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Preliminary assessment of the energy efficiency of a four-panel *Nephrops* trawl

Fisheries Conservation Report

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Key findings

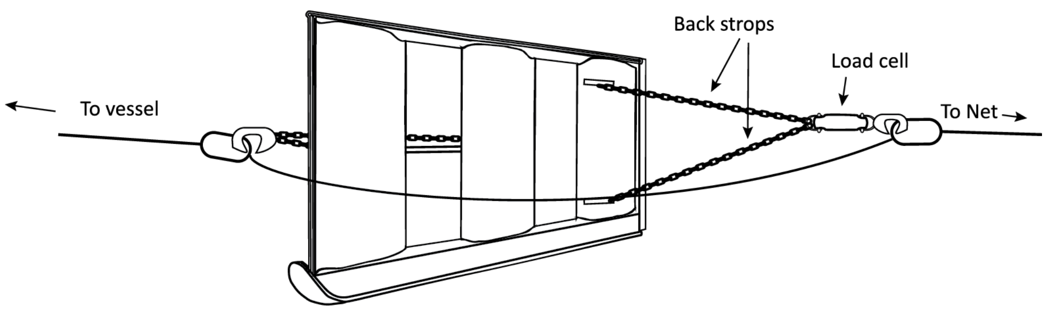
9% increase in wing end spread and swept area

No increase in fuel consumption and minimal increase in drag

Steeper trawl side taper and extensive sections of large mesh likely helped reduce drag

Improved Nephrops catches suggests reduced fuel intensity

Further flume tank and field testing planned



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Introduction

BIM is working with the Irish Fishing Industry to develop bottom trawls with improved energy efficiency. This work addresses a range of environmental and economic challenges around carbon emissions and fuel use (Browne et al., 2021).

The *Nephrops* fishery is a key priority in this regard. Bottom trawling for *Nephrops* is consistently the second most commercially important Irish fishery after mackerel and is worth around the same as all other bottom trawled species combined (BIM, 2020). Also, trawl fisheries for crustacean species such as *Nephrops* are known to be on the higher end of the scale in relation to fisheries carbon emissions (Parker and Tyedmers, 2015).

Lifting gear off the seabed may be an option in some fisheries targeting off-bottom species while incremental approaches are needed for benthic species like *Nephrops* where ground contact must be maintained.

The FAO advises that within the trawl system, the net is responsible for ~ 60% of energy use, with trawl doors ~ 30%, and warps and other cables ~ 10% (Barange et al., 2018). Altering these components can help reduce drag.

In collaboration with PEPE Trawls, BIM recently developed a new four-panel *Nephrops* trawl with extended areas of enlarged mesh in the top sheet of the net which has potential to improve energy efficiency as well as reducing fish bycatch (McHugh et al., 2021).

Mounted directly on the fishing gear, load cells are used to assess differences in drag associated with gear modifications (Notti and Sala, 2012; Priour and de La Prada, 2015). Improved operational efficiencies and increased catch per unit effort can also improve energy efficiency in well managed fisheries (Barange et al., 2018; Feekings et al., 2016).

Here, we use quantitative data on gear performance from load cells, wing end sensors and environmental data, combined with self-sampled data on fuel use, door spread and catch rates to assess potential differences in energy efficiency between the new four-panel trawl and a standard two-panel Nephrops trawl.

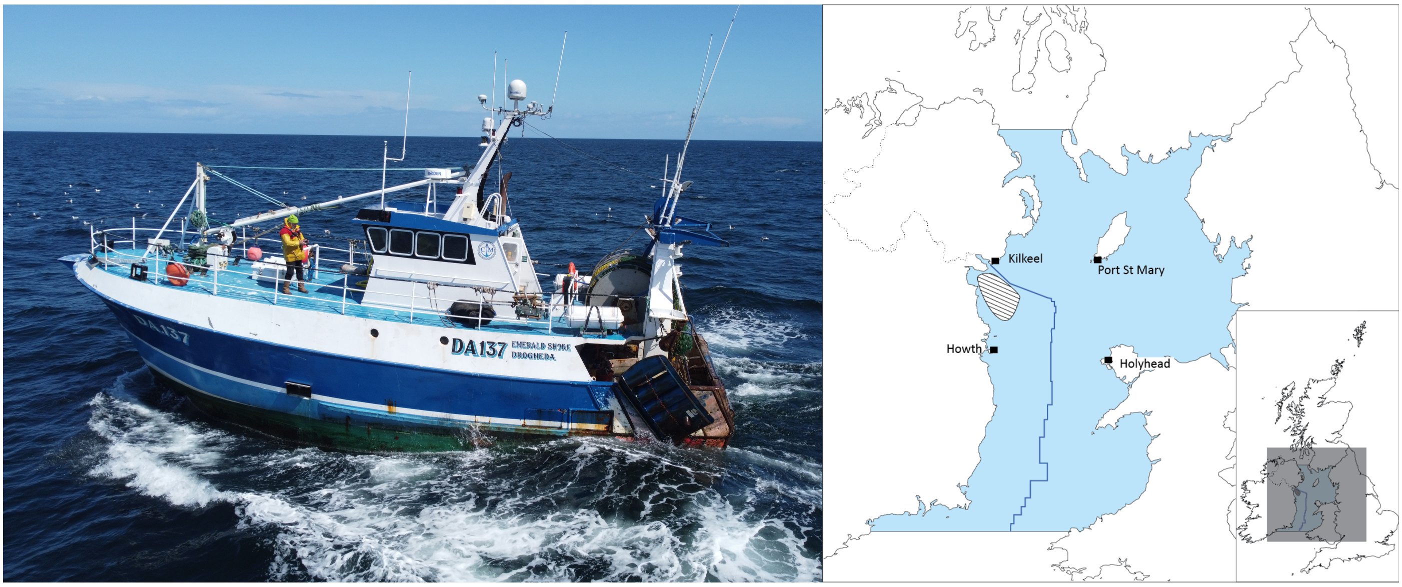

Figure 1. MFV Emerald Shore (DA 137) and trial location (hatched area) within the Irish Sea

Methods

Fishing operations

The trial was carried out on board the MFV Emerald Shore, a 16.89 m vessel targeting Nephrops in the Western Irish Sea (Figure 1). A total of five days fishing were conducted over an 8-day period in November 2021 on a self-sampling basis in line with Covid restrictions.

The test gear consisted of a new four-panel trawl with extensive sections of enlarged 300 mm mesh in the top sheet and upper wings, and a 300 mm square-mesh panel (SMP) in the codend. The SMP was located 4.5 to 7.5 m from the codline, consistent with previous work on escape panels in a four-panel SMP (Tyndall et al., 2017). The control gear was a commonly used two-panel trawl with a 300 mm SMP located 9 to 12 m from the codline. Taking account of the narrower four-panel condend and calculated in degrees to the towing direction, the four-panel trawl had a steeper side taper of ~ 38° compared with ~ 30° in the two-panel trawl (Table 1, Figure 2).

The vessel fished a half-quad configuration which comprised a two-warp system connected to a pair of otter boards with 70 m outer sweeps and inner sweeps, and a chain (~ 1 m distance) between each net's inner wings (Table 1; Figure 3a). Two test trawls were compared with two control trawls in this configuration.

Due to limited deck space, it was not possible to conduct alternate hauls. Instead, we assessed one gear after the other with candidate variables modelled in relation to drag.

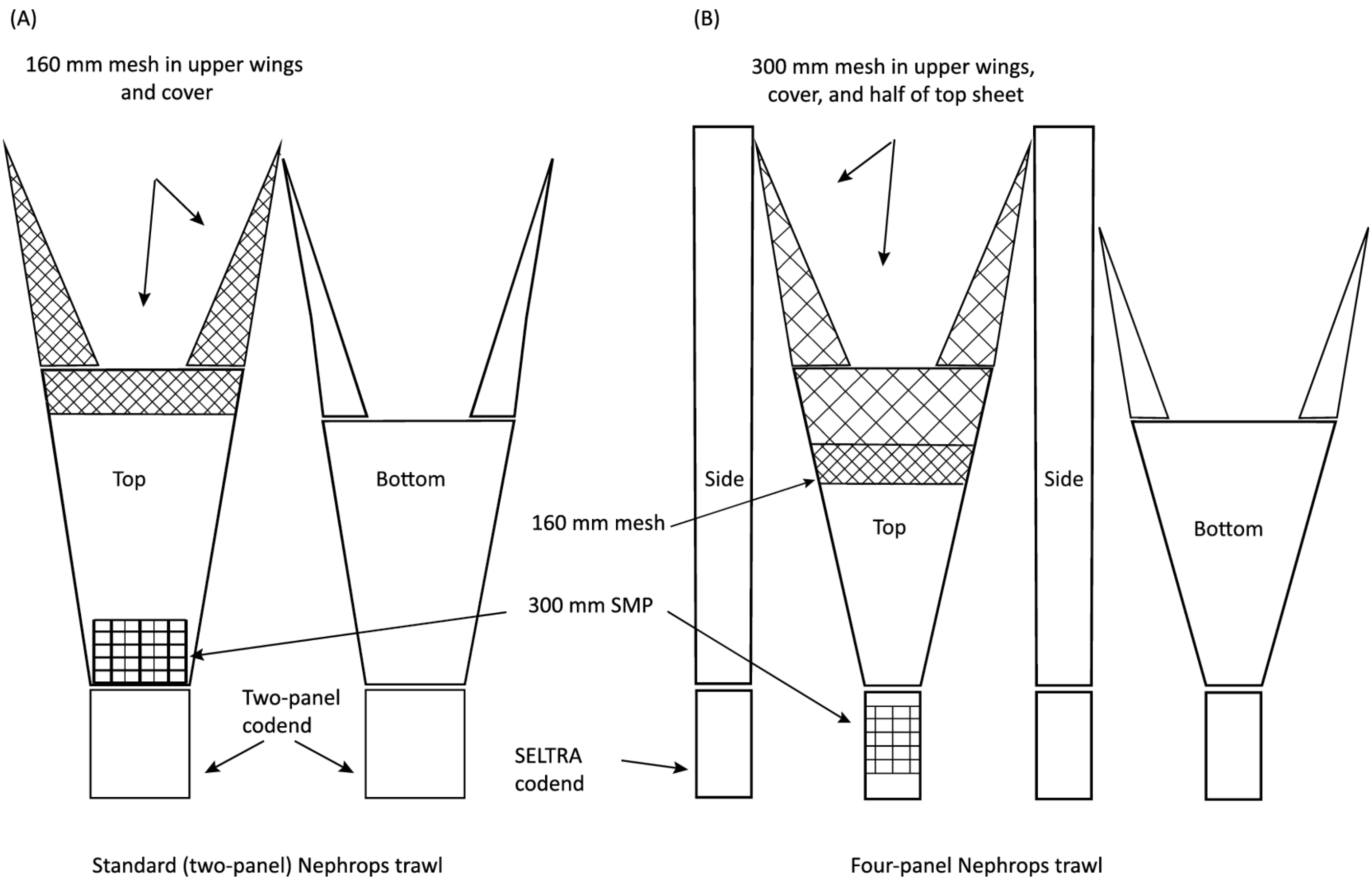

Figure 2. Illustration of the four-panel (left) and two-panel (right) trawls

Table 1. Gear characteristics of the trawls used in the trials

	Four-panel		Standard
Trawl type		*Nephrops*	
Trawl configuration		Half quad	
Headline length (m)		37	
Estimated headline height (m)		1	
Footrope length (m)		42	
Fishing-circle (meshes × mm)		400 x 80	
Sweeps (m)	4 x 70		4 x 70
Number of panels in trawl	4		2
Estimated side taper (degrees to towing direction)	38		30
Door manufacturer & model		Thyboron Thyson	
Average door spread (m)		44	
Codend type	SELTRA		Standard
SMP Mesh size (mm)	300		300
SMP position	4.5–7.5 m from codline		9–12 m from codline
SMP size (mesh × mesh)	18 × 4		18 × 7
No of panels	4		2
Nominal mesh size (mm)	80		80
Measured mesh size (mm)	85		84
Codend circumference (mesh no.)	120		120

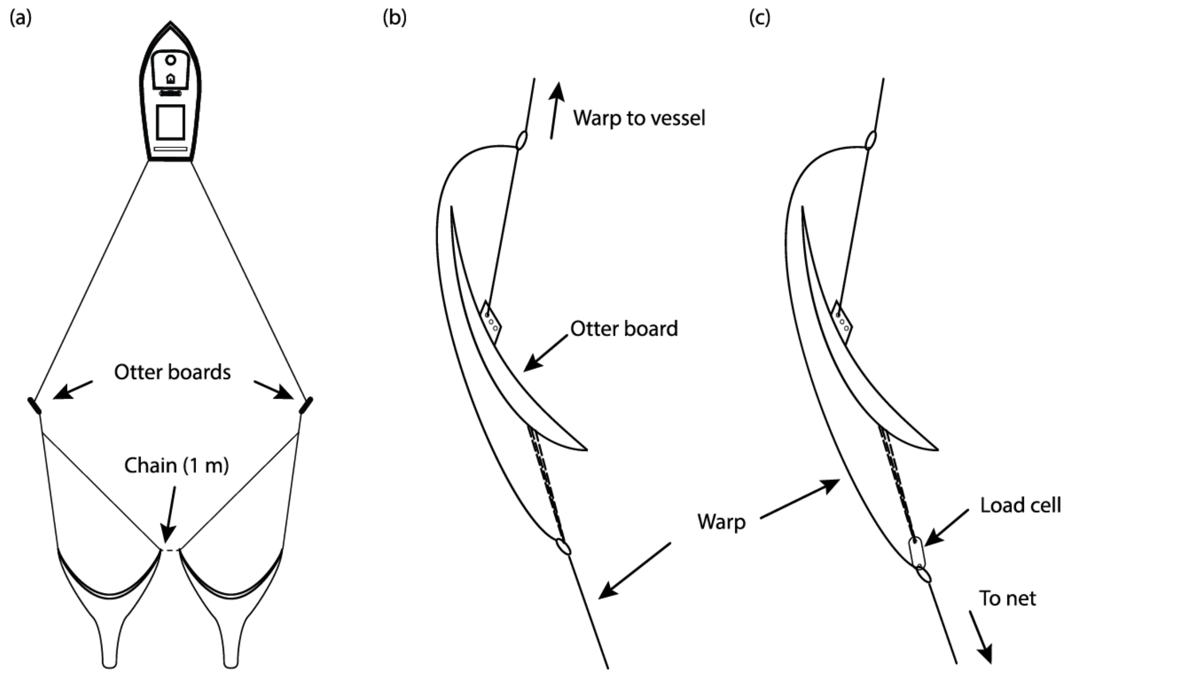

Figure 3. (a) half quad-rig configuration; (b) typical otter board configuration on warp; (c) load cell placement on warp behind otter board

Data collection

Two NKE Instrumentation SF5 autonomous data logger (NKE, 2021) load cells were mounted on the back strops behind the otter boards (Figure 3b, c). This location was easily accessible and helped isolate load measurements to the trawl. Load cell data were recorded at 3 min intervals. Load analysis was restricted to hauls where load cells were mounted behind the doors.

The skipper and crew followed an agreed protocol where catches per haul were sorted by species, weighed, and recorded. Species with low mean catches were combined into species groups (e.g., flatfish and rays).

Additional vessel operational and gear performance data were collected to further explore potential gear effects on energy efficiency. The vessels Caterpillar (engine) Marine Display Output was used to observe fuel consumption rate. The vessels Scanmar sensors were used to observe door spread. The skipper recorded fuel consumption rate and door spread up to seven times per haul. The Scanmar hydrophone was periodically connected to a Marport system that was used to record detailed wing end spread data using Marport sensors at 3 second intervals.

Data on environmental parameters which could influence drag such as wave height, wind speed, and tidal current were derived from a local wave buoy and tide tables on an hourly basis.

Data processing and analysis

We processed load cell data manually by haul to exclude shooting and hauling periods and wing end data by removing implausible values < 6 m or > 20 m and signal to noise ratio (SNR) values less than – 100 and greater than – 6 in line with Marport recommendations (Marport, 2022). These filters removed 222 of 18,316 (1.21%) wing end spread observations. Due to an imbalance in wing end spread observations between gears, we randomly subsampled 220 observations without replacement from each haul in line with the lowest number of observations per haul.

Developed using the GAMLSS package in R, we used generalised additive models (GAM) to predict differences in drag and wing end spread between the two gears.

In the drag model, we treated catch weight as increasing linearly in relation to time from start of hauls. We included candidate variables in the drag model as follows:

Response variable: $y_{h,i}$ total load observation i in haul h

Explanatory variables:

- Gear $g \in \{2\ panel; 4\ panel\}$
- Time - tow ticker i (three-minute intervals)
- Haul h
- Covariates – wave height w, catch weight c

Overall model

$y\mathrm{h},i = \mu\mathrm{h},i + \varepsilon\mathrm{h},i$

Mean model: $\mu_{h,i} = \alpha_{g[h]} + s_{g[h]}(i) + s_h(i) + b_h + s(w_h(i)) + s(c_h(i))$

where s are penalised cubic splines and $b_h \sim N(0, \sigma_b^2)$ are haul-level random effects

Residual model: $\varepsilon_{h,i} \sim N(0, \sigma h, i2)$

$$\sigma h,i = e\alpha g[h] + sg[h](i) + sh(i) + bi + s(wh(i)) + s(ch(i))$$

We used a correlation matrix to explore potential correlation between candidate environmental variables and mixed effects analyses and box plots to explore differences in fuel and door spread. We assessed total catch per unit effort (kg^{-h}) (CPUE) independent of other variables using a non-parametric Mann-Whitney test to help understand gear performance.

Results

A total of 22 hauls, 11 with each gear were carried out. We restricted load cell analysis to 9 and 7 hauls in the four-panel and two-panel trawls where the load cells were mounted behind the doors. Mean drag was ~ 4.5% greater in the four-panel trawl. Mean fuel consumption and door spread were similar between gears. Mean wing end spread was ~ 9% greater in the four-panel trawl. In relation to total catches, haul 18 was an outlier due to an exceptionally large haul of dogfish. Excluding haul 18 mean total catch weight was 30% greater in the four-panel trawl. Overall, the two-panel trawl caught 73% more unwanted catch than the four-panel trawl (Table 2).

We plotted and modeled load in individual hauls to investigate potential trends. Some similarities across hauls and gears occurred but no consistent trends in load were apparent (Figure 4). The best fitting overall drag model based on Akaike's Information Criterion (AIC) showed a significant difference in drag between the two gears ($P < 0.001$) (Figure 5). Catch weight did not significantly affect drag although CPUE was significantly higher in the four-panel trawl when haul 18 was excluded ($p < 0.05$) (Figure 6). Wing end spread was significantly different between gears ($p < 0.001$) (Figure 7) while no significant difference in fuel occurred ($P > 0.05$) (Figure 8).

A correlation plot of environmental variables showed strong correlations between wind speed, max wind gust and wave height (Figure 8) so we chose to include wave height in the drag model. This did not improve the model fit and was excluded. Derived from local tide tables, we explored estimated current strength in relation to drag. Information on vessel heading in relation to tidal direction was not collected, so tide was excluded from the analysis.

Table 2. Key operational parameters

	Two Panel Trawl			Four Panel Trawl		
	Range	Mean	Standard deviation (±)	Range	Mean	Standard deviation (±)
Loadcell force (Kgf)	1239–2455	1860	181.7	1381–2857	1945	203.4
Wing end spread (m)	6.3 – 19.9	12.7	0.96	9.0 – 19.7	13.9	0.93
Otter board spread (m)	45.1 – 48	46.2	0.9	45.5 – 47.8	46.4	0.7
Fuel usage (l/hr)	34.5 – 39.0	36.5	2.0	33.1 – 39.6	36.7	1.8
Tow duration (min)	177 – 354	298	51	99 – 354	247	113
Tow speed (kts)	2.8 – 2.9	2.8	0.1	2.8 – 3.1	2.8	0.1
Trawl depth (m)	26.0 – 50.0	42.9	6.6	18.0 – 49.0	38.4	9.1
Total catch (kg)	147 – 916	257	221	34 – 385	235	100
Total catch (kg)*	147 – 239	191	30	34 – 385	235	100
Total fish (kg)	58 – 846	161	230	29 –221	92	54
Total Nephrops (kg)	22 – 170	95	45	86 – 273	143	80
Unwanted catch (kg)	56 – 828	156	226	27 – 221	90	54
Wanted fish catch (kg)	1 – 18	6	6	0 – 4	1.5	1.4

**Excluding haul 18 (two-panel net; with 630 kg of dogfish)*

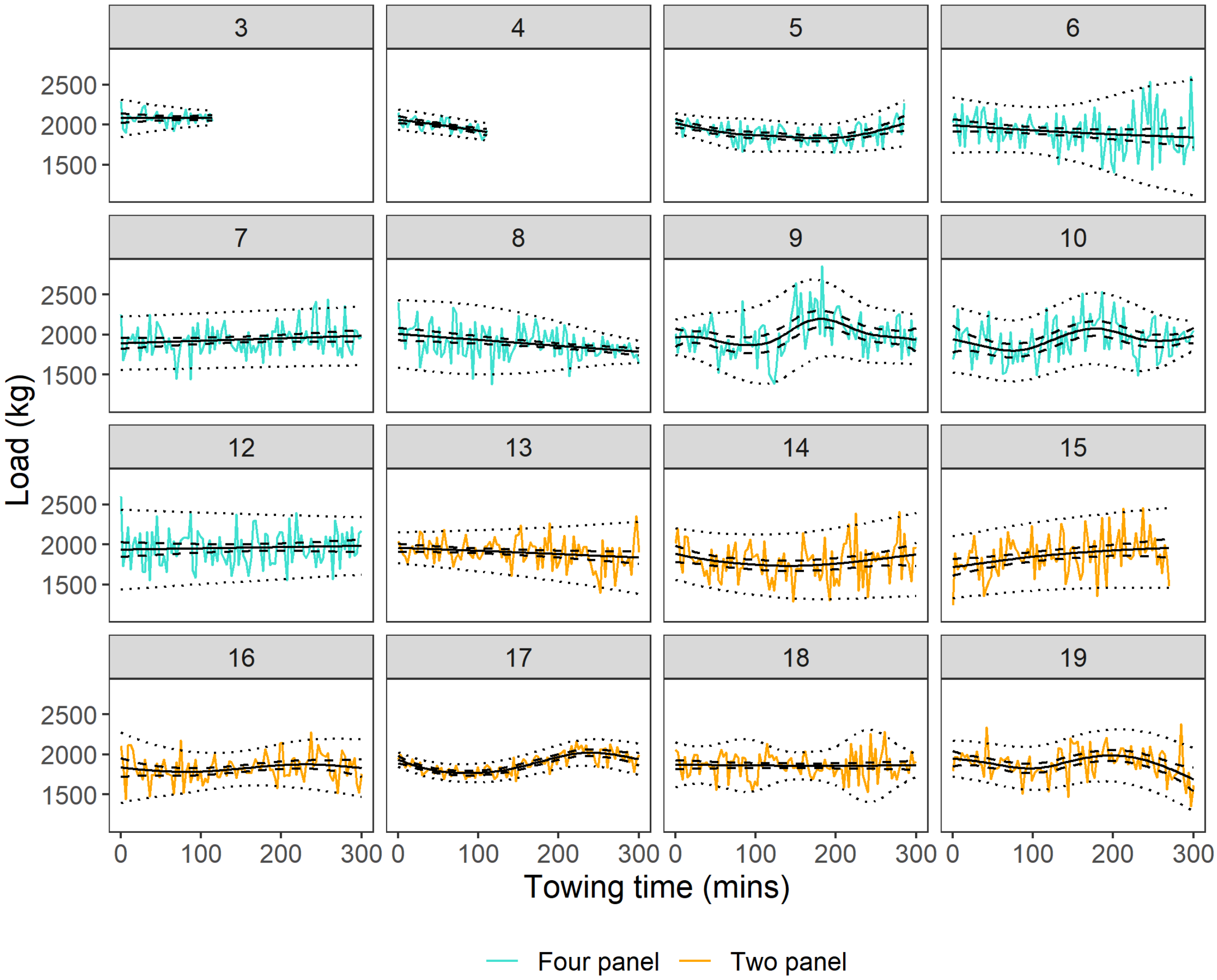

Figure 4. Load by induvial hauls with GAM fits and 95% confidence intervals

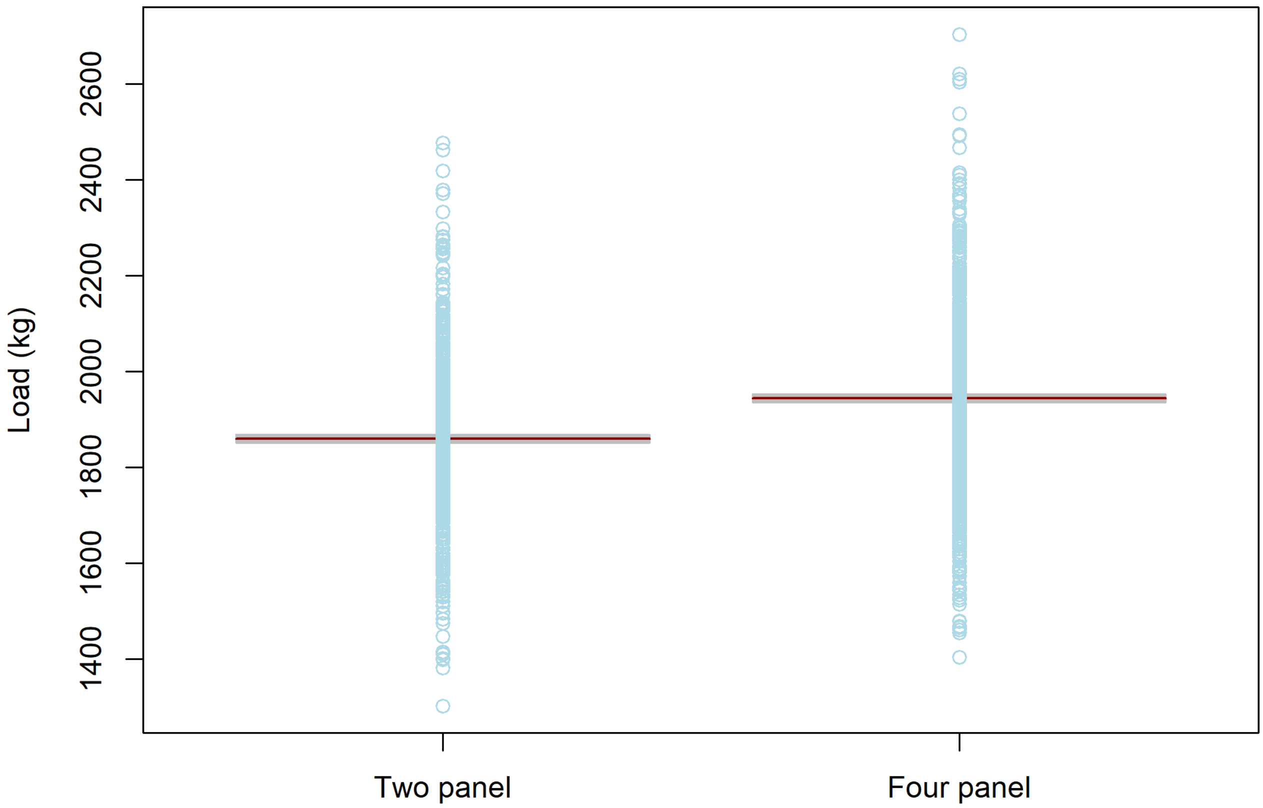

Figure 5. Modeled load of the two gears

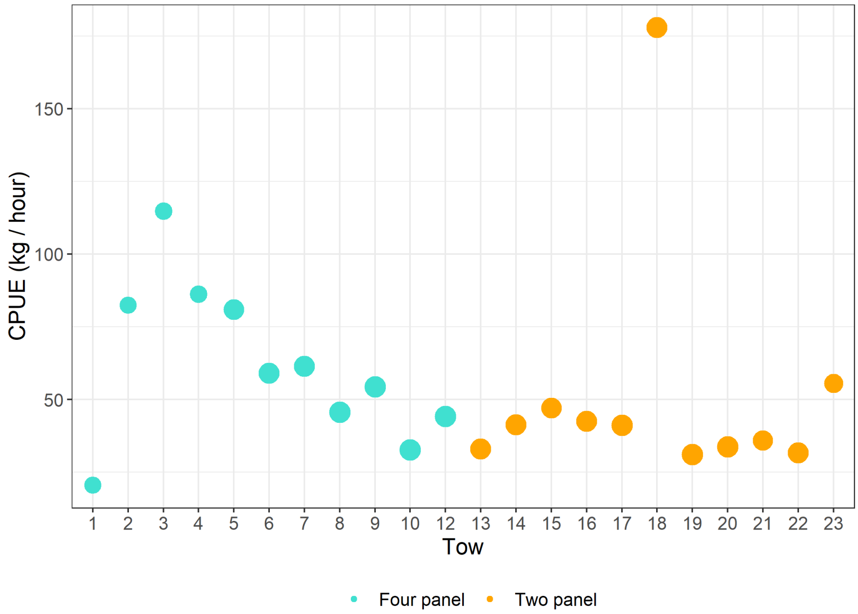

Figure 6. CPUE by tow. Dot size proportional to tow duration.

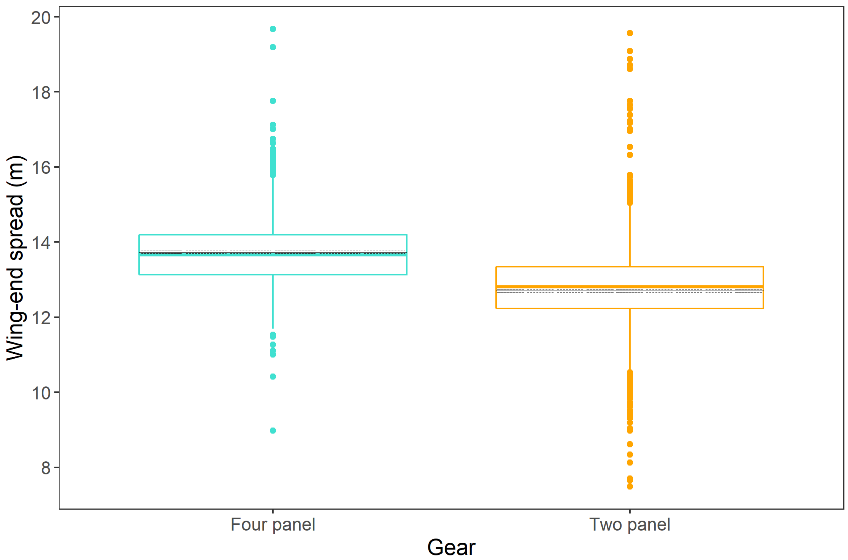

Figure 7. Boxplot of wing end spread by gear with mean values and 95% confidence intervals

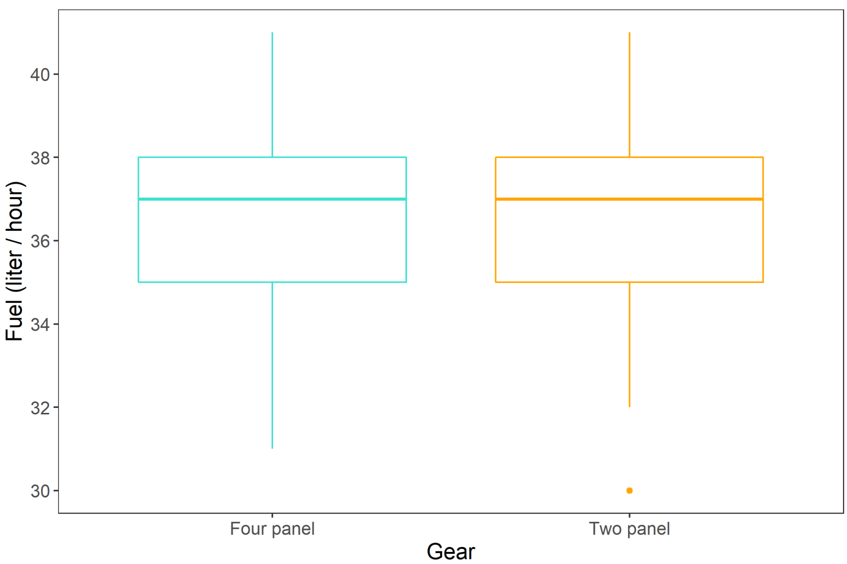

Figure 8. Fuel usage by gear

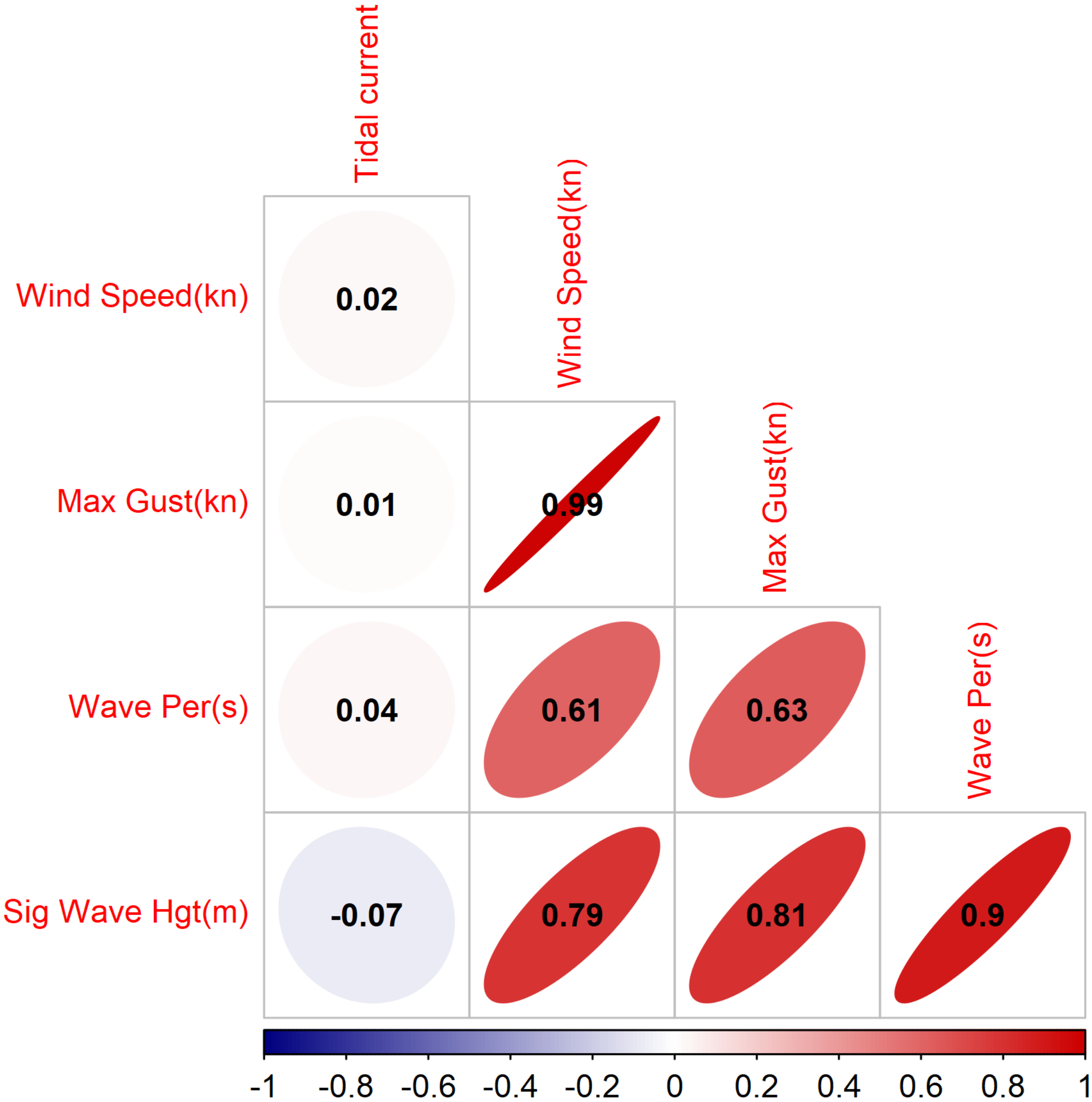

Figure 9. Correlation plot of environmental variables

Discussion

The greatest operational difference between gears was a 9% increase in wing end spread suggesting a greater swept area in the four-panel trawl. Average *Nephrops* catches were 58% greater in the four-panel trawl but this was not a true comparison due to differences in timing of gear deployments.

Previous BIM trials compared catches of the two gears simultaneously in a half-quad-rig configuration demonstrating 8 to 20% increases in catches depending on the codend used (McHugh et al., 2021). That gear configuration likely limited the wing end spread of the four-panel trawl, however, so the catch differences may not be accurate.

Catches are known to increase in line with increased wing end spread and swept area (Jones et al., 2021). Also, Tyndall et al (2017) showed that the SELTRA codend significantly increased *Nephrops* catches by 19% compared with the 300 mm SMP. Based on a 10% increase in swept area and 19% increase in *Nephrops* catches in the SELTRA codend, a 29% increase in *Nephrops* catches is likely a more realistic estimate than the 58% increase observed in the current study.

Mean drag was greater in the four-panel trawl by a marginal 4.5% while no significant difference occurred in fuel consumption. A 29% increase in *Nephrops* catch rates with no increase in fuel would correspond to an estimated 29% reduction in fuel intensity in terms of litres of fuel consumed per kg of *Nephrops* produced.

Results suggest that improved hydrodynamics in the test gear may have helped offset increases in drag and fuel associated with increased swept area and catches. Catches are known to influence gear drag (O'Neill et al., 2005; Priour and de la Prada, 2015). Excluding haul 18, mean bulk catches were significantly greater in the four-panel trawl. Given the 10% and 30% increases in wing end spread and total catches, one might expect greater differences in drag and fuel consumption between gears.

The four-panel codend in the test gear may have assisted in this regard: Hydrodynamic forces acting on the catch are generally such that the surface of the catch facing the flow in the cod-end is concave (O'Neill and O'Donoghue, 1997). O'Neill et al. (2005) described codend drag as a function of towing speed and the maximum frontal area of the concave surface.

Madsen et al. (2015) demonstrated how a standard two-panel codend displayed a concave shape while a four-panel codend maintained a square shape as catches accumulate. Drag was 67% lower due to the reduced catch surface area in the four-panel codend. Hence, despite higher catches, codend drag was likely lower in the four-panel compared with the two-panel codend in the current study. Codend drag is known, however, to form a relatively minor component of the overall drag in the trawl system (Prior, 2009; Stewart and Ferro, 1987).

Characteristics of the main body of the trawl contribute greatly to net drag (Balash et al., 2016). The number of net panels, side taper and mesh characteristics differed between trawl bodies in the current study.

Broadhurst et al. (2012) found no significant difference in drag between two and four-panel shrimp trawls with the same side taper but did find a reduction in drag of up to 4.3% in the steeper tapered trawl. This suggests that the steeper taper rather than the four-panel design more likely contributed to improved hydrodynamics in our test gear.

Mesh size is known to affect the planar twine-area and trawl drag (Sterling, 2005). Extensive sections of 300 mm mesh in the top sheet and upper wings may also have contributed to improved hydrodynamics in the test gear.

Interestingly, Broadhurst et al. (2012) found a significant increase in wing end spread in the steeper tapered trawls. Given, that door spread was the same for the two gears, its likely that the steeper taper also contributed greatly to the increase in wing end spread in the test gear in the current study.

Results of the current study and previous BIM research (McHugh et al., 2021) demonstrate that the four-panel *Nephrops* trawl reduces unwanted catches thanks to the SELTRA codend and potentially the extensive sections of large mesh in the anterior sections of the top sheet. The new gear also has major potential to improve energy efficiency in the *Nephrops* fishery.

BIM is planning to further test and develop the gear at the flume tank facility in Newfoundland in September 2022 and in a follow up gear trial using a full quad-rig configuration.

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