**Development of a robust method for comparing catches in a multi-rig trawl fishery for *Nephrops***

*Nephrops norvegicus* is a commercially important species distributed throughout the North East Atlantic and Mediterranean Sea. Total landings of 66,500 tonnes in 2010 were predominantly attributed to the United Kingdom (58.1%) followed by Ireland (11.7%) and various other European Union (EU) countries operating in Atlantic and Mediterranean waters (FAO, 2010). More than 95% of EU *Nephrops* landings are taken using single or multi-rig trawlers which target *Nephrops* in mixed species fisheries (Ungfors *et al.*, 2013). The use of four trawl multi-rigs known as quad-rigs (Figure 1) commenced in October 2012 and by the end of 2014 accounted for ~ 80% of *Nephrops* landings by the Irish fleet. The estimated value of Nephrops landings at the first point of sale in 2014 was €44.5 m making it the most commercially important demersal species.

The main driver for increased uptake of the quad-rig trawl is increased catches of *Nephrops*. Potentially linked with increased ground contact, *Nephrops* catch weights were observed to increase by 95% in the North Sea and 54% in the Celtic Sea in studies comparing quad with twin-rig trawls (BIM, 2014; Revill *et al.*, 2009). Such increases in fishing power may be beneficial in terms of improving operational efficiency. However, in the context of a discard rate of 15% of total catches of *Nephrops* below minimum landing or market size in Irish waters (MI, 2014), such substantial increases in *Nephrops* catches may lead to increases in unwanted Nephrops catches. Discarding of undersized and non-targeted fish species is also a major issue in *Nephrops* trawl fisheries (e.g. Catchpole *et al.*, 2005; Catchpole and Revill, 2008; Nikolic *et al.*, 2015; Ungfors *et al.*, 2013). New requirements to restrict discarding of demersal species under EU regulation 1380/2013, the Landing Obligation (LO), are likely to have negative impacts on the economics of *Nephrops* fisheries unless such catches can be reduced.

Gear modifications to reduce bycatch are generally assessed using either selectivity or catch comparison experiments (CITATION). The practical advantages of catch comparison include commercial-like performance and handling of the gear. In addition, the ease with which results of catch comparison experiments can be reported and interpreted (Holst and Revill, 2009) is likely to be particularly beneficial in assisting the fishing industry to address challenges posed by the landing obligation. The drawbacks of the method are that it does not provide an absolute estimate of selectivity and therefore comparisons are only possible with gears included in the experiment (Frandsen, 2010). Utilising a quad-rig trawl effectively increases the number of gears that can be included in the experiment to four, providing more concurrent experimental settings and information than traditional twin or single-rig catch comparisons.

Until recently, modeling approaches for catch comparison data were limited with a general reliance on simple paired tests by length classes. The development of a Generalized Linear Mixed Model (GLMM) approach which provides a statistical and graphical comparison of fish length by different fishing gears with an associated measure of error (Holst and Revill, 2009) greatly improved the power of catch comparison analysis. Based on a logistic model with a binomial error distribution, the approach is, however, limited to two gears. Multinomial models can generalize logistic regression to multiclass problems, i.e. with more than two possible discrete outcomes (McCullagh and Nelder, 1989). They can be used to predict the probabilities of the different possible outcomes of a categorically distributed dependent variable, given a set of independent variables. Examples of the application of multinomial models to fisheries include analysis of egg stages (Ibaibarriaga *et al.*, 2007; Stratoudakis *et al.*, 2006), comparisons of age-length keys (Gerritsen *et al.*, 2006), fleet behaviour (Ward and Sutinen, 1994) and discard survivability (Benoit *et al.*, 2010).

Here, we extend the method of Holst and Revill (2009) to multi-rig trials. Our goals are dual to 1) develop a multinomial random effects model capable of including: case-specific and choice-specific covariates, cod-end specific sub-sampling, and multivariate random haul effects as found in multi-rig trials; and 2) apply to data from a designed *Nephrops*  quad-rig trial with four simultaneously deployed diamond mesh cod-end test gears.

**Method**

*Demonstration data*

Daragh insert here

Discussion

Comment on significant factors :

Total catch weight is known to affect mesh openings and cod-end size selection for a range of fish species (Campos *et al.*, 2003; Herrmann and O’Neill, 2005) and the custacean Aristeus antennatus (Campos *et al.*, 2003). The significant effect of total catch weight on the proportion of Nephrops caught by length class in the current study confirms the influence of this parameter on an additional crustacean species (*Nephrops Norvegicus*). This has important implications for the development of improved selectivity measures in trawls with different numbers of rigs. Thought to be associated with lower headline height and altered sweep arrangements, reductions of up to 61% of cod, 38% of haddock, and 59% of whiting were observed in trials which compared catches in quad and twin-rig trawls in the Celtic and North Seas (BIM, 2014; Revill *et al.*, 2009). Substantially lower fish catches associated with quad-rig trawls are likely to cause smaller cod-end mesh openings. Hence, in addition to increased ground contact (BIM, 2014; Revill *et al.*, 2009) lower fish catch associated with the quad-rig is likely to be a key factor underlying increased *Nephrops* catches in quad-rig trawls compared with trawls with fewer rigs. Can refer to swedish grid experiment here showing reduced fish catches affected cod-end selectivy and additional meaures such as square mesh cod-ends or increased diamond cod-end mesh size to ensure bycatch reduction is optimised.

Incorporation of total catch weight into catch comparison analyses may also contribute to improved sampling power for quad-rig trawls. Wileman *et al.* (1996) describe how sample variance can be reduced by increasing the number of hauls made, the number of fish caught or the rate of sampling of the catches. Assessment of a greater number of test gears in a quad-rig experiment effectively reduces the amount of time available to sample each test gear, potentially leading to increased levels of sample variance. Power analyses may assist in determining optimal numbers of sampled hauls or fish needed to obtain significant results (Herrmann *et al.*, 2015; Wileman *et al.*, 1996). Reducing the duration of hauls may also facilitate increasing the numbers of hauls sampled. However, reduced haul duration is likely to be associated with reduced total catch which we have shown affects Nephrops selectivity. Provided a range of values occur, incorporating total catch quantities into a catch comparison model may facilitate shorter haul durations and improved sampling power in future studies.

This study demonstrates the importance of incorporating net position in experimental design and analysis. Can we expand?

Should we comment on why we excluded haul duration as a covariate?

Application to other potential fisheries – Daragh.

Can we make inferences in relation to increased mesh size in relation to Nephrops catches – Is it a good thing?

Can we talk about how model could be improved by utilising data on catch volume rather than catch weight. examples

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