little less than the overall diameter. A small correction for this affect brings close agreement between the drag reduction for Euroline Premium plus and the reduction in twine area for that model compared to 24ply PE.

The Ultracross Dyneema trawl had the greatest reduction in drag and unlike the other materials this was easily commensurate with the reduction in twine area it had compared to the PE trawl. It is proposed that due to being knotless, the removal of knots had a bigger effect on drag than the calculated effect on twine area. It is further proposed that this effect is manifested by the vast area of netting in prawn trawls that has a very low angle of attack to the flow and where form drag on the knots produces a significant contribution to the overall drag of the trawl. Hence removal of knots will hypothetically produce an amplified reduction in overall drag compared to their contribution to twine area, and this seems to be evident in the results.

Table 8: Achieved drag reductions compared to reduction in twine area for the models tested in the flume tank.

	Twine area reduction compared to 24ply PE based on twine area	*Drag reduction compare to 24ply PE for model trawls in the flume tank*
Van Beleen Spectra (* estimated from Low 1997)	37%	29%*
Ultracross Dyneema 1.1mm	33%	31%
Hampidjan Dynex 1.0mm Standard-mesh	30%	18%
Hampidjan Dynex T90	7%	12% increase
Euroline Premium plus	14%	9%

The Hampidjan Dynex material has disappointing drag characteristics because of the incorporation of double knots that restrict the lateral opening of the mesh. This has two detrimental effects on drag leading from the need for more meshes to cover the area of the trawl. Firstly there is a higher twine area in the trawl, and secondly, the trawl's netting surface has a higher solidity ratio than it would otherwise have. A strong conclusion of this study is that the Hampijan Dynex material would be far more user friendly and provide better, low-drag performance if it had single knots instead of double knots. Knot stability is only marginally improved by using a double-knot and returns very limited practical benefits.

Vertical forces on the knots in a PE trawl can have a significant effect on the shape of the trawl and a measurable effect on drag. For the knot pushing modes of practical interest, drag can vary over a range of 3%.

For Euroline Premium Plus netting it is a well held view that netting panels should be arranged such that the knots have their "rough side out" (RSO). There was no conclusive drag difference between a trawl with RSO as opposed to RSI configuration.

For model trawls made of stiff netting, example case being Euroline Premium Plus, a drag difference of 10% was affected by testing the trawl firstly with the Euroline netting stretched in the longitudinal direction and subsequently with the netting stretched in the lateral direction. This test highlighted the effect that trawl shape has on drag.

The conclusions drawn from experiments looking at centreline flow was that centreline flow was not apparently affected by reducing netting-solidity in the trawl body relative to the codend. On reducing the netting-solidity of the codend, by changing the codend material from 45mm X 60ply (2.3mm twine thickness) PE to T90 51mm X 1.26mm braided dyneema (Hampidjan Dynex), the centreline flow was measured to reduce. This was contrary to the prior hypothesis that the centreline flow would increase. A more detailed investigation involving transect surveys of flow velocities inside the trawl is required to clarify the flow processes at work.

The fundamental objective of the flume tank tests was to establish the relative drag of the different materials for the Australian prawn-trawling context. Table 8 summarises the results in that respect and can be used to produce, for testing in the field, a range of trawl systems that have a standardised configuration; i.e. spread ratio, fishing line height and seabed contact. With these variables standardised, measurements of engineering and catching performance, while trawling, will give clearer (un-confounded) indications of each material's relative benefits to industry.

Objective 2. Engineering and catching performance determined in the field for high-performance netting materials in Australian prawn trawling systems

Lowe (1997) compared the performance of prawn trawls constructed from 1.0 mm diameter, twisted, Spectra netting to 1.79 mm diameter, 30 ply, polyethylene netting; given that they were deemed to have similar strength. In a flume tank, the Spectra netting reduced the drag of a model trawl (no otter boards were used) by about 42%; similar to the 45% reduction in twine diameter. However, there was no significant difference in drag between full-scale Spectra and polyethylene trawl-systems (using flat rectangular otter boards) at sea. The spread ratio of the Spectra net was 86%; 14.5% higher than that for the polyethylene trawl. At this very high spread ratio it appears the associated increase in otter board angle of attack and drag, counteracted the drag saving from the Spectra netting. The benefit of the spectra netting in this case was a higher spread ratio, greater swept area rate, and presumably higher catch rates on the fishing grounds; although this was not tested in the study.

Due to the strong interaction between trawl specifications and otter board specifications with respect to trawling performance it is necessary as much as possible to allow contemporary and innovative trawls to be tested across a range otter board scenarios. For this project the assessment of high performance netting materials in the field involved collecting data from two rounds of field trials conducted on five highly standardised trawl-nets constructed from a range of contemporary and high performance netting materials. For the engineering assessment each trawl was tested on three otter boards of different size and for the separate catching trials all trawls were towed simultaneously in a 5-rig system as outlined in the description of methods below.

Methods

Based on the characteristics of the netting materials determined from objective 1, five material types were selected for evaluation in the field and for each a standardised full-scale trawl was designed. Due to features of the Dynex material and the availability of Spectra (1995) material, the trawls constructed from these materials had purposeful technical differences in respect to their net plans. However, all test trawls were equivalent in terms of headline length, lead-ahead, wingend meshes and "gape"[4].

Figure 46 shows net plans for the field trawls.

[4] Gape is the ratio of the width of the trawl mouth, measured in meshes, to the depth of the trawl mouth, measured in points.

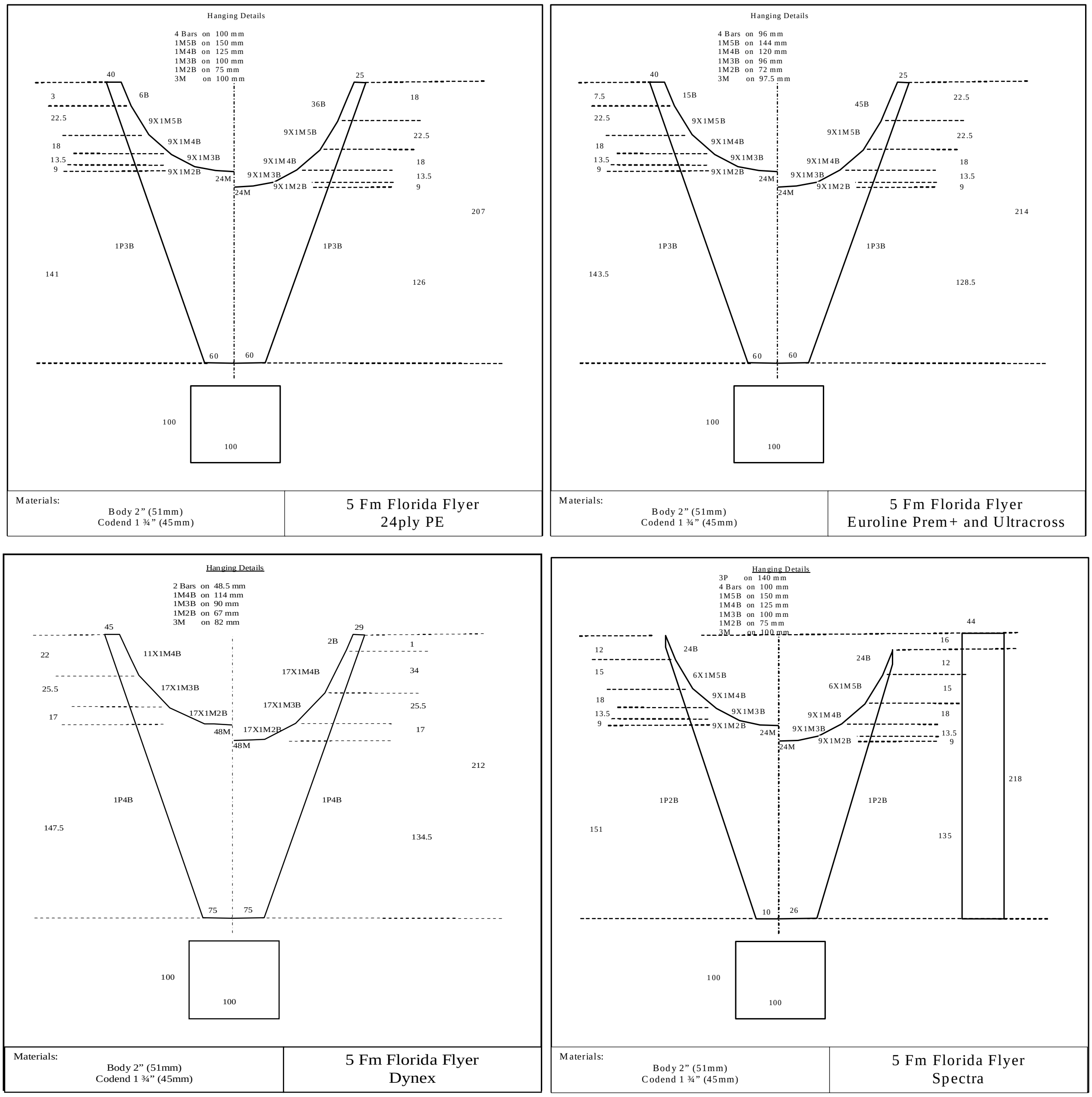


Figure 46: Net plans for full-scale field trawls.

It was envisaged that the low drag nature of the high performance trawls would require that the ground-gear arrangements needed to be different in order for there to be similar geometry between trawls despite having very different applied hydrodynamic and gravity forces. In the first instance the Ultracross trawl was hung on "neutrally" buoyant 6mm dyneema lines (as per Figure 47) rather than 6mm stainless wire to reduce the amount of gravity force around the mouth.

Figure 47: Dyneema frameline configuration for the Ultracross trawl – The fishing line was wrapped with 20mm PE.

Secondly, a dropper chain configuration was selected for each trawl such that their relative weights matched the relative drag of the trawls (as determined in the flume tank). As per Figure 48, the heavy dropper was used for the PE trawl, medium for the Premium Plus and Dynex trawls, and light for the Ultracross and Spectra trawls. This was designed to produce a standardised seabed contact (benthic impact) for the trawls.

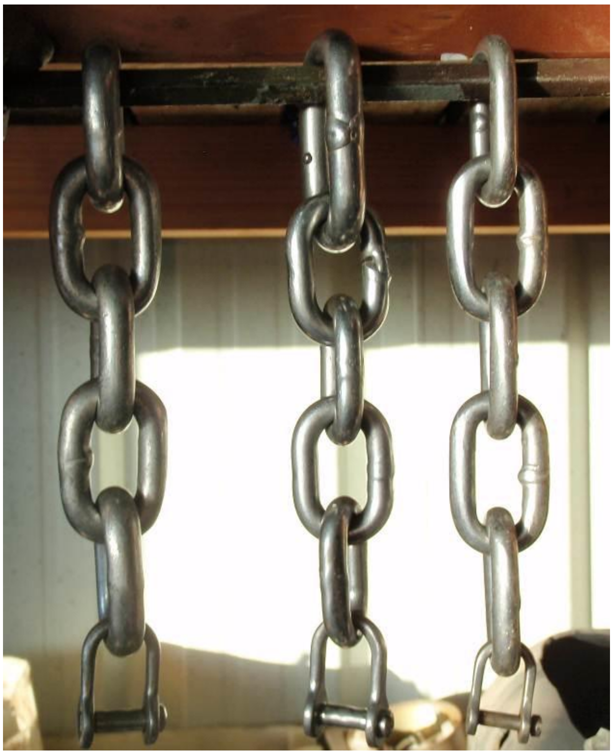


Figure 48: Three dropper chain arrangements; Heavy, medium and light, from left to right.

Engineering Trials

Comparative trials in terms of engineering performance and underwater observations were undertaken over five days (15-20/8/2011) within Rainbow Bay (north of Double Island Point). The five purpose built trawls were compared for three different otter board sizes.

Figure 49: FV Cking rigged for engineering trials of high performance trawls.

FV CKing (shown in Figure 49 with skipper and crew) is the 15m trawler from Tin Can Bay that was rigged to tow a single trawl spread by a pair of otter boards on each side of the vessel (double rig). Each trawl shot therefore utilised two trawls and two pair of otter boards, leaving 3 trawls and one pair of otter boards unutilised at any given time.

Trawls and otter boards were randomly selected to produce a schedule of 22 paired comparisons between 15 possible net/board cases. These comparisons were then reordered to reduce the number of required board changes, as these are difficult and dangerous to accomplish at sea. The resulting comparisons, and their order, is mapped in Table 9 to indicate clearly the number of replicates for each of the 15 net/board cases. The number of replicates was biased towards combinations that were deemed at the outset to be “a good match”.

Table 9: Schedule of paired comparisons for the engineering trials.

	Board	*1*				*2*					*3*				
Net		large				med					small				
1	PE	**1**	**9**	**5**	**16**	**8**	**17**	**20**			**3**	**22**			
2	Dynex	**2**	**8**			**4**	**21**	**22**	**13**	**16**	**11**	**18**			
3	Prem Plus	**7**	**18**			**3**	**6**	**10**	**11**		**15**	**21**	**14**		
4	Ultra cross	**6**				**5**	**15**	**12**			**1**	**4**	**13**	**19**	
5	Spectra	**17**				**7**	**14**	**19**			**2**	**9**	**10**	**12**	**20**

Table 10 provides details of the three pair of Kilfoil otter boards utilised during the trials.

Table 10: Specifications of the three sets of Kilfoil otter boards used during the engineering trials.

	Board 1	Board 2	Board 3
Length (m) X Height (m)	2.130 X1.025	1.865 X1.100	1.960 X 0.940
Number of foils	4	3	4
Foil Area (m^2)	0.956	0.931	0.778
Keel height (mm)	140	0 – weed gaps	130
Weight (kg)	169	155	152

During each paired comparison codends were left open so that catch quantity was not a confounding factor in the generation of drag and the extent of the gear's spread.

Figure 50: Arrangement of instrumentation for the engineering trials.

Figure 50 shows the arrangement of instrumentation displays set up on the vessel to measure drag, spread, speed and record underwater observations with the camera gear. Water depth from the ships echo sounder was also recorded for each trial comparison.

For each comparison a reciprocal tow was applied so that the effect of water currents at any time could be averaged out of the drag data. As it happens it was found that spread measurements could not be obtained simultaneously from both sets of gear, so the trials were organised such that spread on the port side was collected on the first tow while spread for the starboard side was obtained during the reciprocal tow.

Figure 51: Load and spread measuring instrumentation attached to the trawl gear.

Figure 51 shows the load cell measuring tension on the port trawl warp and scanmar distance sensors fitted to the portside trawl system prior to deployment.

Underwater observations of the operational gear indicated that for the low drag trawls, fishing line height was lower than for the 24ply PE trawl and the ground chain contact at the centre of the PE trawl was very light and tended to became non-existent when trawl speed approached 3.0knots or the ground chain was pulled forward to practical settings used for “clean” conditions. Based on these observations the length of the droppers in the centre part of all trawls were increased from 180mm to 250mm and for the 24ply PE trawl more dropper weight was applied before the biological trials. It was presumed that standardised ground contact for the trawls (and associated fishing line heights) was important, so that the effect of these factors on catch is controlled.

Biological Trials

Comparative trials in terms of catching performance were undertaken for the various high performance trawl-nets over five days (29/8/11-2/9/11) within Wide Bay, Queensland, between Teewah Beach, south of Double Island Point, and Eurong on Fraser Island. FV Cking, a 15m trawler from Tin Can Bay, was chartered for the trials.

FV Cking was rigged to tow the five trawls simultaneously between a single pair of otter boards (Board 2). Trawls position in the trawl system was randomly allocated 8 times, with a minimum of four replicates shots undertaken for each configuration. This produced a total of 35 comparisons. Table 11 is the schedule of utilised configurations and the number of replicate shots undertaken for each case. For each trawl shot the trawl speed was approximately kept constant at 3 knots.

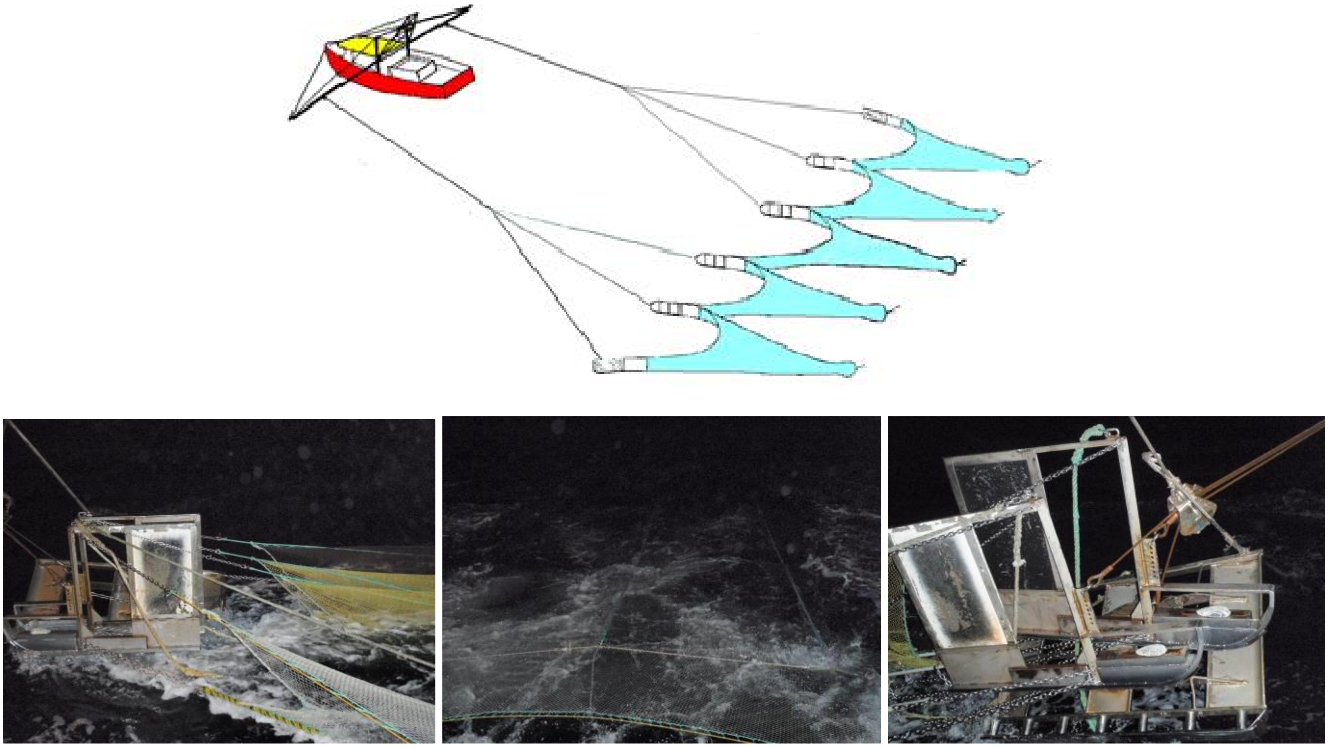


Figure 52: The 5-rig arrangement of trawl gear used for biological trials.

Table 11: Schedule of trawl-system configurations and replicates for biological trials.

	Port	**Port inner**	**Middle**	**Star. inner**	**Starboard**	Replicates
1	Dynex	Ultracross	PE	Prem.Plus	Spectra	4
2	Ultracross	Dynex	PE	Spectra	Prem.Plus	5
3	Spectra	PE	Dynex	Ultracross	Prem.Plus	4
4	Dynex	Spectra	Prem.Plus	PE	Ultracross	5
5	PE	Prem.Plus	Ultracross	Dynex	Spectra	4
6	Ultracross	Prem.Plus	Spectra	Dynex	PE	5
7	Prem.Plus	PE	Ultracross	Spectra	Dynex	4
8	Spectra	Ultracross	Dynex	Prem.Plus	PE	4

After each 30 minute tow each codend was emptied into individual baskets and the catch was sorted into four components at a specific location on the tray for each position in the trawl system (as shown in Figure 53). Four crew undertook sorting of each shot and the same crew member sorted the same rig position for all shots. This methodology produces the effect that standardisation of the results for location in the trawl system also standardises for inter sorter differences in sorting the catch.

Figure 53: The sorting operation whereby the catch of 4 codends are sorted simultaneously by 4 crew. The fifth trawl is sorted subsequently after the first 4 trawls are cleared.

The weights of all catch components were measured using the Marel M1100 motion stabilised scales shown below, and the data was entered after each shot onto a catch spreadsheet (Figure 54).

Figure 54: Catch weighing and data recording areas.

The catch components logged by the sorting and weighing process were:

- Commercial prawns
- Fish
- Crabs
- Benthic material (including non-mobile animals)

Data Analysis

Because of the experimental design, the resulting data sets are quite complicated in structure and require Generalised Linear Mixed Modelling (GLMM) techniques to produce the clearest possible statistical estimates of the relative performance of the different materials in respect to various performance indicators that allude to each material's benefits in respect to fuel efficiency and catching effectiveness in the field. The experimental designs were chosen so that the collection of field data efficiently used vessel-charter time.

The quality of the resulting data is mainly dependent on the accuracy of the instrumentation used to measure the independent and dependent variables of the experiments and the variability existing in the operation of the gears.

SPSS GLMM software was used to model the resulting experimental data and identify the significance or otherwise of material type on performance.

Results

Drag Data - Descriptive Statistics

Figure 55 presents the drag data in terms of the raw means and 95% confidence intervals for each of the 15 standard cases and also one additional case that was tested at industry's request. The special case relates to a treatment conducted on the Prem.Plus/Board 1 combination where thin twine of a length equivalent to a "desired spread" was tied to the noses of the otter boards. This was to test the hypothesis that over-sized boards might be controlled using such a string to cause the angle of attack of the board to reduce once it achieved the desired spread of the gear. The technique appeared to work in the field as planned and potentially generated a practically significant reduction in relative drag.

An immediate surprise in the data is that the drag of all trawls using Board 2 was higher than their drag when using the larger Board 1. This indicates that despite the lower area of Board 2, their three-foil configuration produces more drag than the four-foil configuration of Board 1. Board 2 also had a "weed-gap" configuration rather than the more usual solid keel that was assumed would cause a reduced spreading capacity and potential cause relatively low drag. Net spread information is required to corroborate whether or not the high drag of Board 2 is linked to greater spreading capacity.

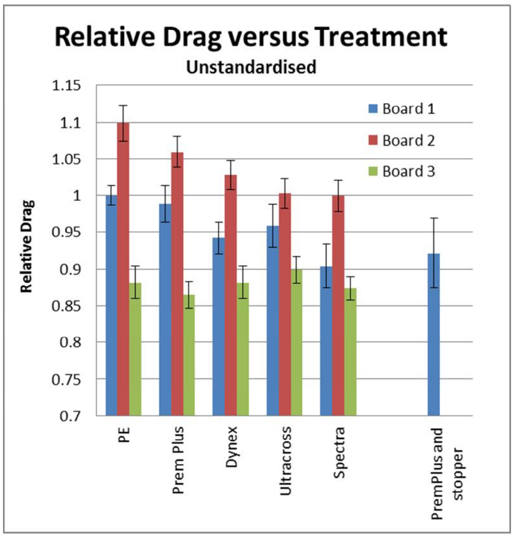


Figure 55: Average drag results for each trawl/board combination with 95% confidence intervals.

In general the indicated degree of drag reduction from connecting trawls with high performance materials to a given set of otter boards was relatively small (<= 10%). The general trend for boards 1 and 2 is as expected with large twine diameter trawls having greater drag than thin twine diameter trawls. However, the results for Board 3 was that drag for the high performance trawls was higher than the drag of the trawls with thicker twine (PE and Prem.Plus). This result could be biased because the analysis does not remove the variation in drag that occurs from one tow to another due to uncontrollable changes in the test conditions (eg wind, currents, applied thrust etc.). These factors cause random variation in the data and also the chance that substantial distortion of the results can occur.

Although there were only 22 paired comparisons undertaken, with a reciprocal course undertaken for most tows and a variety of replicates, depending on circumstances, a total of 54 separate "Tows" are identifiable in the data.

A Linear Mixed Model applied to the data with "Tow" as a random factor allows estimates of the unbiased effect of the trawls and boards on drag. Figure 56 indicates the model estimates of these effects.

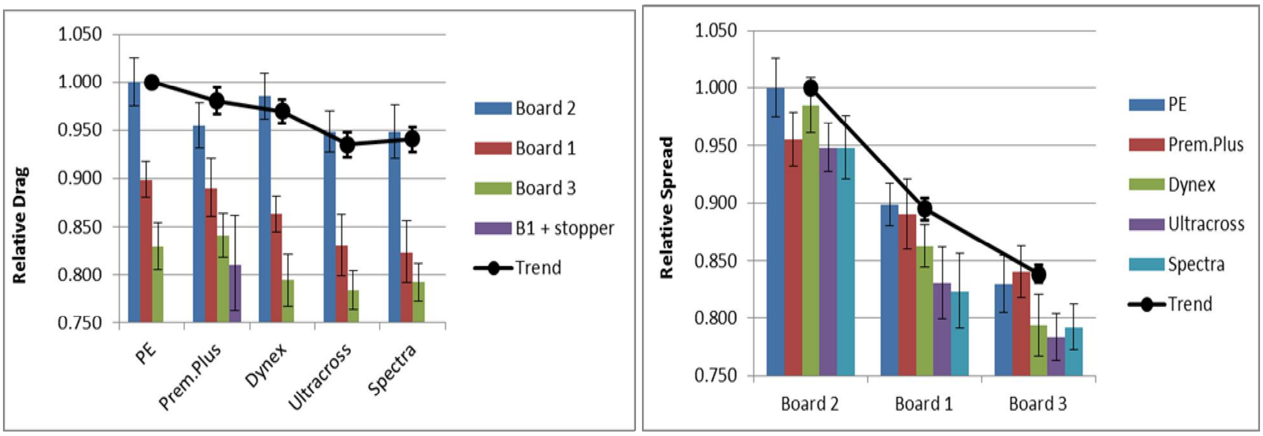


Figure 56: Predicted mean drag effects of trawls and boards and their interactions from a Linear Mixed Model with Tow as random factor.

These results indicate that there was indeed significant distortion in the unstandardized results. The relative drag results for Board 3 now correlate with twine diameter as expected and the results for Board 1 are also somewhat more aligned with expectations. The estimated mean drag reduction due to the reduced twine diameter of the high performance trawls is quite low (about 6% for Ultracross and Spectra trawls). There is however a 16% reduction in drag between the worst case (Board 2) and best case (Board 3) otter boards. If the low drag boards are able to maintain good spread for the low drag trawls then the combination will produce a good level of fuel saving.

Spread Data - Descriptive Statistics

For a stable trawl system the spread of the gear is quite static. Theory and observations confirm that trawl spread is not systematically sensitive to trawl speed to a great extent. Ground contact forces are known to produce a substantial component of the spreading force for boards of this type and varies depending on the ground contact pressure occurring at the time. The amount of spread information recorded was fairly low compared to the amount of drag information due to the slow update rate of the Scanmar distance sensors that were attached to each set of gear. Additionally, problems were experienced with the high variability of the data and the large amount of false data (numbers that did not match the range of physical possibilities). For most of the trials only one set of Scanmar sensors, on one side or the other, were installed as it was suspected that they were causing signal interference with each other.

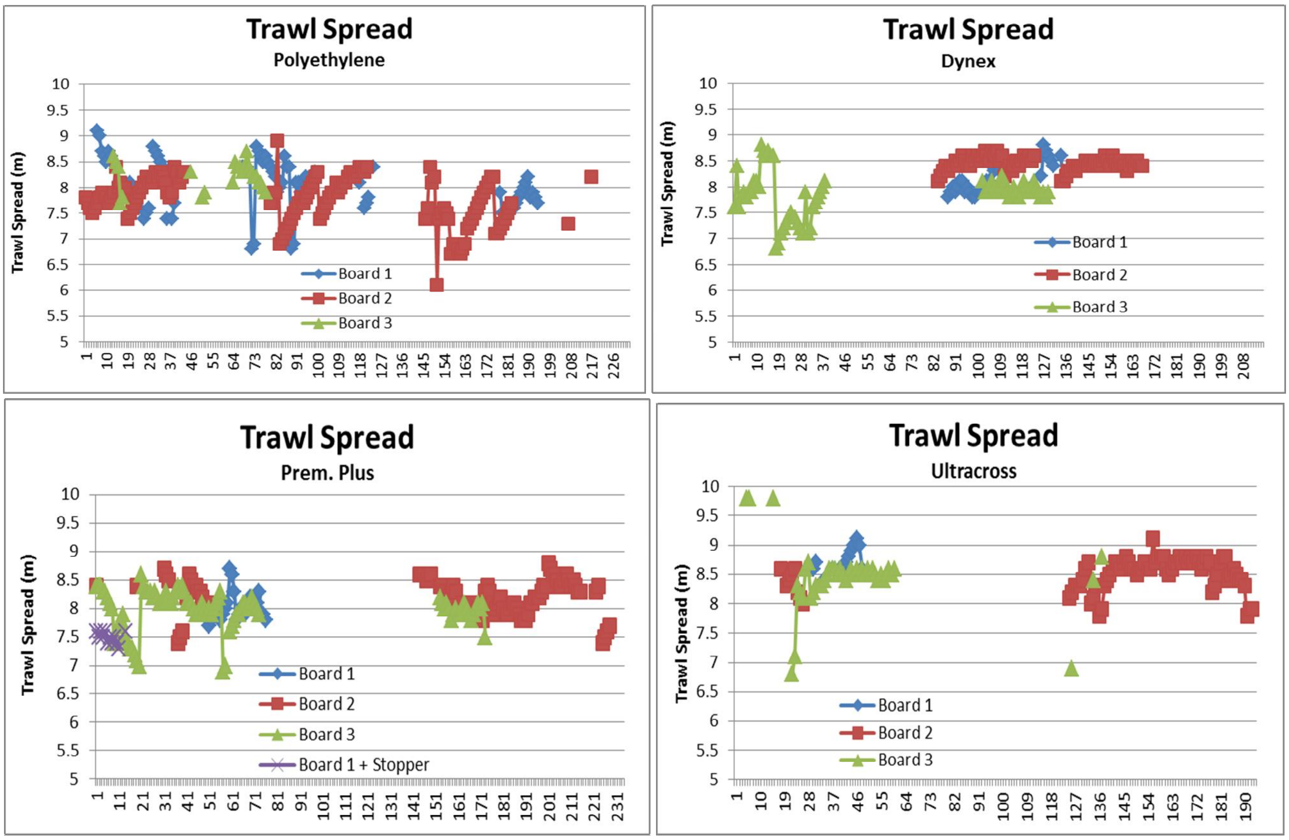
The table below shows the mean trawl spreads obtained for each of the 16 cases. The data indicates that for 3 of 5 trawl materials Board 2 produced more spread than the Board 1, which concurs with the findings above that the drag for the Board 2 cases was higher than for the Board 1 cases.

Table 12: Raw mean spread values for each of the trawl gear cases.

Mean Spread (m)	Otter board			
Trawl	Board 1	Board 2	Board 3	Board1 + stopper
PE	8.04	7.76	8.22	
Dynex	8.13	8.44	7.85	
Prem.Plus	8.04	8.19	7.99	7.49
Ultracross	8.71	8.50	8.46	
Spectra	8.33	8.70	8.15	
Grand Mean	8.16	8.29	8.10	7.49

For most of the high performance materials the spread was higher for the smaller Board 3 than for the more-resistant PE trawl using the larger boards. This tends to support the idea that Board 3 is a better match for the low drag trawls, while the larger boards are an equivalent match for the high drag trawls (PE and Prem.Plus). The trawl-spread dataset though has some inconsistencies in that the PE trawl is also indicated to have a higher spread with the small board compared to the large boards. This feature of the results is believed unrealistic and most likely a result of distortion due to the large amount of spread data variation and the low number of replicates for the PE and small-board's case.

Figure 57 shows the raw spread data obtained by the Scanmar system for the 16 cases. This clearly indicates the lack of clarity produced by the variation in the data.



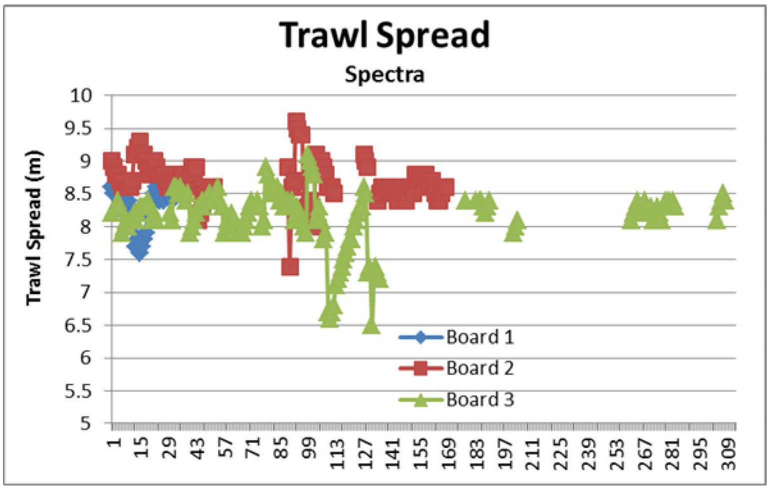
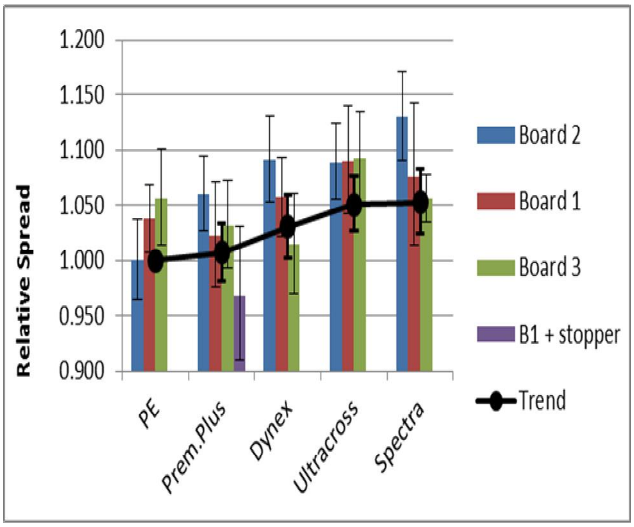


Figure 57: Plots of spread data over time for each of the 15 trawl-board combinations.

A greater abundance of spread data would help resolve conclusions about the performance of the gear, but more so would be the use of an experimental design where some of the variation could be correlated with co-variables/factors in the subsequent statistical analysis. This would be possible if more than one trawl is connected between a given set of otter boards and synchronised spread data could be collected. The latter is not possible for the Scanmar system because although the system contains two sets of distance sensors, they could only be monitored one at a time (even if it was assured they didn't interfere with each other when both on the trawl gear at the same time). The new Notus system purchased for FRDC project 2011/10 also has two sets of distance sensors, which definitely can be operated simultaneously and can produce two streams of spread data that are synchronised to within a few seconds.

The spread ratios for the trawl systems are between 87% and 95%. This is surprisingly high given the previously assumed spreading capacity for Kilfoil otter boards. These very high spread levels most likely produce very high angles of attack for the boards during the field trials, and this might be contributing to the observed high level of spread variation and instability.

Despite the number of individual inconsistencies in the data, which makes fine scale interpretation of interactions between trawls and otter boards very difficult, Linear Mixed Model analysis still allowed useful broader conclusions about the effect of the trawls and boards on spread. Figure 58 shows the results of that analysis. The low drag trawls had 5% more spread for any given otter board, while the lower capacity Board 3 produced 2.5% less spread than Board 2.



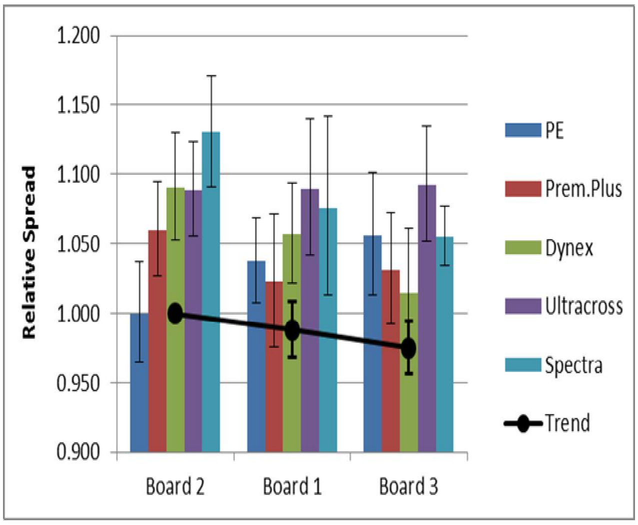


Figure 58: Predicted mean spread effects of trawls and boards and their interactions from a Linear Mixed Model with Tow as random factor.

Combined Engineering result

To determine a useful comparative fuel-consumption result for each trawl, a board was selected for each such that all trawls would be spread most closely to the same amount. Given the high degree of uncertainty in the individual results, it was appropriate to construct estimates of trawl performance for the selected trawl/otter board systems based on the identified trends in the data rather than individual results. The gear selection and the estimated mean performance of these trawl systems are shown in Figure 59. Also shown are 95% confidence intervals that reflect fully the degree of uncertainty in the field data.

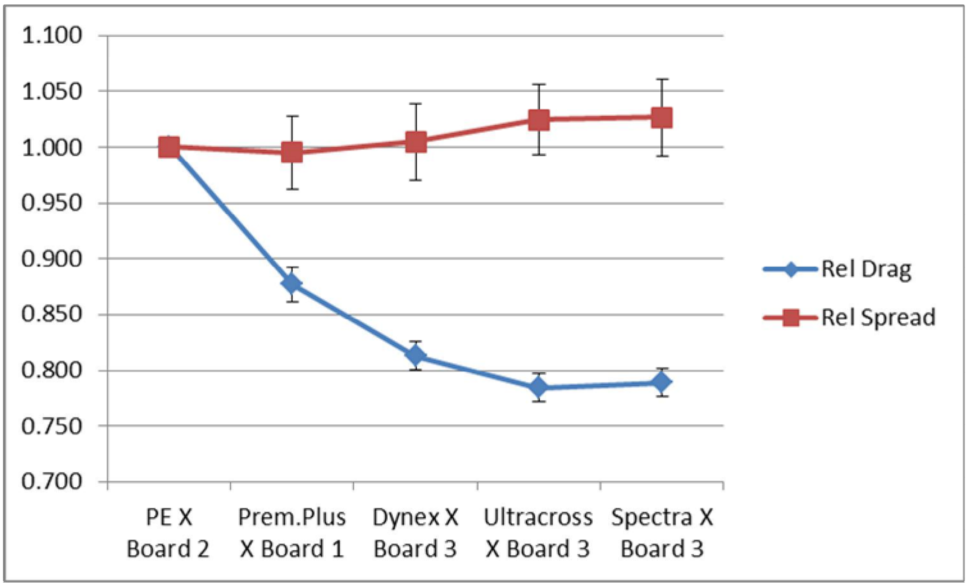


Figure 59: Predicted relative drag and spread of selected trawl systems.

Despite matching the lowest capacity boards with the low drag trawls, the Ultracross and Spectra trawls still probably have 2.5% higher spread compared to the PE trawl with the highest capacity board and the Prem.Plus trawl with the intermediate capacity board. The fuel saving benefits, as reflected by the reduction in drag for a given speed, is quite substantial; about 12% for Prem.PLus, 19% for Dynex and 21% for Ultracross and Spectra.

Catch Data - Descriptive Statistics

Table 13 provides average catch statistics for the five tested trawl-nets across all the trawl shots. Generally the catch rates of prawns were low by commercial standards (about 10kg/hr for the whole trawl system). On the other hand there were high levels of bycatch and quite a large amount of benthic material collected.

It appears that all high performance trawl-nets, except Spectra, caught a greater weight of prawn than the traditional PE net. However, they also generally caught larger amounts of bycatch as well, and the Dynex and Ultracross nets fished quite heavy for benthic material despite attempts to set all trawls up during the engineering trials to have similar ground gear geometry. Partway through the catch trials the ground chain on the Dynex trawl was let back a link to try and reduce the catch of benthic material (mainly starfish). The catch of starfish was particularly problematic for the soft material nets, eg, Ultracross and Spectra, as the starfish tended to foul these nets more readily and it was considerably more difficult to clean starfish out of these nets than the others. The photo in Figure 60 shows a comparison of starfish fouling in the "soft" Ultracross dyneema net compared to the "stiff" PE net.

Table 13: Average catch statistics for the five trawls over all 35 trawl shots.

	Target prawn			*Demersal fish*	*Crab*	*Benthic material shell+squirts+stars*
	wt (kg)	#prawn	count (per kg)	wt (kg)	wt (kg)	wt (kg)
PE	0.84	43.6	52	15.19	0.75	3.38
Dynex	1.00	49.0	49	20.61	1.22	7.11
Prem.Plus	0.93	47.2	51	17.60	1.01	4.77
Ultracross	0.88	38.3	44	16.60	1.22	5.24
Spectra	0.64	27.2	43	15.71	0.79	3.30

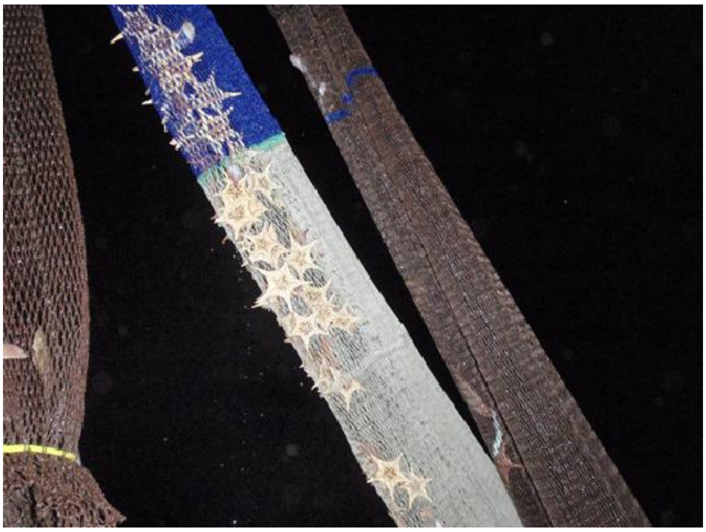


Figure 60: Visual comparison of PE and Ultracross trawls in terms of the retention of Starfish in the throat.

The linear modelling analysis of the catch data produced a more detailed picture of the relative catching performances between the different trawls. A variety of linear models were constructed for each of the catch components and the most informative are reported.

Table 14 is the output for a linear model of the target prawn catches and indicates that there were significant difference in catches between trawls and location within the trawl system. The analysis also indicated that the average prawn size in the catch had a significant effect on the relative catch between trawls.

Table 14: Generalised linear modelling results for prawn catches.

Fixed Effects

Target:prawn_wt

Source	F	df1	df2	Sig.
Corrected Model ▼	6.738	13	156	.000
net_name	13.927	4	156	.000
location	3.051	4	156	.019
net_name*prawn_size	4.728	5	156	.000

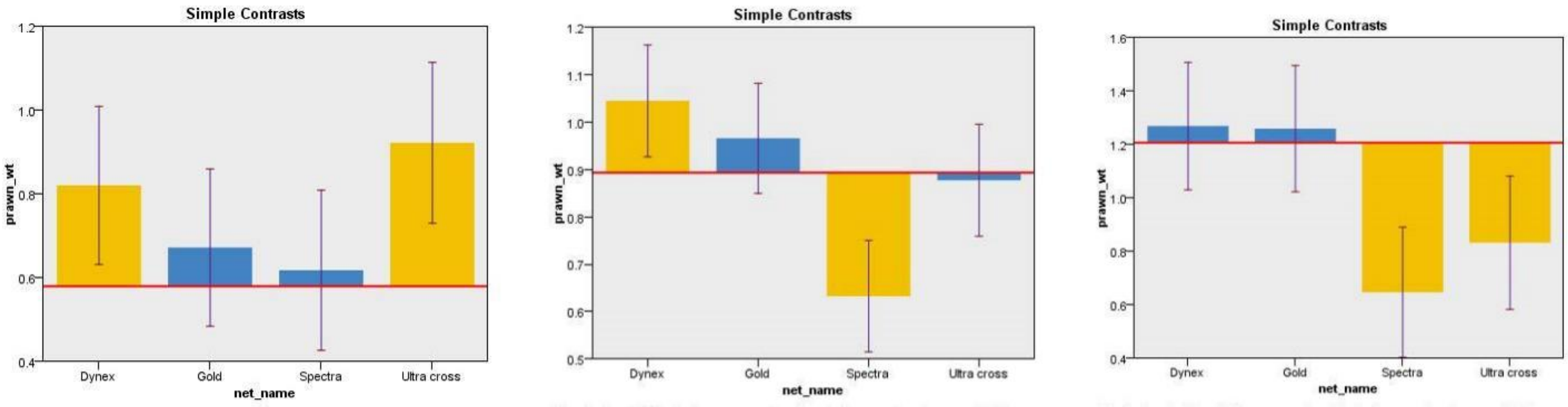
Probability distribution:Normal
Link function:Identity

In Figure 61 the relative prawn catches between the trawls and location within the five-rig are displayed. For the trawls, three prawn size scenarios are considered; 30 count/kg, 50 count/kg, and 70 count/kg, given the significance of this effect.

For all prawn size scenarios the Prem.Plus (Gold) trawl caught approximately the same quantity of prawns as the PE trawl. A slightly higher catch was observed for the Gold trawl, but this was not statistically significant for each prawn size scenario.

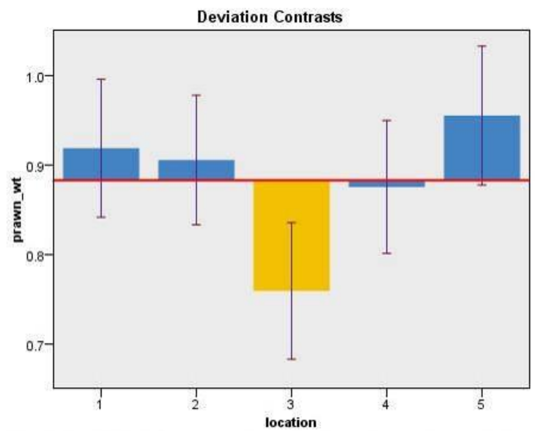
When the catch was dominated by larger prawns (average size of 30/kg), the Dynex trawl and Ultracross trawls significantly caught about 35% more than the PE trawl, while the other ultra-high molecular weight polyethylene (UHMWPE) trawl, Spectra, had no significant difference. For catches of medium prawns (average size of 50/kg), the catching performance of all three UHMWPE trawls reduced relative to the PE trawl, but the Dynex trawl still caught about 15% more while the Ultacross caught no significant difference and the Spectra trawl caught significantly less (by about 18%). For trawl-shots returning small prawns (average size of 70/kg), the UHMWPE trawl's catching performance reduced even further relative to the PE trawl. For this grade of prawn the Dynex trawl caught about the same as the PE trawl while the Spectra and Ultracross trawls both catch significantly less (about 35% less).

It is hypothesised that behind the relative catch results, which are sensitive to prawn size, there are two mechanisms, either of which being causal or perhaps both are at play. Table 15 contains derived linear factors for the reductions in prawn catch, as prawn count increases, for each of the high performance trawls relative to stable catches in the PE trawl. These factors are based on estimates from the linear models of the sensitivity of prawn catches to prawn size and therefore quantify the effects displayed in Figure 61 (a, b, c). For example, the catch of the Ultracross trawl relative to the PE trawl is estimated to reduce by about 20% for each increase of prawn count of 10/kg. The strongest effect of prawn count on catch is shown for Ultracross, followed reasonably closely by Spectra, a moderate effect for Dynex, and a relatively small effect for Prem.Plus (Gold). Given that the strength of the effect roughly equates to the lack of flexural rigidity of the mesh material, it seems plausible that suitably small prawns are able to push more readily through the softer UHMWPE netting materials compared to the stiff materials like PE and Gold.



(a) prawn_size = 30/kg (b) prawn_size = 50/kg (c) prawn_size = 70/kg

The horizontal line is the prawn_wt estimated at net_name = PE. The vertical bars are the simple contrasts (prawn_wt at each level of net_name minus prawn_wt at net_name = PE). Significant contrasts are shaded gold. The least significant difference adjusted significance level is 0.05.



The horizontal line is the prawn_wt overall estimated mean. The vertical bars are the deviation contrasts (prawn_wt at each level of location minus prawn_wt overall). Significant contrasts are shaded gold. The least significant difference adjusted significance level is 0.05.

Figure 61: Estimated mean catch of target prawns per 30min for each trawl and each location in the trawl system with reference to the PE trawl and the average catch respectively

An alternative explanation could be that the catch of larger prawns is enhanced for the high performance trawls that have the lowest drag because there is a greater flow of water through the trawl and this promotes the capture of the larger more active prawns that might more readily escape forward or over the higher drag trawls like PE and Gold. It is not possible from the data to determine which of the two processes is correct or more dominant if in fact both processes are occurring.

Table 15: Estimated escape rate for smaller prawns through high performance mesh relative to PE.

Trawl	*Shift in prawn catch for an increase in prawn count relative to constant PE catch (%/(count/kg))*
Prem.Plus (Gold)	-0.24
Dynex	-0.74
Spectra	-1.63
Ultracross	-2.02

From Figure 61 it can be seen that the significant effect of trawl location on catch is driven by quite a large observed reduction of prawn catch (about 12%) for the middle net of the 5-rig trawl system. This could reflect lower seabed contact for the middle net or an effect of the vessel crabbing (having an angle of yaw to the tow direction). It is the case that if the vessel has an angle of yaw, which it will if there is a side current or side wind, the middle net will experience the most distortion (one wing forward relative to the other). This could upset the fishing process for prawns.

Table 16 is the output for a linear model of fish catches and indicates that there are significant difference in catches between trawls and location within the trawl system.

Table 16: Generalised linear modelling results for fish catches.

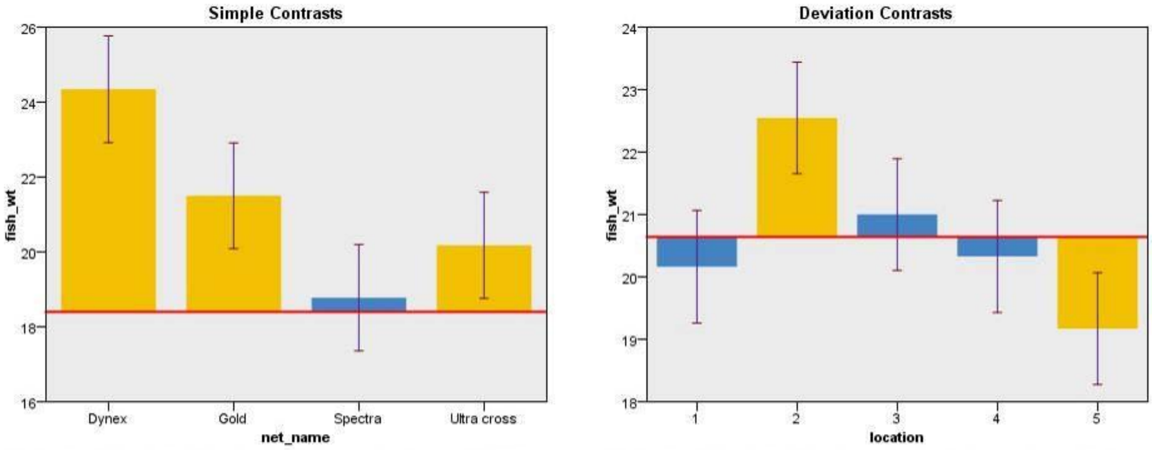
Fixed Effects

Target:fish_wt

Source	F	df1	df2	Sig.
Corrected Model ▼	14.599	8	161	.000
net_name	22.599	4	161	.000
location	6.128	4	161	.000

Probability distribution:Normal
Link function:Identity

In Figure 62 the estimated relative catches of fish between trawls and location within the trawl system is displayed. The Spectra trawl caught no significant different amounts of fish compared to PE, while the other trawls; Dynex, Gold and Ultracross, all caught significantly more fish bycatch. The Dynex trawl caught significantly more fish than any of the other trawls (about 30% more than PE). It's hard to identify a reason why the Prem.Plus (Gold) and two UHMWPE trawls caught more fish than the PE trawl, yet the Spectra trawl did not. Given that generally the Spectra trawl had quite low prawn catches compared to the PE trawl (by about 18%), yet still caught similar amounts of fish, this produces the result that the Spectra trawl actually had the highest Fish:prawn bycatch ratio (about 29). Similarly, taking into account the prawn catches for the Dynex, Gold and Ultracross trawls produces the result that the fish:prawn bycatch ratio for these three trawls are all about the same (about 23) and not substantially higher than the ratio for PE (about 20.5).



The horizontal line is the fish_wt estimated at net_name = PE. The vertical bars are the simple contrasts (fish_wt at each level of net_name minus fish_wt at net_name = PE).
Significant contrasts are shaded gold. The least significant difference adjusted significance level is 0.05.

The horizontal line is the fish_wt overall estimated mean. The vertical bars are the deviation contrasts (fish_wt at each level of location minus fish_wt overall).
Significant contrasts are shaded gold. The least significant difference adjusted significance level is 0.05.

Figure 62: Estimated mean catch of fish per 30min for each trawl and each location in the trawl system with reference to the PE trawl and the average catch respectively

The estimated effect of trawl location on fish catch, as displayed in Figure 62, is a complex picture that is very different from the situation for prawns. No consistency between the results for prawns and fish indicates that very different catching mechanisms are involved and different factors drive performance. Generally, the inside trawls catch more fish than the outside trawls, which could be a result of the bridle arrangement for Five–rig whereby the bridle connected to each otter board pass relatively sharply across the face of the outside trawls. In this case the fish catches on the starboard side (locations 1 and 2) are higher than the fish catches on the port side (locations 4 and 5). This might be a feature of the vessel having a yaw angle in a particular direction, for some unexplained operational reason.

Table 17 is the output for a linear model of benthos catches and indicates that there are significant difference in catches between trawls and no significant difference for location within the trawl system.

Table 17: Generalised linear modelling results for benthos catches.

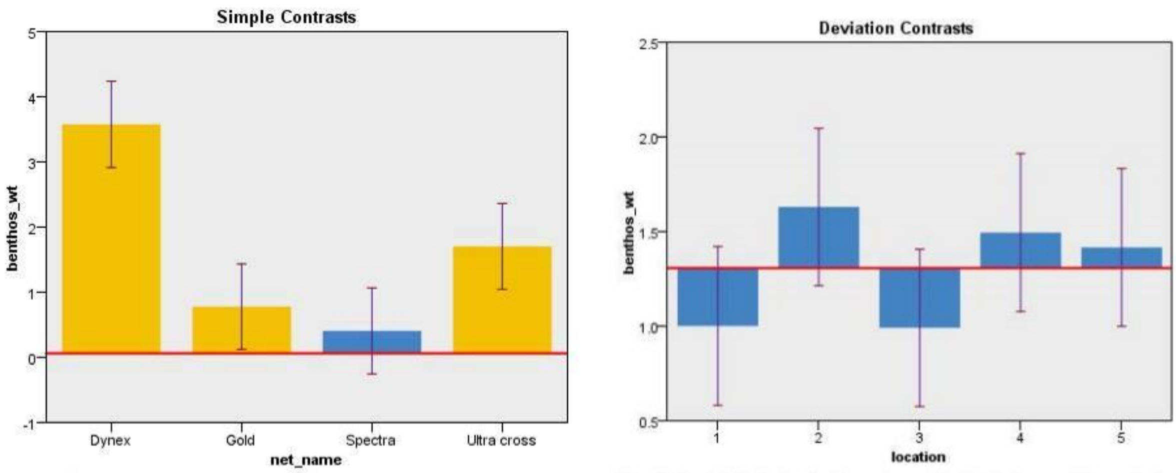
Fixed Effects

Target:benthos_wt

Source	F	df1	df2	Sig.
Corrected Model ▼	18.271	8	161	.000
net_name	35.376	4	161	.000
location	1.534	4	161	.195

Probability distribution:Normal
Link function:Identity

In Figure 63 the estimated relative catches of benthos between trawls and location within the trawl system is displayed. The Spectra trawl caught no significant different amounts of benthos compared to PE, while the other trawls; Dynex, Prem.Plus (Gold) and Ultracross, all caught significantly more benthos. Once again the Dynex trawl caught significantly more of this catch component than any of the other trawls. Given that the PE trawl “fished very clean”, caught very little benthic material, the Dynex trawl by contrast was exceptionally dirty, and the ultracross trawl was somewhat similar. Although the volume of benthic material was somewhat less for the ultracross trawl, the ramifications of the dirty catch are made more significant by the fact that the soft Ultracross netting makes it quite arduous to clear away the benthic material caught in the meshes.



The horizontal line is the benthos_wt estimated at net_name = PE. The vertical bars are the simple contrasts (benthos_wt at each level of net_name minus benthos_wt at net_name = PE).
Significant contrasts are shaded gold. The least significant difference adjusted significance level is 0.05.

The horizontal line is the benthos_wt overall estimated mean. The vertical bars are the deviation contrasts (benthos_wt at each level of location minus benthos_wt overall).
Significant contrasts are shaded gold. The least significant difference adjusted significance level is 0.05.

Figure 63: Estimated mean catch of benthos per 30min for each trawl and each location in the trawl system with reference to the PE trawl and the average catch respectively

It could be that the general cause of the dirty fishing characteristics of the high performance trawls compared to PE is the higher spread ratio that would be occurring and the associated effect of lowering the height of the fishing line relative to the ground chain. This is a recognised effect of trawls that contain lead-a-head due to the fact that the strain in the trawl becomes biased towards the top panel as spread ratio increases. Reduced strain in the lower panel as spread ratio increases, particularly at the centre of the fishing line, reduces the force holding the fishing line off the seabed. This effect might have been mitigated to some extent for the Ultracross trawl because the fishing line was made of dyneema rather than stainless steel. The obvious exception to this general observation is the spectra trawl, which despite presumably having the same elevated spread ratio, maintained quite clean catches. The explanation for this could be the fact that the spectra trawl is the only 4-seam trawl in the series (see Figure 46), which means that its lead-a-head is arranged somewhat differently compared to a standard 2-seam flyer, and the trawl has a relatively low number of meshes in the height of the wingend. The end result of these features is that the trawl has a less netting in the walls of the wings, which gives rises to stronger upward forces on the fishing line.

In hindsight it now seems prudent that for the high performance trawls (except spectra) the headline could have been let back relative to the fishing line to increase the strain in the lower panel and clean up the catch (reduce the amount of benthic material caught). This is achieved by increasing the length of the headline sweeps compared to the fishing line sweeps by a few centimetres. It is possible that this may also reduce the target catch, but being reactive to the gear, any reduction in prawn catch should be relatively smaller than the sort-after reduction in catch of immobile material.

Table 18 is the output for a linear model of crab catches and indicates that there are significant difference in catches between trawls and no significant difference for location within the trawl system.

Table 18: Generalised linear modelling results for crab catches.

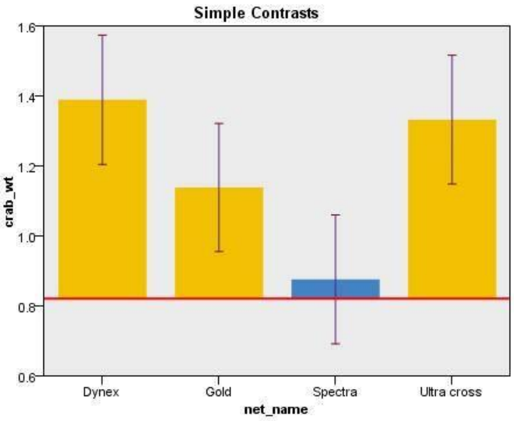
Fixed Effects

Target:crab_wt

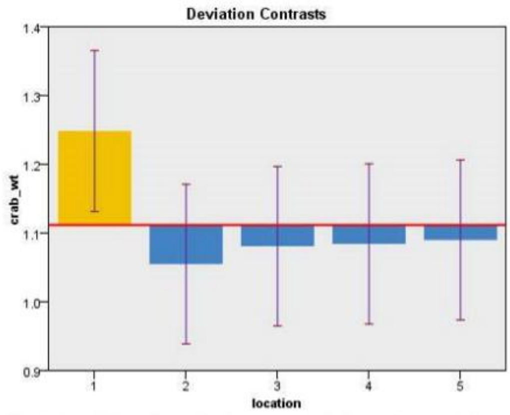
Source	F	df1	df2	Sig.
Corrected Model ▼	9.113	8	161	.000
net_name	15.304	4	161	.000
location	1.370	4	161	.247

Probability distribution:Normal
Link function:Identity

In Figure 64 the estimated relative catches of crabs between trawls and location within the trawl system is displayed. The relative catch picture for crabs is quite similar to that for benthos. The high performance trawls, except spectra, caught substantially more crab than the PE trawl. Most of this crab was non-commercial bycatch and a nuisance to the normal sorting process. All the high performance trawls would be expected to have higher spread ratio, and in response all except spectra could be expected to have lower fishing line height and higher catch efficiency for crabs. Once again it would be beneficial if the high crab catches could be reduced to levels similar to PE and Spectra by “letting go” the associated headlines by suitable amounts. The detrimental effect that this might have on target prawn catches is unknown and well worth investigating.



The horizontal line is the crab_wt estimated at net_name = PE. The vertical bars are the simple contrasts (crab_wt at each level of net_name minus crab_wt at net_name = PE).
Significant contrasts are shaded gold. The least significant difference adjusted significance level is 0.05.



The horizontal line is the crab_wt overall estimated mean. The vertical bars are the deviation contrasts (crab_wt at each level of location minus crab_wt overall).
Significant contrasts are shaded gold. The least significant difference adjusted significance level is 0.05.

Figure 64: Estimated mean catch of crabs per 30min for each trawl and each location in the trawl system with reference to the PE trawl and the average catch respectively

Although no position in the trawl system gave a significant different crab catch compared to any other location, the plot of the associated deviation contrasts in Figure 64 indicates that location 1 (starboard side) returned crab catches that were significantly higher than the average crab catch for all locations. This is not consistent with the estimated effects of location on benthic catches (no location produced benthic catches significantly different from the overall average) and given that it was only marginally significant, no practical importance is placed on the result.

Conclusions and recommendations

Although the effect on trawl system drag of netting material on its own was only about 6%, it was demonstrated that the combination of low drag netting matched with appropriately sized otter boards produced a system drag reduction of over 20%. This is a conservative benefit attributable to the implementation of high strength netting because the smallest boards used still produced about 2.5% more spread for the low drag trawls than the largest capacity boards on the standard PE trawl. This means that even smaller boards could be used to give commensurate spread for the low drag trawls, and this would reduce system drag even further.

The catching performance of the low drag trawls with respect to target prawns was generally impressive; except for the Spectra trawl, where the catch of prawns matched the catch from the PE trawl only for large prawns and was substantially lower for small prawns. The low prawn catching performance for the spectra trawl is hypothesised to be due to its 4-seam construction and lesser meshes in the wings, which plausibly has caused it to have a higher fishing line height and possibly lighter ground chain contact.

It was demonstrated that the low drag trawls seemed to exhibit a great preference to catch large prawns compared to the PE trawl, particularly those that had a soft netting material (eg. Spectra and Ultracross). Due to the small twine diameter the size of the mesh opening is somewhat larger, for a given mesh size. This, combined with the softer flexibility of the twine seems to promote the escape of smaller prawns. Less flow resistance could also promote the free movement of the trawl through the water and the associated reduced disturbance of the water might promote the capture of large fast swimming prawns.

The high performance trawls, other than Spectra, generally caught disappointingly large amount of unwanted fish, crabs, and benthic material compared to the PE trawl. It is hypothesised that this was due to the higher operating spread ratio for those trawls, and that this could have been mitigated by increasing the length of the headline sweeps a few centimetres relative to the fishing line sweeps. For the Dynex trawl and the Ultracross trawl it is essential for commercial viability that this strategy delivers the intended reduction in bycatch as it was quite a burden to sort their catches. There is room for this measure to inadvertently reduce target prawn catch, as the catch of larger prawns was substantially higher than for the PE trawl. The bottom line is that the measures taken to mitigate "dirty" catching performance for the high performance trawls, that being reduced dropper chain weight, the use of dyneema framelines for the Ultracross trawl and the use of underwater observations to detect residual differences in ground gear geometry, where insufficient to practically deal with the problem, which in this case seems to be driven by very low fishing line tension and exacerbated by the very high operating spread ratios. Unfortunately the methodology of the field trials did not incorporate a component of experimentation to counter-balance these issues and their effect on bycatch retention through adjusting the extent that the headlines were let back relative to the fishing line. The unresolved question is how much the target prawn catch would be reduced in the process of achieving cleaner catches. It is feasible that the target prawn catch might not be reduced substantially, however the lower prawn catches observed for the spectra trawl does suggest that this possibility should not be disregarded casually.

Benefits and adoption

The main output from the research is knowledge of the relative performance of trawls made from thin, high strength netting compared to conventional netting in respect to service life, engineering performance (drag and span of the trawl gear) and catching performance. There is also documentation of design and operational issues associated with the use of high performance materials, as identified by the project, and the methods used or suggested to resolve the ramifications of these issues.

The knowledge developed from the various stages of the project was made available to research colleagues and industry via various fisheries magazine articles, meetings/workshops and refereed conference proceedings:

1. Fishing News International, August 2009 "Australian Netting Tests".
2. The Queensland Fisherman, September 2009 "Results from study into high strength trawl netting".
3. Fisheries Queensland workshop for observer/extension officers, January 2010 "Prawn Trawling in Queensland".
4. First International Symposium on Fishing Vessel Energy Efficiency, May 2010 "Trawl-gear innovations to improve the energy efficiency of Australian prawn trawling".
5. FAO Expert Workshop on Energy Use in Fisheries, November 2010 "Energy Use in Fisheries – An Australian Industry Perspective".
6. QSIA Climate Change Conference, February 2011 "Ways to Save Fuel and Energy Costs".
7. QSIA Fraser Island to Mackay Trawl Fishery EMS Workshop, March 2012 "Australian Carbon Policy: Opportunities and Constraints for the Fishing Industry"
8. Second International Symposium on Fishing Vessel Energy Efficiency, May 2012 "Prawn Trawl Drag due to Material Properties – An Investigation of the Potential for Drag Reduction".

9. Proceedings of the 31st International Conference on Ocean, Offshore and Arctic Engineering OMAE31, June 2012 "High Porosity Net Drag at a Low Angle of Attack in Application to a Representative Prawn Trawl".

3 hours of high quality underwater video footage (taken in very clear water), showing the operation of trawl gear in respect to otter boards, trawls and ground gear, is available for the production of industry videos. In the coming months Oceanwatch will be producing a range of videos for the Moreton Bay Trawl fishery in conjunction with a value-chain development initiative funded in partnership with the Seafood CRC and industry. This footage will be amalgamated into those video outcomes.

It is envisaged that practical extension of the results to industry will also occur through the process of applying energy audits to fishing businesses. The scientific results of the project on the implementation of high strength netting to prawn trawl fisheries provides rare quantitative information on the subject to the energy auditing process and allow the proposition of high strength netting to be put to trawling businesses as a carefully considered strategy for achieving higher fuel efficiency.

Further development

Further work is required to clarify the effect of critical adjustments to the gear that appear to be required for purposeful standardisation of the catching process. It was envisaged upfront that catching performance would be sensitive to the geometry of the ground gear, and it was presumed that this interacts intimately with the hydrodynamic characteristics of the netting used in the trawl. It appears that mitigation measures taken in the design and construction of the various trawls, including the reduction of dropper chain weights for the low drag trawls and the use of light-weight dyneema framelines in the case of the Ultracoss trawl, were insufficient to standardise the operation of the ground gears. Such is the sensitivity of the geometry of this part of the gear to other variables, such as spread ratio, the experimental program should have included methodology to make adjustments to the degree to which the headlines of the trawls were let back relative to the fishing lines so that "optimal' or "standardised" fishing performance was obtained for all trawls. A robust methodology to achieve this outcome might best involve a systematic investigation of the effect of that trawl adjustment on the relative magnitude of catch components for a subset of strategically selected trawls. The approach taken in this project to standardise the results for these effect was to ultimately rely on underwater video observations to detect residual differences in ground gear geometry and take relevant action to make the geometry "standard" across all trawl nets. This was conducted during the engineering trials, which compared the trawls in various double rig configurations. Video feedback concentrated on combinations of trawls and "matching" otter boards, which therefore tended to focus on the trawls at a similar spread ratio. Substantial adjustments to the ground gear were made, including the lengthening from 180mm to 250mm the length of the 4 centrally located dropper chains on all trawls and increasing the weight per unit length of these droppers for the PE trawl, to remedy observed problems with the ground gear arrangements. It appears that the flaw in the methodology is linked to the use of kilfoil boards, the use of five-rig for the catching trials, underestimating the spreading power of kilfoil otter boards, and assuming that the geometry of the ground gear would not be strongly sensitive to the differences in spread ratio that would occur across the trawls. These issues and the implications did not become apparent during the engineering trials because the collected spread information was sketchy and variable and the observed differences in spread across the different trawls for a given otter board was quite small in absolute terms (5%). However, these differences in spread were occurring at exceptionally high spread ratios (average of 90%) and therefore actually represent very large differences in the spread and in-pull force scenarios across the different trawl gear arrangements and a wide range of strain distribution situations within the trawls.

Planned outcomes

Successful adoption of high strength netting with 33% smaller twine diameter into the Queensland prawn trawling industry should produce 30% reduction in fuel usage and costs for operators (this is the theoretical benefit). For the experimental trawls that had this level of twine diameter reduction (Ultracross and Spectra with 1.1mm and 1.28mm twine versus 1.68mm twine for PE – average of 29% reduction), the demonstrated reduction in overall drag was only 21%. However this is probably conservative compared to the best possible outcome because the field trials failed to produce test cases where spread ratio was exactly standardised. With a reasonable degree of certainty the Ultracross and Spectra trawls could have used smaller otter boards to achieve a spread equivalent to that of the PE trawl (reduction of 2.5% spread) and this would have produced a greater drag reduction.

Nevertheless, a 21% reduction in fuel consumption for a typical east coast trawler is equivalent to a financial saving of about $28,000 per year. This easily covers the cost of purchasing more expensive netting for the trawl gear. It was also demonstrated that there is not likely to be any reduction in overall target prawn catch, particularly if larger prawns are being caught; so there is not likely to be any reduction in revenue.

Similar benefits would occur for all prawn fisheries in Australia. This outcome represents a substantial contribution to the need to reduce fuel costs in the Australian fishing industry and improve economic viability.

The materials testing program undertaken in the laboratory before the field evaluation provided a detailed indication of the relative strength of the subject materials in terms of tensile mesh strength, tensile T90 strength, tensile square mesh strength and the effect of a standard abrasion exposure on tensile mesh strength. The resulting information proved that the advanced forms of high strength netting (Ultracross and Dynex) had a mesh strength that was still about 3 times higher than the PE material despite having a 25% reduction in twine diameter. Additionally, the standard abrasion test showed that the strength reduction rate was similar for all materials, except Spectra which wore very badly. This indicates that the dyneema netting products could afford to lose 66% of their strength through wear processes in the field and still have a residual strength that is as good as new conventional material. Therefore trawls made of modern dyneema materials are likely to have a much longer service life and lower levels of maintenance than trawls made from conventional PE netting.

Conclusion

The results of the project produced conclusions with respect to the objectives of the project as outlined below:

Objective 1. For commercial netting of 50mm nominal mesh size, measure and compare the dimensional, mechanical and hydrodynamic characteristics.

a. *Measure the relative strength of various netting materials suitable for Qld prawn trawling.*

The superior strength features of high-performance netting were confirmed by quantitative load-to-failure tests. Despite the reduced twine diameter of the high performance materials, they all had similar or greater strength than the traditional polyethylene netting for the diamond-mesh samples (Standard-mesh and T90). For the Spectra and Euroline materials the strength was about the same as polyethylene, but the mesh strength of the two Dyneema materials (Dynex and Ultracross) were about 3 times higher despite having a 25% reduction in twine diameter.

The orientation of the netting used in a trawl is largely based on choice. Given the wide variety of netting constructions their relative performances does vary with mesh orientation. For the single knot materials T90 strength was higher than standard mesh strength, but it was determined that this was a feature of the shape of the test pieces rather than the material itself. From this conclusion it is proposed that the most reliable indication of the general relative strength of the netting materials, in normal service, comes from the breaking strength of the materials when in T90 orientation. The square mesh tests fundamentally indicate the knot stability of the various materials and returned the result that the single knotted materials were similarly relatively weak, while the double knotted material, Dynex, was able to support a load 3 times higher before the knots began to slip, and the knotless Ultracross netting was the only material that supported a load contingent on the actual strength of the twine rather than slippage of the joints. The strength of Ultracross square mesh was easily 10 times higher than all of the single knotted materials and more than 3 times higher than Dynex. Ultracross therefore is highly recommended for square mesh applications because of its highly superior strength and its perfectly square mesh-shape. The double knot in Dynex netting does produce elevated knot stability, which has been identified as useful for some trawl designs (eg. WA Flat trawl) that have a tendency for knot slippage. Dynex is not ideal for square mesh applications though, because the double knot does not allow the mesh to form regular square openings and knot slippage occurs well before the load carrying capacity of the twine is approached.

b. Assess the relative wear resistance of various netting material types.

The wear resistance tests indicated that the rate of strength reduction during service is likely to be similar for high performance materials compared to traditional material. The wear treatment produced an average strength reduction across the materials of about 60% (40% residual-strength), although the Van Beelen Spectra material, was effectively destroyed by the treatment and had zero residual strength. The Spectra material was supplied in the late 90's for the work by Lowe (1997) and has been replaced by a superior product.

None of the materials, apart from the Spectra appeared to be significantly different ($P<0.1$) from traditional polyethylene in terms of % residual-strength. There is some indication in the results that the Euroline material might have better wear resistance if the rough side of the material is opposite to the side experiencing the more intense wear treatment. But the result was not significant at $P<0.1$. There is also a suggestion, which cannot be proved by the current results, that the Ultracross material has a lower wear resistance than standard knotted Polyethylene. Despite the observed lower % residual-strength of the worn Ultracross material compared to worn polyethylene, it was still as strong as new polyethylene, in absolute terms, after a 65% reduction in strength because of the very high initial strength of the Dyneema products. Therefore trawls made of modern dyneema materials are likely to have a much longer service life and lower levels of maintenance than trawls made from conventional PE netting.

From the experimental data it is feasible that the tested dyneema netting would have about 2.5 times the service life of the standard PE netting. Given the high labour component to the cost of building trawl gear, the savings associated with the extended service life of the trawls already offsets the added material costs of building the dyneema trawls.

c. *Conduct a detailed drag and flow study for various materials and trawl construction techniques, using the flume tank.*

The tow resistance tests in the flume tank indicated that large drag reductions occur commensurate with reduced twine diameter, while knot structure also plays a practically-significant role in determining drag.

Although the removal of knots (knotless netting) has a relatively small effect of the transverse-projected-area of the netting, there is an emphasised effect on drag for prawn trawls, presumable because of the large effect "going knotless" has on the in-plane projected-area, or roughness, of the netting sheet.

Crucially it was found that double-knots in the Dynex material had a detrimental effect on drag as they effectively reduce the mesh size of the netting by restricting the lateral opening of the mesh. However , if due account is taken of this process in the selection of "mesh size", by aiming for equivalent area of mesh opening, then most of the negative drag impact would be removed.

There was no conclusive drag difference for Euroline Premium Plus trawls with a "Rough side out" knot arrangement as opposed to "Rough side in".

Objective 2. Compare the engineering and catching performance of prawn trawling systems in the field; each configured to be compatible ("optimal") respectively to the five netting types under investigation.

The field work highlighted the highly complex, diverse, and chaotic environment in which the prawn trawling industry operates and how this makes it challenging to introduce new technology. Substantial drag reduction (21%) was demonstrated in the field for the thinnest netting material (twisted Spectra) and the knotless dyneema trawl. It was concluded that a greater drag reduction could have been achieved if still smaller boards were used for the lowest drag trawls.

The catch of target prawns was strong for the low-drag trawls compared to the conventional trawl, and heavily biased towards larger prawns for the trawls made from soft flexible twine.

High bycatch retention, particularly immobile benthic material, was a substantial problem for most of the low drag trawls. But given the contrasting clean catches for the Spectra trawl, which also happened to be a 4 seam trawl, it was identified in hindsight that this serious practical problem could have been remedied by the common industry practice of letting the headline back relative to the fishing line to increase the strain in the lower panel and fishing line and ensure there is a functional "trash gap" between the fishing line and the ground chain.

For the trawls constructed of soft material, much of the additional retained material became lodged in the netting such that the trawls became very labour intensive to keep operational.

Further targeted field trials are required to thoroughly understand/document the interactions between high-performance netting materials, the catch of benthic material and bycatch, and appropriate mitigation measures. The unresolved question is how much the target prawn catch would be reduced in the process of achieving cleaner catches. It is feasible that the target prawn catch might not be reduced substantially because it is more reactive to the trawl compared to the immobile benthic material, however the low prawn catches observed for the spectra trawl does suggest that a strong negative affect on prawn catch is a possibility.

Utilization of the Dynex material in trawl construction was found to be somewhat complicated because of the double knots. The double knot restricts the opening of the mesh in the lateral direction and careful attention has to be paid to the calculation of hanging lengths for frameline tapers. One of the benefits of Dynex netting over Ultracross is the stiffer nature of the twine due to the inclusion of a monofilament core to the dyneema braid. In the field trials it was demonstrated that this stiffer feel to the netting made the trawl much easier to keep clean. Despite being the dirtiest performer based on the volume of benthic material retained in the codend, the Dynex trawl was far less problematic compared to the Ultracross trawl in regards to benthic material (starfish) being snagged in the meshes.

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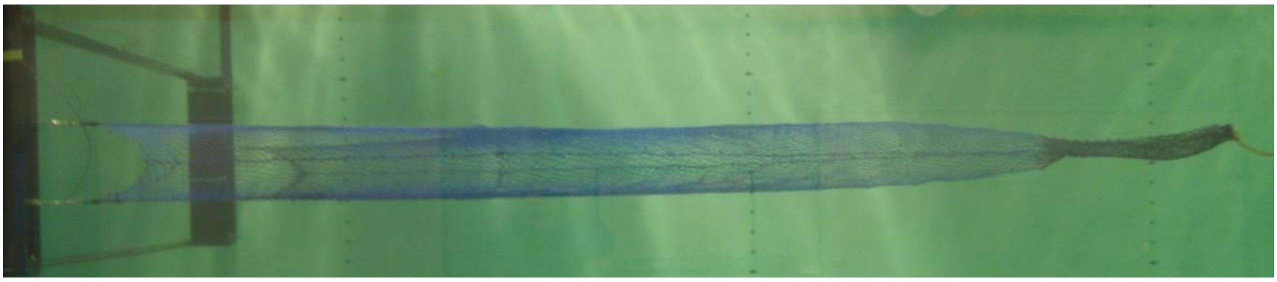
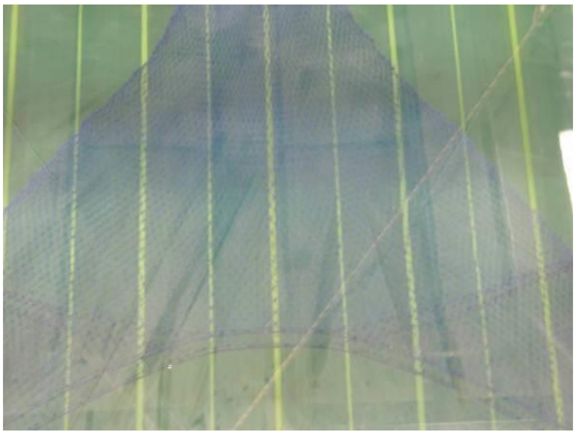
Appendix 1: Photo Gallery for Drag Tests in the Flume Tank

24ply Polyethylene (knot forces out)



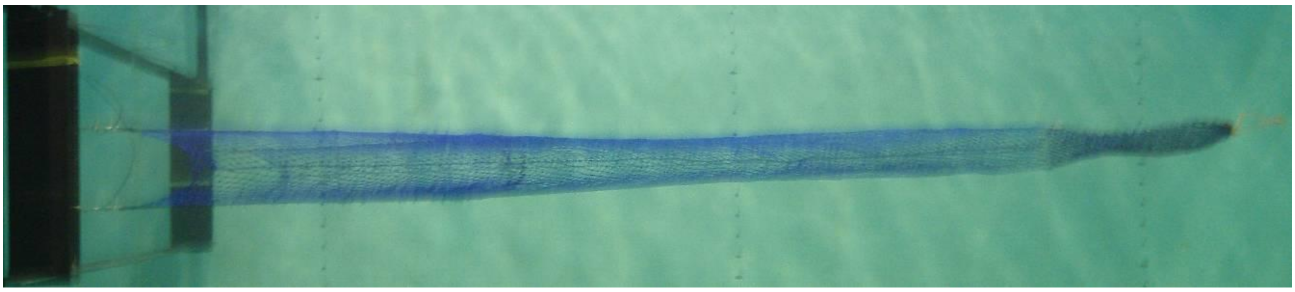
(a) Side view PE, knot forces out, with struts.



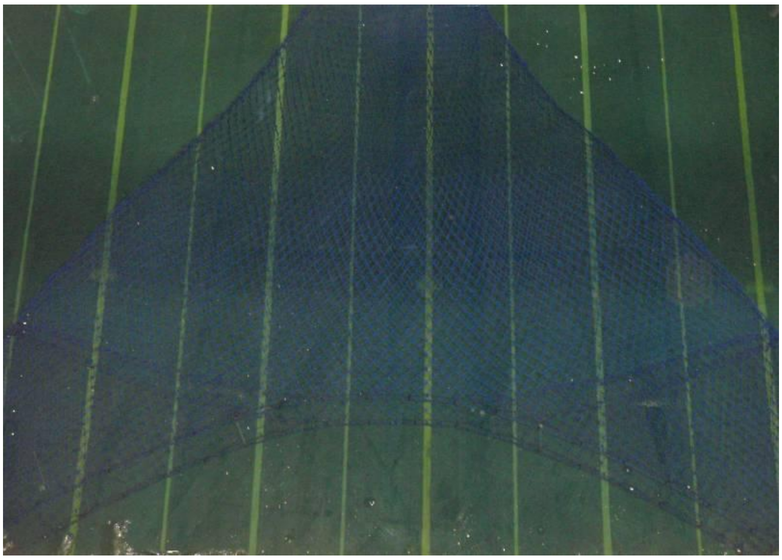
(b) Top view PE, knot forces out, with struts.

(c) Side view PE, knot forces out, without struts.

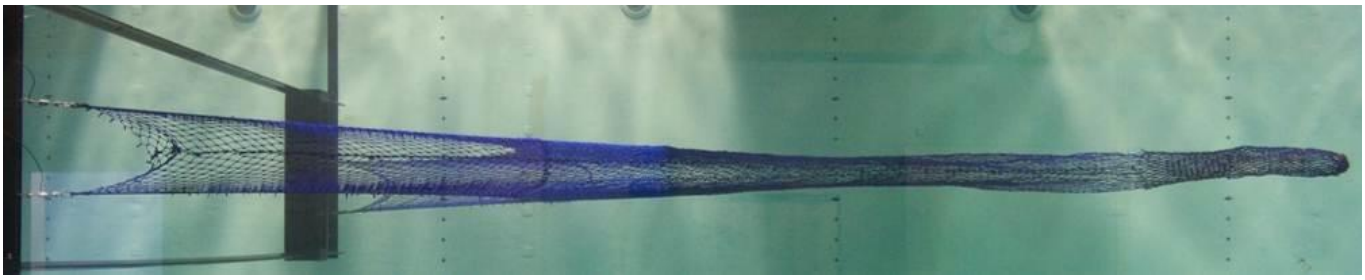
24ply Polyethylene (knots forces in)



(a) Side view PE, knot forces in, with struts.

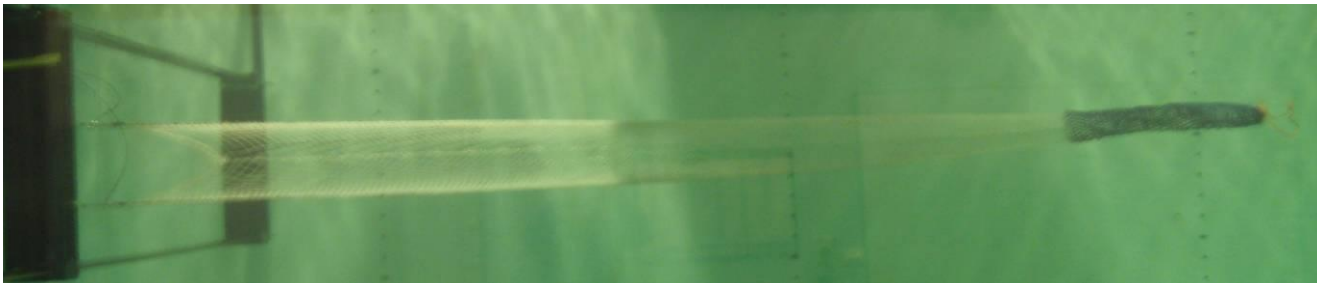


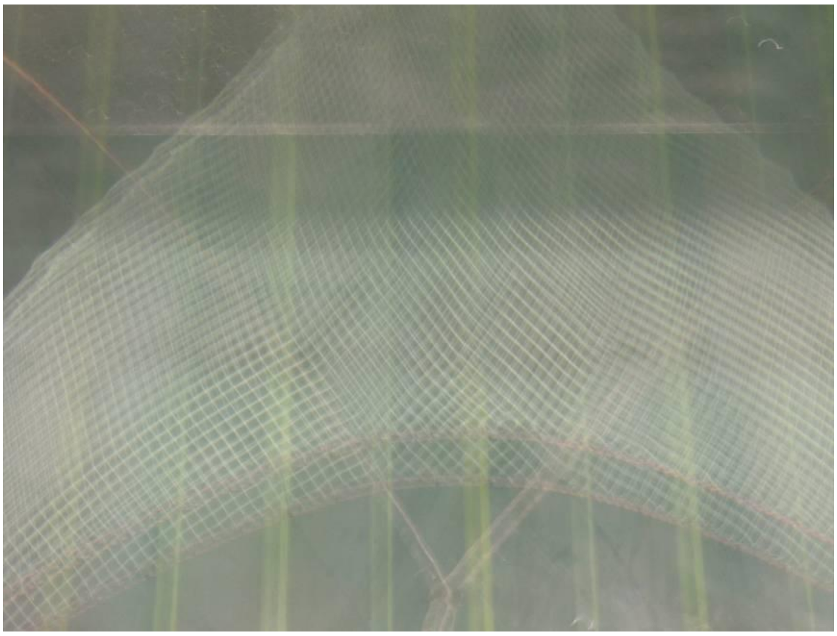
(b) Top view PE, knot forces in, with struts.



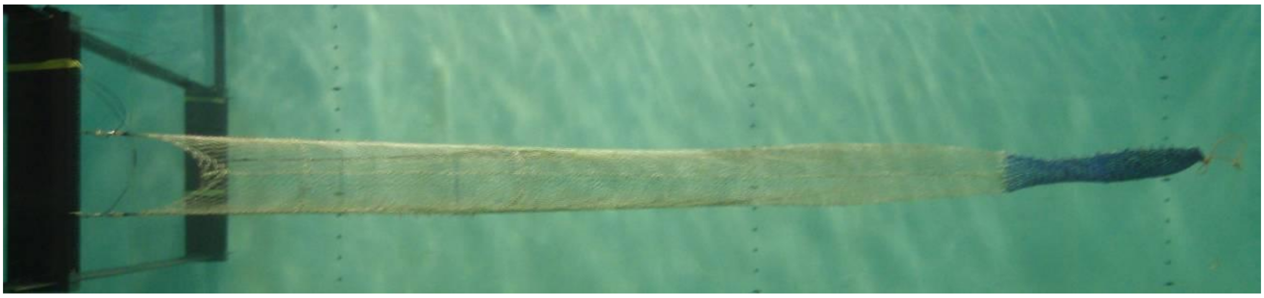
(c) Side view PE, knot forces in, without struts.

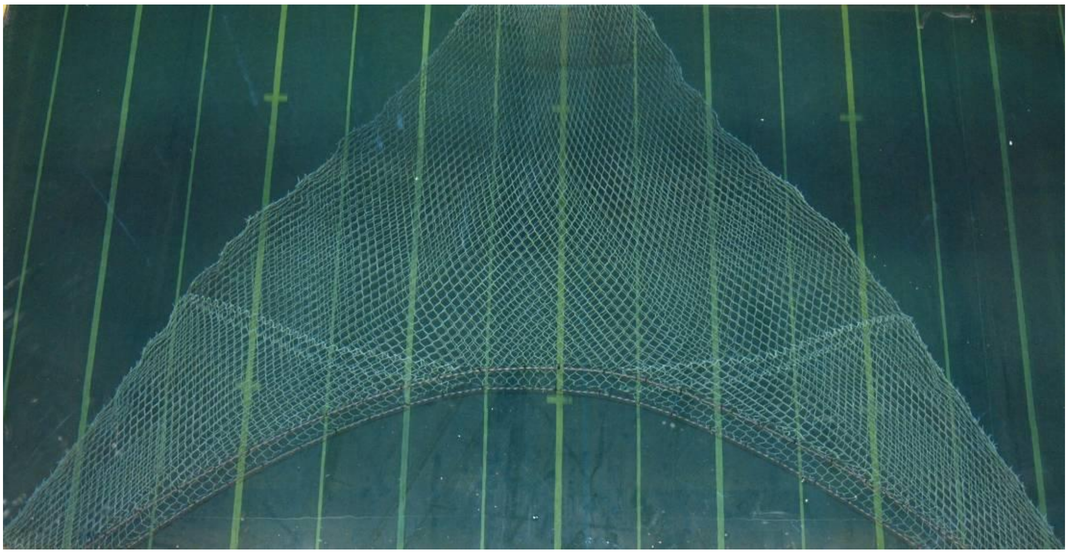
Ultracross Dyneema



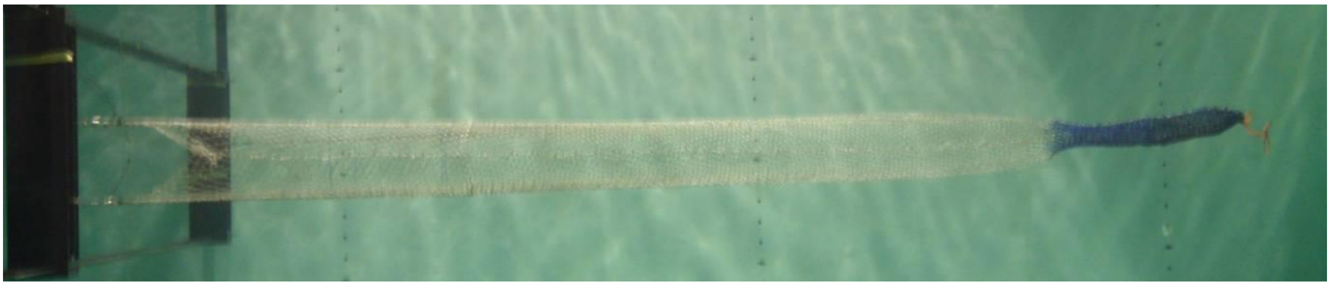


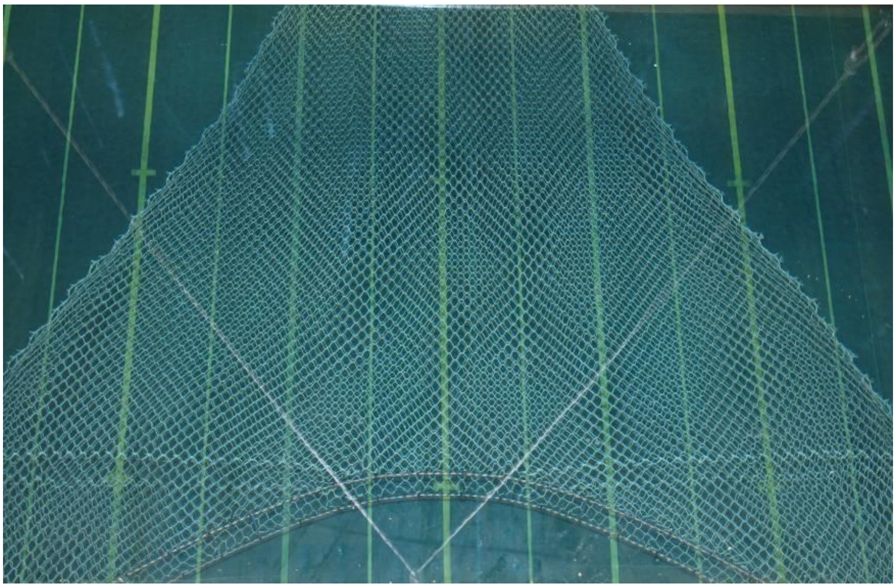
Hampidjan Dynex (standard-mesh)



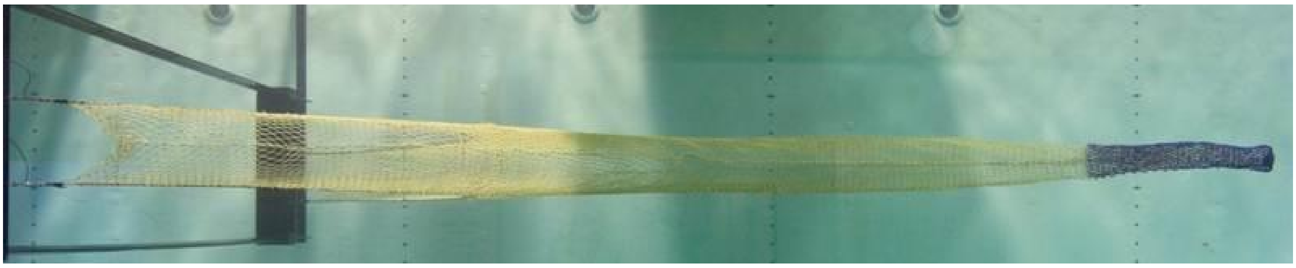


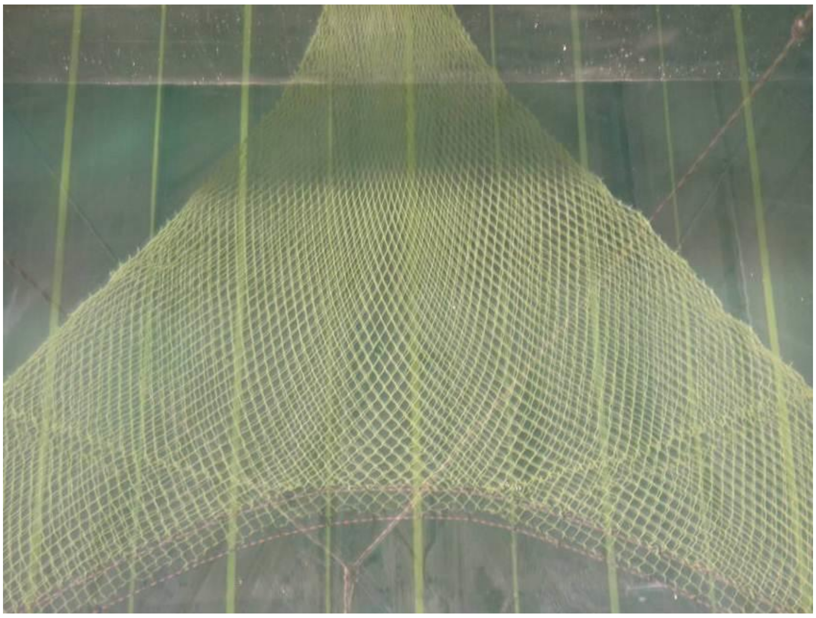
Hampidjan Dynex (T90)



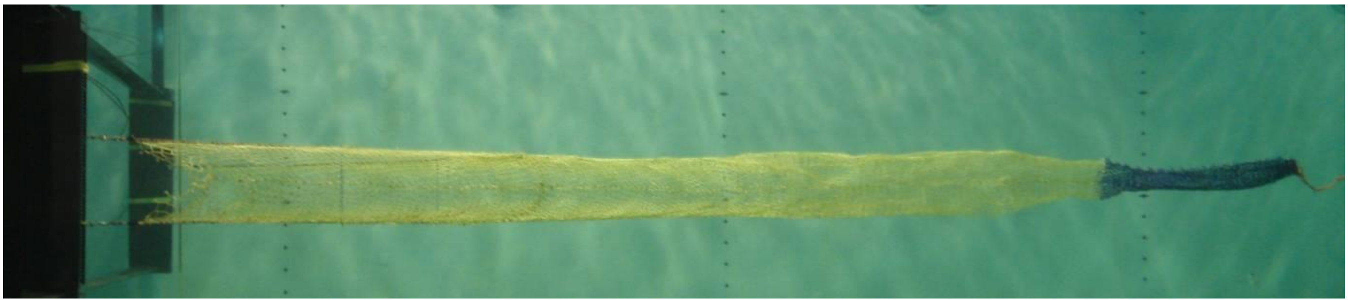


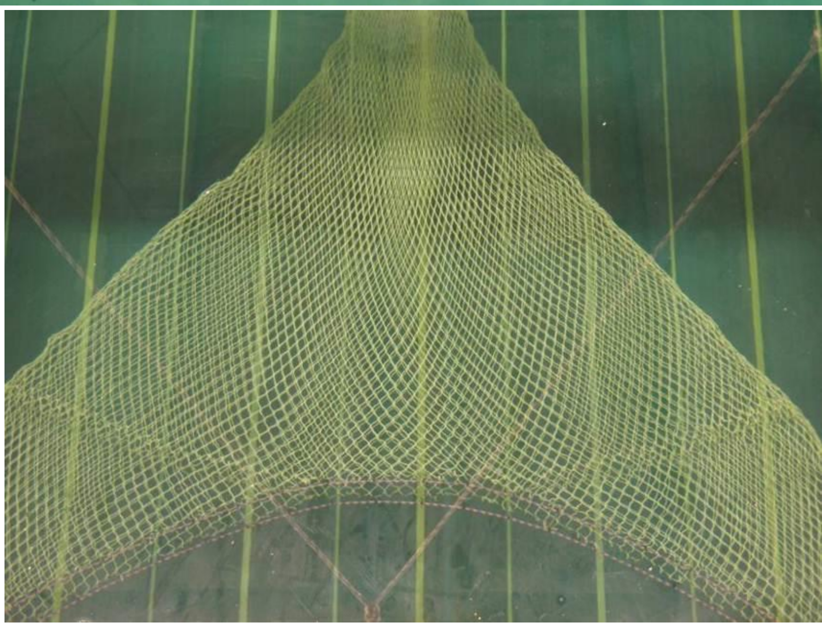
Euroline Premium Plus – Rough side out



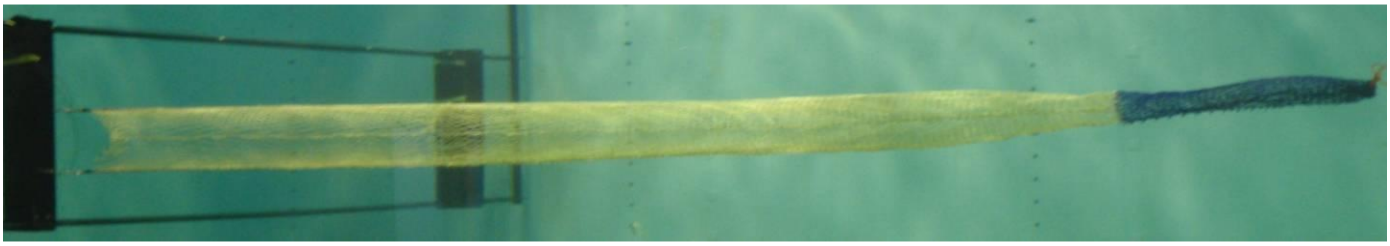


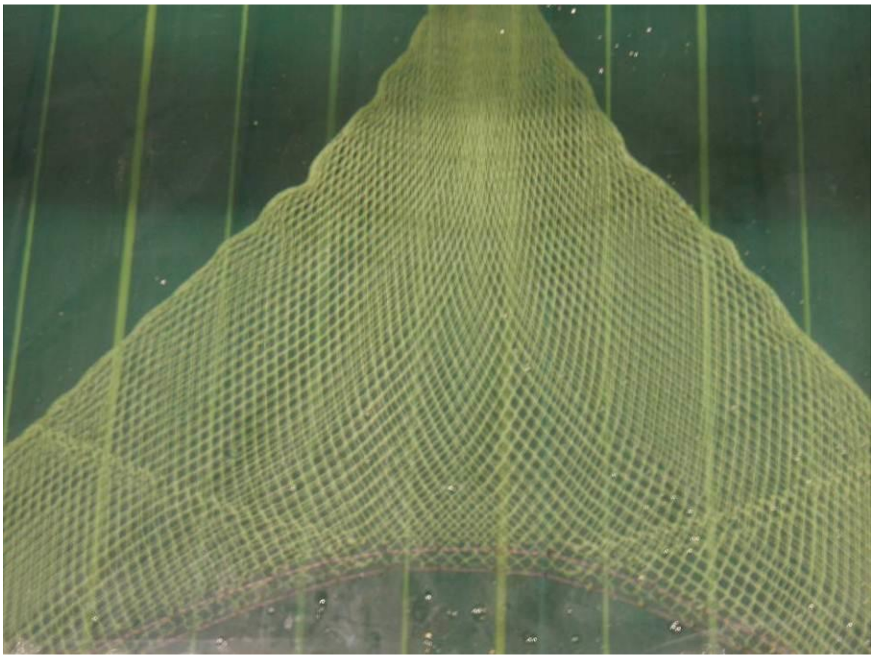
Euroline Premium Plus – Rough side in



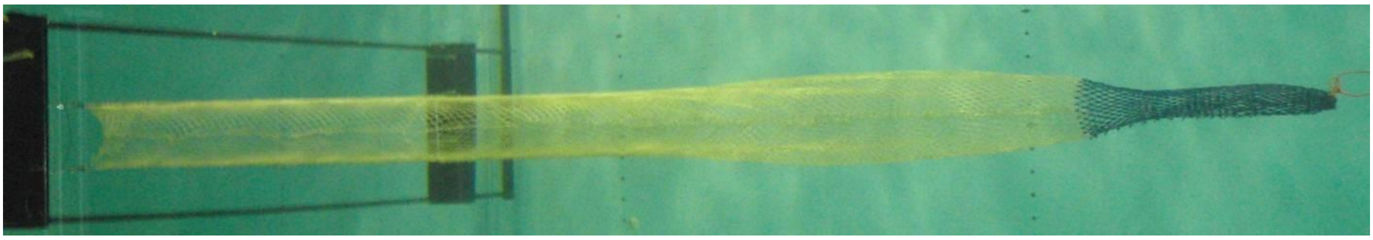


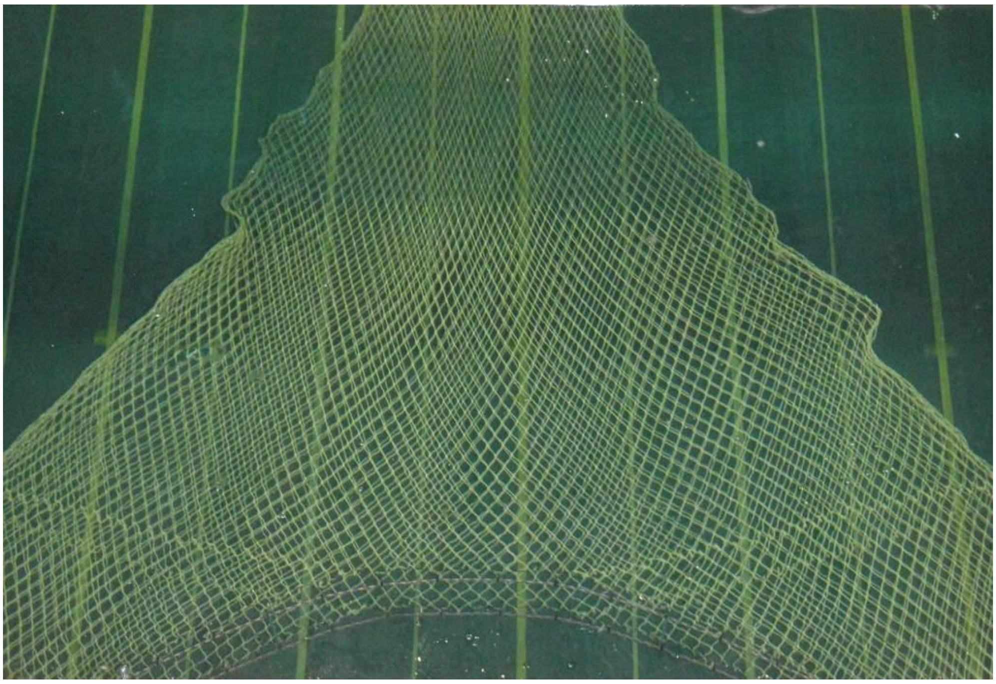
Euroline Premium Plus (Rough side out – stretched longitudinally)





Euroline Premium Plus (Rough side out – stretched laterally)





Appendix 2: Intellectual Property

There is no intellectual property arising from this project.

Appendix 3: Staff

Dr David Sterling - Director: Sterling Trawl Gear Services