**A simple method for comparing catch composition in multiple test gears**

*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 commenced in October 2012 and by the end of 2014 accounted for ~ 80% of *Nephrops* landings by the Irish fleet. Sales notes data compiled by the Sea Fisheries Protection Authority show that the total value of Irish landings of *Nephrops* landings at the first point of sale in 2014 was €44.5 m making it the second most commercially important species landed in Ireland after mackerel.

Discarding of undersized, over quota and non-targeted species is a major issue in *Nephrops* trawl fisheries (Catchpole *et al.*, 2005; Catchpole and Revill, 2008; Nikolic *et al.*, 2015; Ungfors *et al.*, 2013). Also known in an EU context as technical measures, a variety of gear modifications including increased cod-end mesh size, sorting grids, modified cod-end mesh shape and orientation have been evaluated and in some cases implemented to improve selectivity and mitigate dsicarding in *Nephrops* trawl fisheries (eg. Briggs *et al.*, 1999; Briggs, 1986; Catchpole and Revill, 2008; Catchpole *et al.*, 2006; Frandsen *et al.*, 2011; Graham and Ferro, 2004; ICES, 2007; Nikolic *et al.*, 2015; Sala *et al.*, 2015). New requirements to restrict discarding of demersal species under EU regulation 1380/2013, the Landing Obligation (LO), are likely to incentivise increased uptake of technical measures and promote the use of more selective fishing gears. Some potential benefits of quad-rig trawls have been demonstrated in this regard. Potentially linked to 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).

The main driver for the widespread adoption of the quad-rig trawl in Ireland, however, 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 higher catches of small *Nephrops*. Restrictions on discarding under the Landing Obligation are likely to have negative impacts on the economics of the Irish *Nephrops* fishery unless such catches can be reduced. Furthermore, although quad-rig trawls catch less fish than trawls with fewer rigs, unintended catches of gadoid species are likely to continue to pose major challenges in terms of meeting requirements under the LO. For example average whiting discard rates in Irish Sea demersal trawl fisheries were 88% from 2010 to 2012 (CEFAS, 2014) and restrictions on discarding of whiting are likely to have major economic impacts on *Nephrops* trawlers operating in the area (Poseidon, 2013) Clearly there is a need therefore to develop technical measures which address discard issues in the quad-rig trawl *Nephrops* fishery.

Technical measures are generally assessed using either selectivity or catch comparison experiments. 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 may also be preferable (Holst and Revill, 2009). This facilitates more effective communication of results to the fishing industry which is particularly beneficial in terms of assisting the fishing industry in developing solutions to LO requirements. 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, potentially providing much more information that traditional twin or single-rig catch comparisons[IN ADDITION TO CLOSER REFLECTION OF COMMERCIAL DEPLOYMENT].

Increasing the number of test gears does, however, pose a number of challenges to experimental and analytical designs. Potential bias in fishing power associated with different net positions in twin-rig experiments may be addressed by interchanging gears between positions at regular intervals (Wileman *et al.*, 1996). Regular rotation of gears is feasible in quad-rig experiments but resulting net position effects should ideally be modelled in conjunction with other candidate variables affecting catch composition. Wileman *et al.* (1996) also 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 is known to affect the size of diamond mesh openings and size selectivity of fish species (Herrmann *et al.*, 2006; Millar, 1992; Robertson and Stewart, 1988). While this issue has yet to be studied for *Nephrops*, results from hauls of shortened duration may not be representative of hauls of normal commercial duration. However, assuming a range of values occur, incorporating total catch quantities into a catch comparison model would permit quantification of the effects of this parameter which may facilitate shorter haul durations.

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 test the potential benefits of applying a multinomial modelling approach to a comparison of *Nephrops* catches in four different test gears with different diamond cod-end meshes ranging in nominal size from 70 to 100 mm. The effects of parameters such as total catch quantity are included in modelling and graphical outputs, and differences in *Nephrops* catch composition are discussed.

INCLUDE PARAGRAPH WITH DEVELOPMENTS

* DESIGN AND IMPLEMENTATION
* ANALYSIS
  + MULTINOMIAL, MULTINOMIAL RANDOM EFFECTS, DIRICHLET-MULTINOMIAL, ALL HAVE SAME GOAL DESCRIBING PROPORTION RETAINED BY LENGTH ACROSS GEAR CONFIGS
  + COVARIATES INCLUDED: SUB-SAMPLE RATIOS, CARAPACE LENGTH (POLYNOMIAL OR ADDITIVE EFFECTS), BULK WEIGHTS, NET POSITION
  + AVERAGE EFFECT IN THE PRESENCE OF CATEGORICAL COVARIATES
  + HAUL EFFECTS
  + CODE: PRESENTLY ADMB FOR RE

**Method**

*Demonstration data*

Discussion

Can talk about how model could be improved by utilising data on catch volume rather than catch weight. Other potential applications e.g gillnets, other multi-rig fisheries ?

Diamond mesh cod-end openings are known to affect the quantities of *Nephrops* retained (Catchpole and Revill, 2008; ICES, 2007). Results suggest that similar to fish species species (Herrmann *et al.*, 2006; Millar, 1992; Robertson and Stewart, 1988), increased catch accumulation and associated diamond mesh openings also affect *Nephrops* selectivity. Hence, in addition to increased ground contact (BIM, 2014; Revill *et al.*, 2009)lower fish catches 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.

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