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Best Available Technology makes Drastic Cuts in Fuel Expenses in Trawl Fisheries

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Abstract—**The project aims at development of a new trawl system, designed to increase catch, eliminate bottom contact of the trawl doors and reduce energy consumption. The project is governed by the industry and is using best available technology, from a range of different well known sources. The vessel was able to improve the profitability of bottom trawling by around 40% by using Dyneema warps, flying pelagic doors, an innovative trawl design, with netting in T90 and made from Dyneema. The economic calculations proved that the payback time on the total investments was less than 12 months and the return on the investments were around 300%. At the same time the environmental impact will be reduced dramatically when the doors are lifted away from the bottom and the emissions per kilo of fish caught reduced.**

Keywords – trawls; fuels costs; trawl design; trawl doors; T90;

I. INTRODUCTION

The energy costs are a large and a growing share of the operational costs in the Danish fishing fleet. According to Fødevareøkonomisk Institut (2011) fuel costs represented 30% of total operating expenses in 2009 for the fleet on average. This share is expected to have risen to 38% in 2011. The average fuel consumption per vessel in the segment from 15 to 18 meters increased from DKK 216,000 in 2007 to DKK 432,000 in 2009 and is expected in 2011 to be, ie. a doubling in 4 years. Fuel costs strikes markedly heavier on trawl vessels than on other fishing vessels.

This trend is expected to continue in the future. It is partly because oil generally becomes more scarce, partly because a number of commercial vessels can not use heavy fuel oil after 2015, as a result of IMO's rules on emission zones in many areas limits the sulphur emissions and NOx emissions. This will force some commercial vessels to use diesel and other lighter oils.

In addition the new fisheries policy in the EU is likely to reduce the role of technical conservation measures currently in place and give fishermen greater freedom to select the most efficient fishing gear and gear design. The new fishing regulation based on transferable permits, catch quotas and full documentation should help create incentives for effective fishing gear and thereby increase the vessels' return.

Finally, there is growing opposition to bottom trawling from a number of environmental organizations. This creates a need to explore ways to reduce gear impacts on bottom habitats - whether the resistance to trawling is justified or not.

II. MATERIALS AND METHODS

A. Vessel

The selected vessel R254 Katrine Kim is a traditional fishing vessel in the Danish fleet (39.1 BT, 215 HP, LOA 17.3 m).

It is rigged for double trawling with two net drums on the stern, behind the wheel house. The codends are emptied in front of the wheel house, where a conveyor belt brings the fish to a gutting machine.

The vessel was given a full energy audit before the project commenced, and all the recommendations were carried out. That was in order to avoid “noise” from various sources on board, for instance a propulsion system which needed a thorough overhauling, or a hull needing maintenance.

It was found that the vessel had been continuously updated, with a new efficient propeller of the "high skew" type and propeller nozzle, and an electronically controlled main engine. Generally the vessel was found in good maintenance condition.

In order to assess the catch of the vessel and to utilize the data collected on board the vessel was registered in the “Catch

Illustration 1 Fishing vessel "Katrine Kim"

Quota System" which some EU countries have been testing in recent years. That is a system where it is the fish caught and not the fish landed, which is deducted from the vessels quota. To control the amount of fish in the trawl the vessel must be equipped with surveillance CCTV cameras on board sending information to the authorities. The reward for the fishermen is that the vessel quota is raised 30%.

B. *Trawl Gear*

The overall purpose of this project was to investigate how the fuel consumption per unit of catch caught can be reduced by changing the rigging. The rig includes towing warps, trawl doors, bridles, and the net itself. By allowing a multitude of parameters to be changed at the same time, it was not possible to isolate the effect of each and every alteration, but only the combined effect.

1) Trawl doors

The drag component of the doors is mainly reduced in this project by lifting them away from the bottom, and thereby separating the spreading element of a trawl door from the weight element. By doing so it is possible to use pelagic doors, instead of bottom trawl doors. If a certain weight of the trawl door is needed to bring the trawl to the bottom, a small chain weight can be used to compensate for a lighter pelagic door. On larger vessels the weight can be in form of a roller clump, but in this project an in-line chain was selected. The distance between the doors and the chain weight was 40 m, - made from 10 mm Dyneema®.

Pelagic doors are generally much more efficient, and to give a certain spread on a trawl relatively smaller doors are needed.

The raised or flying doors will reduce the trawl drag, and it will also reduce the bottom impact of the trawl system.

Illustration 2:Dyneema warps protected against wear with Nylon sheaves in the blocks

2) Towing warps

In order to facilitate the raised doors the 12 mm steel trawl warps were exchanged for warps made from 10 mm the high-tensile material Dyneema®. This material is made from extended chain polyethylene and has a density around 0,91. Therefore they do not contribute with any weight in front of the doors. The warps are normally sold with a braided cover to reduce weir and tear. However it is the opinion of the authors that this is not necessary, at least not for smaller diameters.

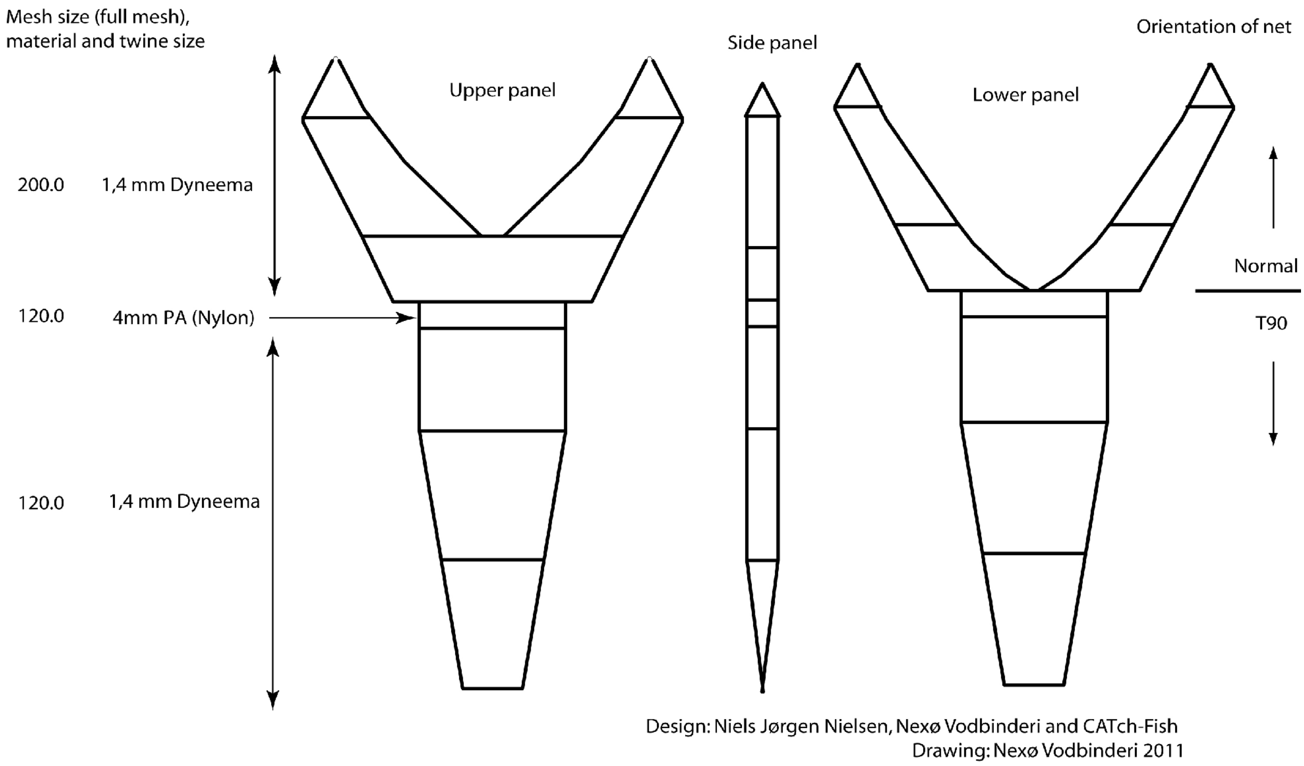
It is necessary to protect the synthetic rope from wear on board. In this project it was done by exchanging the guiding blocks to a softer material, so sheaves were made from Nylon instead of stainless steel.

3) Trawl

The new trawl was designed in a constructive partnership between the skipper, Niels Jørgen Nielsen, Claus Hjort Hansen from Nexø Vodbinderi and Ulrik Jes Hansen from CATch-Fish. The job was to design and construct a trawl that met two requirements:

- Trawl should be designed using the best possible knowledge and technology with a focus on reduction of drag resistance and fuel consumption.
- Trawl should have equal or better selectivity than the trawls that meet the requirements regarding mesh size and selection devices that are listed in the technical conservation measures for the Baltic Sea.

Illustration 3:Trawl Specification



The netting resistance is the biggest part of the drag, and it is directly related to the amount of netting material. Thinner twine and larger meshes is a way to minimize drag. In recent years the synthetic material Dyneema® have proven to be a very effective way to reduce drag. In this project the whole trawl, except the codend, net was made in 1.4 mm Dyneema®.

The elasticity of Dyneema® is very low, and the implication of that is that peak loads quickly builds up when the netting is loaded net its breaking strain. Therefore it is vital for a success with using such high-tensile netting material, to build in zone in the trawl with an elastic material. Here such a zone was made from a short section of around 60 cm in length which was inserted behind the fishing circle, - at the first section in the belly of the trawl.

It was chosen to extract the benefit of thinner twine by making the new nets larger than the old nets. It is difficult to predict the actual drag in a trawl, but a simple twine area calculation was used was regarded as accurate enough to be used. Table I gives the result of the considerations.

The new nets were made bigger in order to keep the load on the engine at the normal 75 – 80% of the maximum towing power, but a small margin was left to allow for uncertainties in the calculations. Therefore the old net was 8.9 m^2, while the new net was made slightly smaller, 8.4^2.

TABLE I. TWINE SURFACE AREA

	Twine Surface Area, m^2
Old trawl	8.9
New trawl, same size, Dyneema®, bigger meshes, T90	3.2
New trawl, size adjusted	8.2

It was chosen to construct the whole trawl from T90 netting except the front part. T90 is conventional netting material used in a configuration where it is turned 90º in relation to the traditional direction. The term is T90 as opposed to T0 for normal netting.

When the netting is turned 90 degrees, the shape of the knot bodies spread the net open more than will T0. When the netting remains open during fishing operations, it is thought to facilitate water flow and, moreover, reduce twine area. Both factors should reduce water resistance, although Arkley (2008) indicate that the drag reduction might be marginal. Furthermore commercial experience with T90 have demonstrated that the amount of trash (plankton, jellyfish, algae etc.) can be markedly reduced, - also for the benefit of fuel reduction.

In addition to low drag, it was also important that the trawl was made with a low bottom impact. This could also be achieved by lifting the trawl doors up from the bottom.

A side panel was added to the net, because it is much easier to manage and alter the performance of the net. By pulling forward in the side panel it is possible to acquire better height and/or better bottom contact.

Along the headline and footrope series of fly-meshes were added. When mounted correctly to the framing lines, fly-meshes can also contribute to extra height or extra bottom contact. On the footrope this can seriously reduce the need for chain weights to maintain a good bottom contact.

4) Codend

The codend was made from double 4 mm polyethylene. The mesh configuration was T90 because it gives a 10 – 12 times larger cross section area (Hansen, 2004) compared to a similar size normal codend in T0. The wider codend is expected to have a beneficial effect on fishing efficiency and on the catch quality. The reason not use high-tensile material in the codend to save fuel is that the contribution from codend drag is marginal and because the thicker double twine could give a large spreading effect and cross section area.

The project aimed at showing that by using best available technology is was possible to increase profitability. That also included the feeling that some of the very strict and detailed EU technical regulation measures were hampering the profitability of the fishing enterprises without really increasing the sustainability or selectivity of the fishing gear. In that way the project acted as a pilot study for a new fisheries management, with not discards and no technical regualtion measures. An application to the Danish authorities to allow a circumvention of the regulation was granted provided that it could be demonstrated that the selectivity of the proposed trawl gear was on the same level as the trawls using the codends specified in the regulations. The codend was therefore made much wider than the specification in the regulation, - 100 meshes around instead of 50 meshes and the mesh size 110 mm.

Illustration 4:The pelagic doors, not the trawl door sensor

5) Instrumentation

It is difficult to operate pelagic trawl doors on a trawl, which has to maintain bottom contact at all times. The vessel was equipped with conventional trawl monitoring electronics for taking door spread trawl height and measurements. The position of the trawl doors had to be acquired by investing in sensors which could measure the depth from the surface. It should be noted, that this is not ideal, because a depth measurement is not particular accurate, - especially not in the Baltic waters, where a prominent haloclíne dominate the hydrography.

C. *Measurements*

Fishing trials were attempted to be standardized in terms of towing time and towing speed. Towing time was set to 3 hours and the towing speed 3 knots.

Warp length was adjusted so that the doors were "flying" 3 – 5 meters over the seabed.

The vessel was registered to the "Catch Quota System" and was therefore also using an electronic log book, giving reference to time of the day, fishing ground, catch size on species and discard. Furthermore the following parameters were observed:

- Type of doors,
- Type of trawl,
- Codend,
- No. of trawling hours
- Fuel consumption, before – after
- Fuel flow,
- Towing speed

III. RESULTS

A. *Pelagic doors*

It is an interest on its own to find out how much the fuel consumption drops by switching to pelagic trawl doors from the vessels traditional bottom doors. This measurement was carried out by comparing fuel use on the new trawl rig with the bottom doors and pelagic doors. The results are given in table II.

TABLE II. DIFFERENCE BETWEEN BOTTOM DOORS AND PELAGIC DOORS

	Consumption, total, litre	**Hours**	**Litre per hour**
Bottom doors	820	14.5	57
Pelagic doors	7,700	153	50
Difference			14%

The trials showed that there is an 14% reduction in fuel consumption. This is in correspondence with similar trials in the Hirtshals flume tank and new project trials conducted in the North Sea with two fishing vessels (yet unpublished).

B. Catch and fuel consumption

After the initial tests and adjustments, a total of 80 hauls were made during the fishing trials, where the catch and fuel consumption was recorded.

Table III summarizes the catches and fuel consumption during the trials.

TABLE III. FUEL CONSUMPTION AND CATCH PER HOUR

	New Trawls	Old trawls	Difference
Fuel consumption, total, litres	6,124	4,709	
Catch, total , kg	32,240	21,520	
No. of trawl hours	128	91	
Catch per hour, kg	275	236	17%
Catch per litre fuel, kg/h	5.8	4.6	26%
Average fuel consumption, l/h	47.8	51.7	7%

During the trials samples were frequently taken to determine the size range of the discards. The size range of the catch was determined at the landing site.

On a single trip, the performance of the net was monitored by underwater camera of the type TrawlCamera, see www.trawlcamera.com, from JT-Electronic from Faroe Islands. Specific areas of interest were the bottom contact in the bosom and the selective performance of the T90 codend.

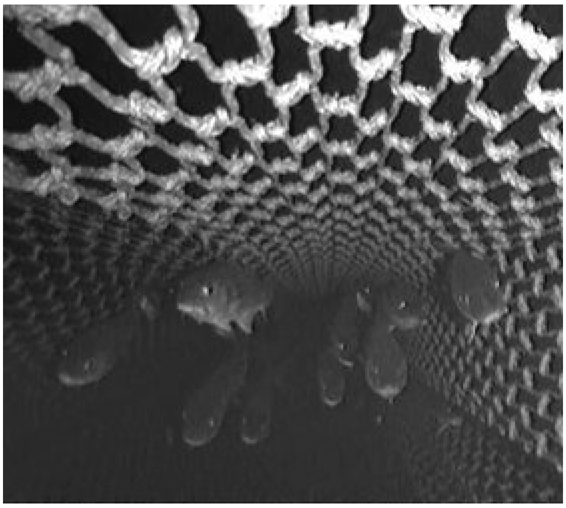


Illustration 5:Underwater observation in the codend, note the open T90 meshes

IV. DISCUSSION

A. "Best available technology"

The results of the project does not leave much chance to identify the cause of the demonstrated fuel savings or increase in catch efficiency. Many parameters have been altered on the new trawl rig. Only the effect of the going from traditional bottom doors to pelagic doors have been documented.

B. Dyneema® in trawl gear

Dyneema® have hardly been used in Denmark for towing warps and only for top-sheets in the trawl. It is therefore interesting in this project to get at thorough test of Dyneema® in the Danish fishing industry. It is not, that is has not been used at all until now, but the first attempts have been very cautious. Unfortunately some of the experiences have been gained at a very early stage of use of this material, when the knot stability and overall use was not fully determined.

The experience in the project have been very positive. It is hardly possible to see that the new warps have been used, and the longevity is guessed to be more than five years. In other fisheries Dyneema® warps are known to last up to 10 years and maybe more.

The skippers opinion of the netting is that it has not been damaged and subsequently repaired more than other materials would have been in the same fishery.

C. Economy

Concerning the economic gains by using larger and lighter gear the following calculations can be made. Such calculations are by the very nature very vessel specific, and connot be taken as Vessel entry was in 2010 approximately DKK 3.9 million, of which approx. 60% were cod fishing. The total fuel cost was approximately DKK 562,000. The trials show that approximately 40% of fuel can be saved per kg of cod. Since the old trawl rig caught 5 kg cod per liter of fuel, the fuel used in this fishery is equivalent to around DKK 300,000. The vessel will thus in today's prices save DKK 120,000 by using the new rig and use just 80% of the usual time in the cod fishery.

However, it will be much more interesting to use the higher catch capacity of 20% more per hour to catch more cod, -corresponding to 60 tonnes per year. These fish can be leased for around 2.50 DKK/kg and sold for 8 DKK/kg (prices obtained by mid-October 2011). There will also be a saving of 15% fuel in the cod fishery. So not only will the 60 tonnes of cod to be caught without extra costs. They will be caught by using approximately 10 to 15% less fuel.

In this situation it is possible to save around DKK 40,000, but this amount is small in relation to what can be gained when exploiting the possibility of leasing more quota. The calculations are given in table IV.

TABLE IV. ECONOMIC GAIN FROM NEW TRAWL RIG AND LEASED EXTRA QUOTA

	Price, DKK/kg	**DKK**
Selling 60 t cod	8	480,000
Leasing 60 t cod	2.5	-150,000
Less fuel consumption		40,000
Annual net revenue		370,000

The investments in this project have been around DKK 390,000, see table V, which means that there is a payback time of less than a year.

TABLE V. GROSS INVESTMENTS

SIMRAD door sensors	150,000
New trawls in Dyneema®	120,000
Pelagic doors	80,000
Dyneema® towing warps	40,000
Total	390,000

It must be emphasized that this calculation is very conservative: the figures are the total amount of investments, they are not corrected for alternative investments in trawls, doors, warps, etc.

V. CONCLUSION

A. Efficiency

The trials have demonstrated that it is possible to save more than 40% of energy consumption per kg of fish caught by optimizing the trawl and trawl doors. The savings stems partly from a lower consumption of oil per hour and partly from an increased catch per hour. The distribution on more catch and less consumption of fuel can be altered as a function of optimization and economic considerations.

Vessel's gross profit can be doubled if for example the increased capacity (20%) is used to lease cod quota (using the prices for lease and sale of cod, which was in force in mid-October 2011). The increase in annual profits correspond to the vessel's total fuel cost (though cod accounts for only 60% of the catch). This result is achieved as a result of a system with transferable quota in the Danish fishery. Without that opportunity the effect would be approximately a third.

It is also shown that an efficient fishing for cod in the Baltic can be made with bottom trawl which do not affect the bottom (ie. pelagic trawl boards). This reduces the impact of fishing on benthic fauna. It is beyond the scope of the project to quantify this effect.

When using pelagic trawl on a bottom trawl the fuel consumption will be reduced by approx. 15%, which corresponds to a halving of the contribution from the trawl doors on the total fuel consumption.

B. Other major findings

Dyneema warps are a suitable alternative to steel wire ropes in use as trawl warps, - both technically and economically.

The T90 meshes are apparently suitable for reducing the water resistance and enhance the selectivity with respect to conventional meshes (T0), - and also compared to the prescribed Bacoma exit window.

In connection with a new fisheries policy there will be significant potential to increase earnings by changing or removing technical regulation measures.

There seems to be an improvement in quality when using T90 meshes in the codend. It is however beyond the scope of the project to quantify this.

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- GEMBA Seafood Consulting A/S (Project Implementation and Management)

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