Towards Zero Emission Fishing

Design and Sea Trials of a New Collapsible Mast System in Fishing Vessel less than 15 meters in Shetland waters.

Highlights

- The history of traditional sail-fishing in Shetland waters is referred to.
- The relationship between sea surface temperature, marine biomass and seabird breeding pollutions are discussed.
- How important fishing is to Shetland.
- A collapsible mast system within a fishing vessel and its potential.

Abstract

An innovative solution was designed and tested as a sail-system compatible with the commercial fishing industry. Sail Line Fish Ltd with its Balpha Mast (patents pending) conducted an 18 month feasibility study to research the potential of sail-assisted fishing. The research gave results on its fuel saving capabilities and its importance within a sail fishing vessel.
Weather observations were made within 20 miles of Shetlands coastline to estimate the potential sail power could have within the industry.
Scientific research has already been conducted into the possible relationship between CO_2 emissions, sea surface temperature, marine biomass and sea bird breeding populations.
The necessity to reduce carbon emissions may be particularly important for our marine environment which the fishing industry depends on.

Keywords

CO_2 emissions, sea surface temperature, marine biomass, integrated propulsion, collapsible mast system.

1. Introduction

1.1 - Like most coastal communities Shetland has maintained its population of 22,000 from its surrounding marine resource. If you are fortunate to visit the Shetland Museum and Archives in Lerwick you will appreciate the continuity from the Herring Boom **(1)** to the Haaf fishing **(2)** and Whaling **(3)** all these periods brought a marine resource to a marketable product.
Where the land had little sustenance the sea certainly did. With its excellent marketing credentials for both health and taste the seafood industry is still the mainstay to long term prosperity in these areas.

1.2 – Through careful monitoring of seabird populations Fair Isle Bird Observatory have experienced declines and low breeding success in various species since the 1990s. Worst hit have been kittiwake, shag, puffin, razorbill, guillemot, artic skua and artic tern. North Sea breeding populations of kittiwake have declined by more than 50% since 1990. In studies undertaken by **(4)** Dr. PGH Evans 'Tracking Changes to Fair Isles Marine Environment' into the relationship between sea surface temperature, plankton distribution, sandeel biomass and seabird breeding populations have shown a significant correlation between them. Where sea surface temperatures of the North Atlantic and

UK coastal waters have increased sharply since 1980, by between 0.2 and 0.8˚C every 10 years, with the decade of the 2000s being the warmest on instrumental record. Increased sea surface temperatures have led to extensive changes in plankton communities. In the North Sea the population of the previously predominant and important zooplankton, the cold water copepod (*Calanus finmarchicus)* has declined in biomass by 70% since the 1960s. Species with warmer affinities (e.g. *Calanus helgoandicus*) are moving northward to replace it, but are present at much lower abundance. The life cycle of sandeel is timed to make use of the seasonal production of copepods which in turn depend upon planktonic plant production. For most UK seabirds, sandeels form an important component of chick diet and this has led to successive years of poor breeding success. The effect of this significant change of sea surface temperature and therefore marine biomass has the potential to change the whole makeup of the marine food chain.
Through scientific research conducted in the marine environment increases in sea surface temperatures and ocean acidification can be directly linked to CO_2 emissions **(5)**. However it is less understood how individual fish species respond to these changes. Thermally sensitive species may decline or move to higher latitudes whilst more adaptable species may thrive to a certain degree of SST rise. It is more likely to be the change in the fish marine habitat (including food source) due to increase in SST which could reduce populations. Also diminished predator avoidance leading to higher mortality rates of juveniles could also reduce populations.

1.3 – The Shetland fishing industry has interests in all types of fishery from 60m pelagic boats to whitefish trawlers and seine netters to 10m shellfish boats. All these vessels play an important role in maintaining services and market for the daily catches. Almost all vessels are owned by the vessels crews. Employment is created at sea and ashore within the coastal communities in fish catching, processing, marketing, transport and supply/repair services. In the main Port of Lerwick **(6)** for 2014, 61,000 tonnes of fish were landed, valued at £69 million. Having more fish landed than in England and Wales combined the Shetland Seafood Industry represents one third of the Islands economy **(7)**. It employs more people locally than the Oil and Gas Industry and is central to Shetlands immediate and long term future.

1.4 – Fishing worldwide consumes 38-42.5 Mt/year of fuel (1.2% of the world's total, from which Europe has 6% of its share), generating about 134 Mt of CO_2 emissions every year **(8)**. Typically 40% of vessels total expenses are fuel related. This fuel dependency significantly hampers viability, investment and therefore development of the industry.

1.5 - Sail Line Fish was established in 2009 to develop new technology for carbon reduction in the shipping and fishing industries. The potential of sail-assisted fishing was demonstrated in an 18 month feasibility study with joint funding through innovation smart: Scotland. The objective was to design a sail system compatible with the operation of a modern fishing vessel. The intention was not to reinstate traditional sail rigs and materials but to be innovative and develop new pioneering systems. However reference was made to these traditional vessels for possible fundamentals of sail-assisted fishing. Full automation and integration with other low/zero carbon propulsion systems is the ultimate goal.

2. Method

2.1 Selection of vessel

Modern day fishing vessels have been designed and built to be propelled with engines. This has meant that their design has evolved to have higher block co-efficient **(9)** than older traditional (sail) fishing vessels. These modern vessels have a higher length beam ratio i.e. shorter length/greater beam. This has made them less suitable for sailing. In order to test the use of sail power in a fishing vessel a traditionally designed and built Shetland Model boat was chosen as a trial vessel. It had capacity for sailing and for fishing. The vessel chosen was the larch on oak clinker built 'Star' by Walter Duncan 1970 length 6.5m beam 2.1m. This vessel is a direct descendant of the Longships of Shetlands Viking era **(10 & 11)**.

001- Sail-assisted fishing trials, Sail Line Fish®©

2.2 Selection of Mast

Two masts were tested. For the first 6months a fixed mast was used. For the remaining 12 months of the study a collapsible mast system was used. The same sail rig was used though the whole study.

With its application on a working fishing vessel the mast had to be quickly and simply operated with a limited number of crew. The criteria stipulated for a free standing mast without rigging. Calculations were made using the displacement of the vessel, its maximum righting moment, sail area and maximum operating wind speed to design a suitable strength of mast. Tubular aluminium was chosen as a material for its durability and high strength/weight ratio. The boom was also tubular aluminium for continuity of material and strength.

2.3 Selection of Sailing Rig

The selection of sail rig was undertaken after consultation with Naval Architect, Dick Koopmans. His ocean sailing including Round Britain Race experience was significantly important as the sail rig would be tested in the North Atlantic and North Sea region. The chosen sail rig was a rigid triangle where the single large genoa sail furls around the fore stay **(ref photo below)**. This sail rig is specifically designed for single handed operation without the necessity to go forward onto the exposed foredeck. To tack the sail the clew is passed around the foreside of the mast using the sail

sheets. To vary the sail area, depending on wind strength, the sail can be furled and unfurled safely from the cockpit aft.
This rig was specifically chosen so that it could be used both when testing the static mast and the collapsible mast. The vessel, sailing rig and distance travelled were kept constant. The variable was the collapsible capability of the mast.

002-Sea Trials, Sail Line Fish®©

2.4 Selection of Fishing Method

The required hull form suitable for sailing, with its finer lines, is more compatible with lighter fishing equipment. Line fishing is a particularly suitable fishing method as the total weight for a 6000 hook fishing system would only weigh 400kg. This includes automated line hauler, baiter, lines, floats and weights. This arrangement would be sufficient and economically viable for up to a 15m boat fishing with 1 or 2 crew. This fishing method is also chosen for its passive nature where fish come to be caught. It removes the need for high powered engines to tow heavy fishing apparatus **(12)**.

2.5 Fishing Trips

Seventeen fishing trips were undertaken on the inshore fishing grounds of St Magnus Bay, Shetland. Each trip varied from 4 hours to 12 hours depending on weather conditions and fishing opportunities. Fuel consumption was measured using a float gauge meter and tank soundings taken before and after each trip. The total distance covered by sail and motor power was measured using a GPS system. The effectiveness of the sail system on-board was also recorded.

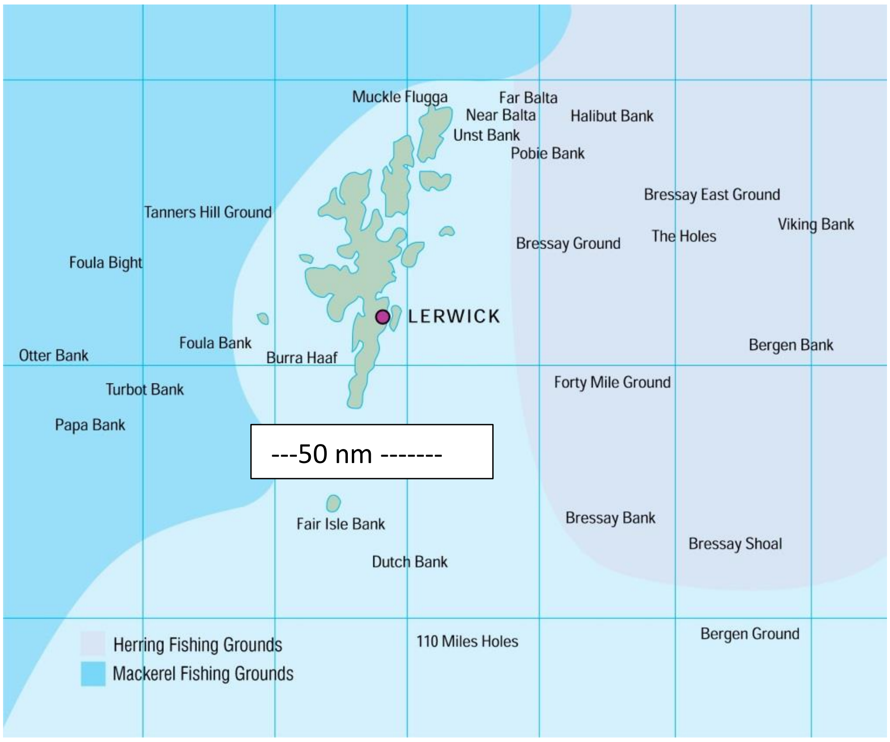
2.6 Desk Research - optimum vessel size

To determine the ideal size of a sail fishing vessel, documents detailing legislation of UK fishing vessels were consulted **(13 & 14)**.

Authors experience of working in the fishing industry and reference made to vessels working in the present Shetland fishing fleet were made. This concerned the limitations on a vessel due to its size and catching capabilities when working in exposed waters. Fishing licenses and quota entitlement was a relevant factor. The economic viability of the vessel as a business was a critical factor in the research. The availability of experienced and certified crew was also considered. Specific to sail-assisted fishing was the compatibility of the sail-system with the vessel size.

2.7 Desk Research optimum fishing grounds

The factors of chosen fishing method, capability of boat, fishing experience, prevailing weather/sea conditions and legislation had to be considered in order to arrive at the optimum fishing grounds.



Dia. 1-Shetland Fishing Grounds

2.8 Weather Data

Weather observations were recorded using applied experience of Marine Meteorological Office contributions. The wind direction and speed observed using the Beauforth Scale was taken daily at 12 noon over 12 months from January 2009 to January 2010. The sea state and swell were recorded using local observation at the scene (Sullom Voe, Shetland) and combinations of offshore data applied.

2.9 Other methods researched

A kite propulsion system has been developed which can be used on fishing vessels. Designers claim that the sails are easy to deploy and stow. The system is available for vessels up to 20m. For larger sizes the kite line is operated by a small winch that allows the height of the kite to be controlled from the wheelhouse.

Recent theoretical research and design has been undertaken by B9 Shipping **(15)** in conjunction with Rolls Royce where a sail/bio-gas propulsion system was developed for a 100m cargo vessel. This vessel's soft sail system, featuring a square rig design, where masts could rotate according to relative wind direction was tank tested and found fuel reductions of 46 – 55% on conventional powered vessels.

3 Results

3.1 Fishing Trials

An important outcome of this study was the development of the Sail Line Fish collapsible **Balpha Mast** system (patent's pending EU EP.1177.4074.6 & US.14/000.592) to a prototype stage. This innovative design allows the Seafarer to sail and switch from a mast up vessel under sail to mast down power driven vessel without extra crew on-board. Thus allowing the vessel to utilise this free resource as circumstances and conditions dictate.
Historically a similar facility was typical in our traditional sail-fishing vessels the 'sixareen' and 'herring drifter'. In the book 'The Sail Fishermen of Shetland' Halcrow (1950) – Whilst at sea, lying to nets or lines in a heavy North Sea or Atlantic swell, severe damage could be caused to mast, rigging and hull by an upright mast. The mast and spars were therefore lowered and securely stowed during this time.
The sail rig used during the study was capable of pointing 60˚off the wind. To reduce on passage time and keep the fishing opportunity viable engine power had to be used when the destination was dead in the wind. The collapsed and secure mast kept the vessel operational in marginal conditions when pitching into a head sea. In conjunction with the weather data, it was found this could allow an extra 76 days per year fishing in marginal conditions (marginal conditions when wind speed F5 – F7 Beufort). The sail could be furled and unfurled from the aft cockpit without having to go forward to the exposed deck. As an objective of the study the sail system proved effective as it could be operated safely by a single crewman. Speeds achieved under this sailing rig were at maximum 4.5 knots in favourable 15-20 knot winds, with a sail area of 15m2 this was as you would expect from this type of vessel. The collapsible mast system enhanced the sail-assisted fishing trials by the following:

- Allowing the mast to be stowed and secured horizontal to increase fishing time when weather conditions were marginal, especially when pitching into a head sea.
- Once fishing the mast was lowered and this reduced the wind drift effect on the vessel to leeward.
- Whilst hauling lines the lowered mast kept the vessel more head to wind which made hauling easier and more fuel efficient.
- With the mast lowered and making little headway through the water the rolling effect was less and the stability condition better.
- A switch from a motor vessel to sailing vessel could be achieved within 5 minutes.

The technical outcome of these fishing trials showed how beneficial the Balpha Mast was when sail-assisted fishing.

003-Balpha Mast prototype public demonstration, Sail Line Fish®©

<u>3.2 Collapsible Mast system</u>

The first prototype **Balpha Mast** was designed and constructed through developing the initial idea of an apparatus capable of raising and lowering a simple aluminium pole. The objective here was to identify weakness, stress and friction points within the system.

From this design the key components could be further advanced. These included the pivot point, mast heel guide and lowering/raising mechanism.

From this first prototype, work began designing and completing technical drawings for a Balpha Mast suitable for the 6.5m vessel “Star”. Calculations were made on the dimensions allowable for this relatively small boat. With limited space available sourcing a 3 stage, double acting hydraulic ram was challenging. A company making equipment for the US Military was discovered who could produce this for a competitive price. Once the closed size goes beyond 340mm then this component is much more commercially used and therefore accessible. A technical outcome here was that for a boat of this size, due to the balanced and low friction design of the mast system, a small trailer winch was sufficient to operate the Balpha mast. A ratio of distances relative to the pivot point of the mast system has also been learnt from this designing process. This will be used to advance the design suitable for larger vessels.

The first working example of the Balpha Mast was completed by 30/05/11.

004-First Prototype Balpha Mast, Sail Line Fish®

005-Fitted Balpha Mast, Sail Line Fish®©

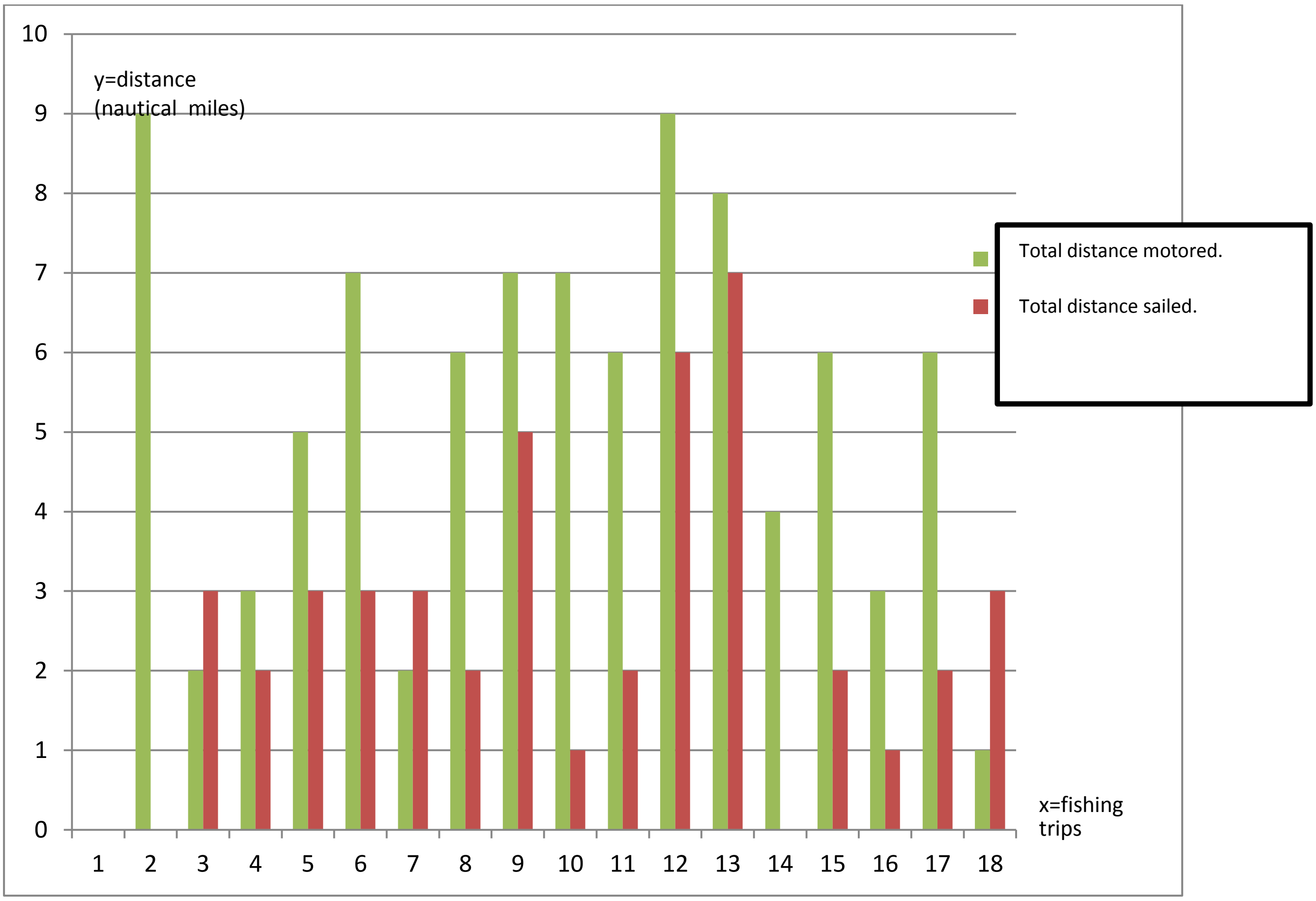
<u>3.3 Analysis Fuel Consumption Data</u>

In order to quantify the reduction in fuel usage through sail-assisted fishing the following data was recorded and calculations made.

Please note the following points:-

- A GPS chart plotter was used for positioning, distances and speed.
- Sail power was not used if vessel speed made good less than 3.5 knots as not commercially practical.
- A total of 17 sail-assisted fishing trips were made.
- Through continual assessment of engine fuel consumption it was noted that 0.8 litres of fuel (2.14kg CO_2) was used per nautical mile under engine power at 1800 rpm. This fuel was not used when under sail. The percentage that fuel consumption reduced was calculated from the total distance covered, how many miles under sail covered and on how much fuel used.

Dia.2-Graph showing distance travelled using sail and motor power during 17 fishing trips.



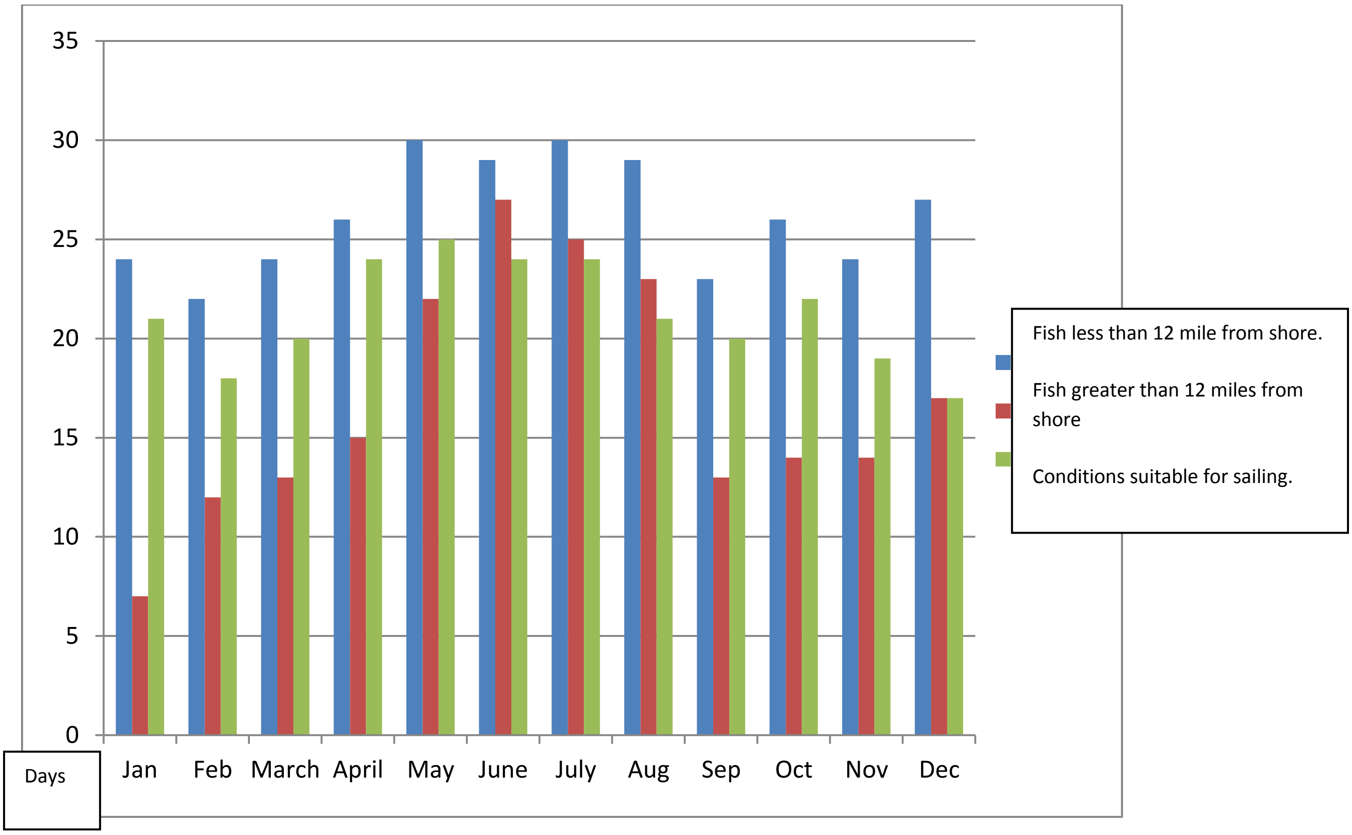
- Total distance motor & sail – 136 nm
- Total distance sailed - 45 nm
- Total distance motored - 91nm
- % distance sailed - 33%

With all fuel usage taken into account (including whilst shooting and hauling lines) sail assisted fishing reduced fuel consumption by 17.6%, *Sail Line Fish®©.*

3.4 Weather Recordings and Observations

The data recorded and now shown in the graph below will be important when quantifying the potential use of sail power whilst fishing.

Dia.3-Graph showing weather and sea conditions suitable for fishing with a 15 meter sail assisted fishing vessel for period Jan 2009 to Jan 2010, *Sail Line Fish®©*



- Total days fishing <12 nm from shore (wind < F6 & sea state low or moderate) – 314
- Total days fishing >12 nm from shore (wind <F4 & sea state low) – 221
- Total days suitable for sailing (wind F3 – F6) in Shetland fishing waters - 255
- % days of year suitable for sailing - 69%

Weather and sea state recordings and observations made at 12:00 GMT daily in Sullom Voe, Shetland with a combination of offshore data. Note: - 12 nm from shore is significant as recognised transition of less and greater fishing opportunity in Shetland fishing grounds.

3.5 Vessel size

In order to establish an optimum vessel size for a sail-assisted fishing vessel suitable for Shetland waters the following points were considered:-

- Mast system – for a free standing collapsible mast greater than 12m in length the mast diameter in access of 300mm becomes unworkable for the construction of a carbon fibre or aluminium mast. Using the rig (photo 2.3) a 12m mast is sufficient for a 15m sail-assisted fishing vessel.

- Prevailing weather and sea conditions – With gale force winds experienced in any month of the year. Shetlands offshore fishing grounds require capable vessels designed for these extreme conditions. A vessel < 15m would severely reduce your number of days fishing per year.
- Fishing grounds – Species suited to longlining are cod, haddock, whiting, ling, tusk, skate, halibut and turbot. These species are more prolific > 12 miles from Shetland shore (ref diagram 2.7 Shetland Fishing Grounds).
- Fishing capability of vessel – A vessel < 10m would have insufficient refrigerated hold space which is essential for fishing trips of 3 days+. It is accepted that on passage time would increase with sail-assisted fishing.
- Legislation – UK Fishing vessels are certified under the Marine and Coastguard Agency regulations. A cut off size for higher standards of construction and equipment is 15m.
- Crew availability – A longlining vessel < 15m would operate with 1 or 2 crew. Greater than this size 3 + crew would be required. The younger generation are showing less drive to become fishermen due to uncertainties in the industry which include quota management and a planned discard ban on all fish. Contributory factors are other Marine opportunities in the Merchant Navy and Oil Industry. The excessive capital investment required for vessel and fishing entitlement ownership is very restrictive. The ironic thing is fish stocks are in good health in Shetland waters. This is evident from the value held on fish quota and the increase in fish landings locally. Demand on seafood is also ever increasing as a healthy food product.

With all of the above factors taken into account the size of a 15m vessel was chosen. However if for example a fishing partnership has greater financial resources a larger vessel with greater fishing capabilities and less disruption due to weather could be a better option.

3.6 Other methods researched

The kite propulsion system has potential for vessels trading on ocean passages rather than on short coastal routes like fishing vessels. The system would need to have potential to be easily and automatically deployed without the need to be manually handled on the exposed fore deck. A fishing vessel regularly alters course relative to the wind due to its varying fishing activities. From the fishing trials using the Balpha Mast system it was evident how important an easily and fully automated system is. The Balpha Mast also gives a wider arc of wind which can be used under sail therefore reducing fuel usage further.

B9 Shipping sail system is a fixed mast system where effective for an on passage cargo vessel it is less suitable fitted on a fishing vessel. The study showed the importance of a collapsible sail system for this particular application.

Discussion

Fish

The fishing industry is fundamental to Shetlands future. This indigenous way of life is 100% dependable on a natural, sustainable marine resource. Through human activity the continual use of burning fossil fuel, creating CO_2, may be threatening this balance. Are the massive reductions of seabirds in Fair Isle the first indications of the course we are taking? Further research into this should be conducted at a local level in collaboration with the fishing industry, coastal communities and marine research centres. This should be undertaken in conjunction with knowledge from institutions engaged in assessing the projected changes to the atmosphere (e.g., World Meteorological Organisation) and ocean (e.g., NOAA). It is crucial to projecting the consequences of climate change and ocean acidification for coastal fish habitats and fisheries production **(16)**.

Wind power and its potential

It is recognised by Naval Architects that Sail Power with 100m² sail area and a 16 knot wind can give 40 kW power. This resource is uniquely on hand to the user with no storage tanks to take up space on-board. There are no harmful substances to carry and no pollution risks to the environment, either sea or air. The constraints of sail power include the extra miles covered through proceeding on a head to wind destination. This can be improved on to give higher pointing abilities but no matter how well designed your vessel and sail-system is you are unlikely to go beyond the achievements of modern yachts built for the leisure industry. The present use of wind power at sea is limited to a necessity to have integration with prop power when conditions are not suitable for sail. Refer to weather data of the study 3.4.

Collapsible mast system

This mast system was specifically developed as a solution to an opportunity where fishermen have a free means of propulsion at hand but are not exploiting it. The mast system was designed as a means to sail when the conditions (wind speed & direction) and situation (on passage to and from fishing grounds) allow. As researched it is necessary to lower the mast when lying at nets or lines to avoid damage to the mast and rigging. Through conducting the sea trials it was also found to increase fishing time in marginal weather conditions. Modern materials of aluminium and stainless steel were chosen to construct a durable and substantial mast housing. The mast and boom was also of aluminium in order to keep continuity of material. Aluminium stands well against a material like carbon fibre on-board a fishing vessel as it is more durable and easier to repair when damaged.

Reduced fuel consumption

Through conducting the 17 fishing trials it was found the sail-system reduced fuel consumption by 17.6%. This included fuel used during fishing time when shooting and hauling lines. Fuel reduced during passage to and from fishing grounds was 33%. It is important to consider both these results as it demonstrates the total energy used on a fishing vessel. On larger vessels there would also be a refrigerated hold to run and other fishing equipment to power. This is where other low/zero carbon power supplies need to be developed to be integrated in with sail power. These could include hydrogen or batteries as a form of stored power supply which may be derived from wind or tidal power.

Weather observations

Weather observations were made in order to have indications on the potential of using sail power in Shetland fishing grounds. No other data is available for this area specific to using sail power. Sea state and swell observations were recorded and combined with the wind speed to give the potential for using sail power < 12 nautical miles from shore and > 12 nm from shore. This study has shown the potential wind power can have in reducing fuel consumption whilst fishing.

Conclusion

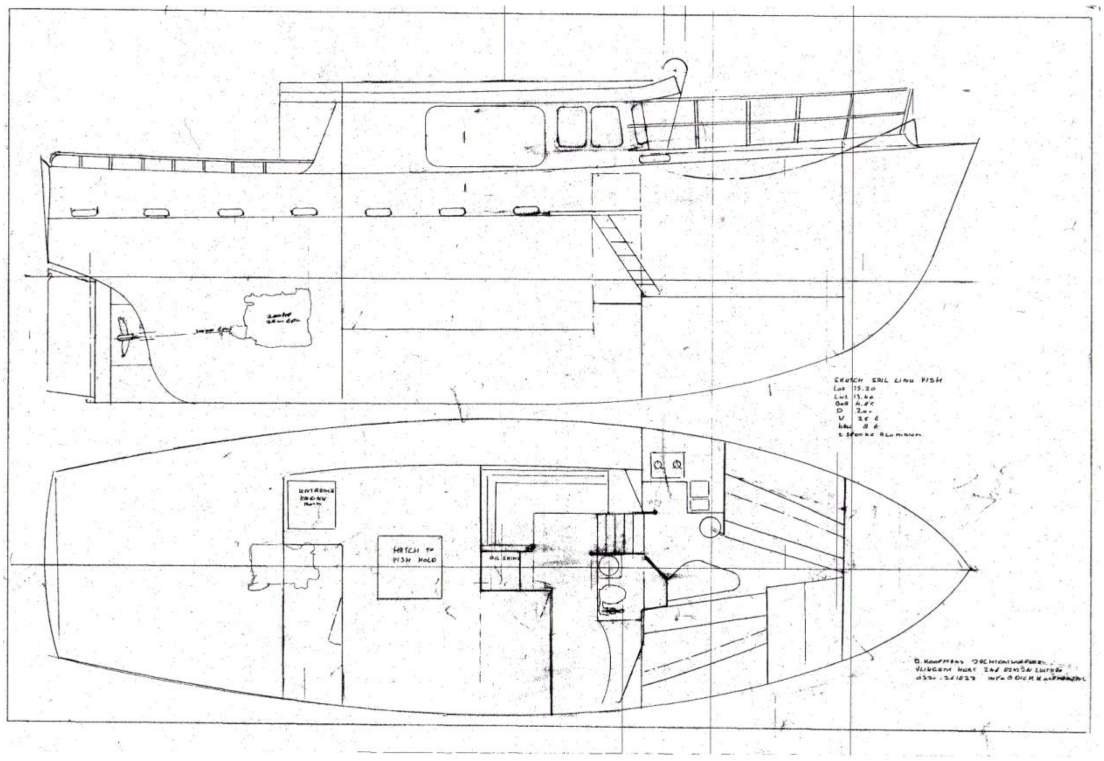
The new collapsible mast system, **Balpha Mast** provides a means to exploit a carbon free resource readily at hand to the fisherman. Through the research undertaken it was demonstrated with the prototype mast system and traditional 6.5m sail fishing vessel that total fuel consumption was reduced by 17.6%. This equated to 0.8 litres of fuel (2.14kg CO_2) per nautical mile under engine power at 1800 rpm. The research identified important historical knowledge of how sail fishermen had to adapt sail systems for this specifically dangerous application. Combining this knowledge with modern innovative solutions has laid the groundwork for further collaborative research. It is important to note the efficiency of sail power relative to other forms of marine propulsion. Sail power has no fuel tank with hazardous substance on-board. There is no loss in energy through energy transfer (diesel to prop power). It is a resource immediately at hand with zero emissions and no fuel cost to the mariner.

More detailed and scientific research is required in the resource of wind power at hand. This data may already be available from existing sail users e.g. the leisure sailing industry. It is an important factor for the adoption of sail power and its potential use in the commercial marine industry.

It is also a significant factor to note the relatively small percentage of carbon emission the fishing industry contributes on a global scale, however the possible consequences of the continued effects could have major impact to our marine resource.

Future plans

Full automation and integration with other low/zero carbon propulsion systems is the ultimate goal. Since this study we applied the knowledge gained to design a 15m purpose built sail-assisted fishing vessel along with Naval Architects Dick Koopmans and Eric Sponberg.
This mono-hulled aluminium vessel will have 2 tonne refrigerated fish carrying capacity and with its further developed Balpha Mast system a 90m2 sail area.
The objective of this design is to harmonize the activity to be undertaken with the environment as a whole. Using the passive fishing method of line fishing where less engine power is required and only 400kg fishing equipment meant a leaner sailing hull form could be utilized. This will be a commercial fishing vessel but also a living lab to develop, test and trial sail-hybrid propulsion systems.
Weather observations for Shetland waters have now been recorded for past 6 years with the intention to continue daily obs.



Dia.4-Proposed new Sail Line Fishing vessel with integrated Balpha Mast, Sail Line Fish®©

References

(1). Herring boom - In the early 19th Century, the British Government gave a bounty of £3.00 per ton to owners of herring boats. By 1880 there could be up to 30,000 vessels on the East coast herring fishing season.

(2). Haaf fishing – During 18th and 19th century an open sail boat fishery up to 50 miles from Shetland coastline. Using longlines for ling and cod.

(3). Whaling - The British Government introduced the Bounty Act in 1749, offering 40 shillings per ton on all ships that were fitted out in this country that were 200 tons or more. The Arctic whaling continued on till the early 20th century with whale stations based in Shetland. Shetlanders continued as Antarctic whalers until 1963.

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