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# Detection and quantification of differences in catch rates among research vessel gears and commercial vessels

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## ABSTRACT

Commercial fishing vessels can be a cost-effective alternative to research vessels for performing towed gear fishery-independent surveys, if catch rates are comparable among commercial vessels and with research vessels. A parallel fishing experiment was conducted off the coast of Wales, United Kingdom, to compare the king scallop (*Pecten maximus*) catch rates of three commercial vessels using commercial dredges and a research vessel using two types of scientifically modified dredges. The scientific dredges are currently used in the fishery-independent survey of local scallop populations. Size-structured scallop catch-per-unit-effort (CPUE) was compared among vessel-gear combinations. Two similarly sized commercial vessels had generally similar CPUEs, however there were some significant differences with scallop size. A smaller commercial vessel had significantly lower CPUEs for a broad range of scallop sizes. The research vessel dredges had significantly higher CPUE for smaller scallops than the commercial vessels. Vessel size is likely to be driving the differences among commercial vessels and belly ring size is likely to be driving differences among research and commercial dredges. These findings highlight commercial vessel CPUE should not be assumed the same, whilst also showing that vessel size may be the best indicator of catch rate similarity. These results also highlight that changing the fishery-independent vessel and gear to the commercial options

trialled here would result in a considerable loss of information about the smaller scallops in the population. These findings will be of interest to fishery scientists or managers using multiple vessels, or considering a change of vessels, for fishery-independent surveys.

**Keywords:** catch rates, catch comparison, scallop dredging, survey design, gear design.

## 1. INTRODUCTION

Fishery-independent surveys are designed to obtain samples that can serve as indices of stock status over time, whilst minimising bias (Hilborn and Walters 1992; Fraser et al 2007; Dennis et al 2015). These indices are often used to estimate relative or absolute stock size (Hilborn and Walters 1992; Walters and Pearce 1996; Pennington and Stromme 1998). Estimating stock size is highly useful and can be a key piece of evidence for sustainable management advice (Pennington and Stromme 1998; Fraser et al 2007). Such advice may be used to set a catch limit over a period or to control effort through various gear and vessel restrictions, to prevent overfishing and ensure long-term resource availability (Hilborn and Walters 1992; Pennington and Stromme 1998).

Sampling with towed gears during fishery-independent surveys is a common method for a wide range of target species, and commonly conducted by research vessels (Hilborn and Walters 1992). The catch rate of a towed gear fishery-independent survey is typically expressed as the biomass or number of individuals of the target species caught divided by the effort applied. Effort can be measured as the time spent fishing, number of dredges or trawls used, or the area that the gear sampled (Hilborn and Walters 1992). The size-structure of fishery-independent samples is usually expressed as counts or proportions of measured animals at size intervals (Wileman et al 1996). A wide range of environmental and technical factors influence catch rates (Fraser et al 2007). Environmental factors can include sea state, depth, tidal flow, bathymetry, and substrate type (Dare et al 1993; Fifas and Berthou 1999; Fifas et al 2004). Technical factors include gear operations, specifications, and vessel characteristics, which can each interact to create unique catch rates for each vessel-gear combination (Byrne et al, 1981; Fraser et al 2007; Weinberg and Kotwicki 2008). Vessel size has been shown to be a key driver of catch rates (Basch et al 2002; Thorson and Ward 2014). A small and lighter vessel is more likely to roll and pitch in poor weather conditions, and therefore will find it harder to maintain gear in the optimal position or maintain desired speeds (Byrne et al 1981). In addition, a less powerful vessel may also have difficulties maintaining speed in strong water currents.

The king scallop (*Pecten maximus*) is a commercially important bivalve species in the northeast Atlantic and, in the UK, is often fished using Newhaven dredges which are hauled in gangs of three to twelve from each side of a vessel (Figure 1; Lart et al 2003). Each of these dredges is fitted with a spring-loaded tooth bar designed to dislodge scallops from the sediment, which then pass into a chainmail bag attached to a steel frame (Boulcott et al 2014). Scallop catch rates are affected by the chainmail bag belly ring diameter, with higher catch rates of smaller scallops in dredges with finer belly rings (Fifas et al 2004; Roman and Rudders 2019; Poirier et al 2021). In addition, the size, number and spacing of teeth on each dredge affects the size composition of scallops that are dislodged from the sediment and therefore affects catch rates (Lart et al 2003; Fifas et al 2004).

Scallops (king and queen scallops (*Aequipecten opercularis*)) were the fourth most valuable wild-caught fishery in the UK in 2020, at a first sale value of £42.1 million (MMO 2021). Within Wales, scallops were the third most valuable fishery in the same year (MMO 2021). Because of this commercial importance, annual fishery-independent surveys of Welsh scallop populations have been conducted since 2012 using dredges operated by a research vessel (Delargy et al 2019). The consequent scallop catch rates and length-frequency distribution samples have been used to assess scallop population status (Lambert et al 2014; Delargy et al 2019).

Commercial vessels can be a cost-effective alternative to research vessels for conducting fishery-independent surveys (Cadigan and Dowden 2010). In addition, using commercial vessels in fishery-independent surveys helps engage fishers in the assessment process by improving communication and reducing scepticism between scientists and fishers (Thorson and Ward 2014). To characterize any potential effect that the use of commercial vessels may impart, the catch rates between research and commercial vessels need to be quantified and compared as vessel attributes can affect the collected samples. Previous research studying vessel effects have differed on whether commercial vessels produce comparable catch rates to research vessels during fishery-independent surveys (Helser et al 2004; Thorson and Ward 2014), which implies the issue is complicated and should be investigated further.

Typically, when size distributions are compared, it is common to have one non-selective gear that is assumed to collect a representative sample of the target species (Millar and Walsh 1992; Munro and Somerton 2001; Kotwicki et al 2017). However, it is often expensive and time consuming to assemble a non-selective fishing gear, and useful catch comparisons can still be made when the gears involved are all selective and the true population size-structure is unknown (Bethke et al 1999; Prchalova et al 2009; Reid et al 2012). In particular, the catch comparison rate, which is the ratio of the catch from one vessel/gear to the total from both vessels/gears, can be estimated to describe the relationship between the catch rates of the two vessels or gears (Halliday 2002; Krag et al 2014). Catch comparison rates are often useful in stock assessments as a correction factor when survey vessels are changed or when multiple vessels are used during a survey (Cadigan and Dowden 2010; Kotwicki et al 2017). The catch comparison rate has been referred to by several other names, such as relative efficiency or selectivity ratio (see Kotwicki et al 2017 for a full review of alternative terminology).

Currently, British vessels targeting king scallops in Welsh waters are subject to several restrictions including vessel size, engine power, closed areas and a closed season, as well as various technical specifications of the dredges used (The Scallop Fishing (Wales) (No. 2) Order 2010, Delargy et al 2022). Vessel engine power is capped at 221 kW and the maximum number and size of teeth and number of belly rings on each dredge is controlled. In addition, there is also a minimum landing size (MLS) that requires that king scallops smaller than 110 mm in shell width are returned to the sea in Welsh waters. The king scallop fishery in Welsh waters has also been targeted by vessels from the European Union that operate at a MLS of 100 mm shell width under European Union law.

The aim of the current study was to test for and quantify differences in the catch comparison rates of size-structured scallop CPUE among three commercial scallop vessels and a research vessel. The three commercial vessels hauled dredges operating at the maximum local legislation limits, and the research vessel hauled two types of modified dredges. It was not possible to rotate gears among vessels due to strict Covid-19 regulations at the time of the experiment preventing mixing of personnel among vessels.

The study allowed for a comparison of catch rates between three commercial vessels using almost identical gears, permitting investigation of vessel effects on catch rates. This would help inform selection processes if multiple vessels were to be used in future the fishery-independent surveys. In addition, although it was hypothesized that the wider belly rings of the commercial dredges would catch fewer small scallops than the research vessel dredges, the magnitude of difference in size structured catch rates of scallops was unknown. The commercial and research gears studied also differed in the number and length of teeth, and the vessels differed by size, weight, and engine power. Therefore, it was unknown whether any of these factors would outweigh the likely size-selection caused by belly ring diameter. This finding will help to assess the effects on the long-term fishery-independent survey indices if the vessel-gear combination conducting the survey was to change to one of the options tested here in the future. Whilst switching from survey dredges with finer belly rings to those with wider rings is not likely to be ideal, uncertainty over future survey funding may result in this being a realistic option.

## 2. MATERIALS AND METHODS

### *2.1 Catch comparison experiment*

The four vessels fished alongside each other in a parallel fishing experiment within areas where scallops were expected based on previous survey data and fisher knowledge (Delargy et al 2019). Scientific observers were present on all vessels for all hauls. The fishing was conducted in Cardigan Bay in the eastern Irish Sea off the coast of Wales, UK, on 25$^{th}$ to 28$^{th}$ April 2021 (Figure 2). The substrate was primarily gravelly sediment with a few small patches of sand and water depth in the area ranged between 20 and 60 m (EMODnet 2021). Most hauls were conducted on commercially fished grounds and the positions selected using a mixture of randomly generated survey locations and locations chosen by fishers involved in the experiment, to ensure sufficient scallop catches would be obtained for statistical analyses. In addition, permission was obtained to conduct five hauls within an area closed to commercial scallop dredging since June 2009 (Scibberas et al 2013), as this closed area was known to have higher scallop densities than the commercial grounds (Delargy et al 2019). Sampling this closed area allowed assessment of catch comparison rates over a wider range of densities than likely available on the commercial grounds. These five haul locations were randomly generated as part of the annual survey design (Delargy et al 2019).

Three commercial vessels fished alongside the research vessel *Prince Madog* with two to the port side and one to the starboard side, forming a line of vessels fishing in parallel. The positions of the commercial vessels in this formation were rotated after every two hauls to ensure their position relative to the research vessel was not affecting catches. The distance between vessels was determined by the skippers who were instructed to fish at the safest, closest distance, which was expected to be around 500 m.

All dredges were spring-loaded Newhaven dredges with mouth width of 76 cm. The commercial vessel dredges each had eight teeth of 110 mm length and belly rings of 90 mm diameter (Table 1). Two commercial vessels each hauled eight dredges evenly split between two tow bars (four aside) (vessels FV2 and FV3), while the third commercial vessel used six dredges split between two bars (three aside). One commercial vessel (FV3) had two 76 mm wide skids fitted underneath the chainmail bag of each dredge. These skids, which are akin to skis, are designed to raise the bag and reduce the area of the dredge that contacts the seafloor (Catherall and Kaiser 2014). The research vessel hauled four dredges from a single tow bar. Two of these dredges had nine teeth of 110 mm length and belly rings of 80 mm diameter, hereafter “research vessel king dredges” (RVK). The other two dredges had ten teeth of 60 mm length and belly rings of 60 mm diameter, hereafter "research vessel queen dredges" (RVQ). These two types of dredges have been used during the annual surveys, which the research vessel has conducted since 2012 (Delargy et al 2019).

Hauls were made against the direction of the tide for 20 minutes from when the gear touched the seafloor until hauling commenced and hauls were conducted at speeds between 2.5 and 3 knots, consistent with that of the annual surveys (Delargy et al 2019). The annual survey also uses a 3:1 warp length to water depth ratio, which was employed by the research vessel during the experiment. The warp length used by the commercial vessels was not standardized as the aim was to have the vessels perform under their normal operations to obtain a representation of what each vessel considered optimal fishing conditions. Haul depth (m) was recorded from the research vessel echo sounder at the start and end of each haul and corrected to account for the depth the echo sounder was at (3 m below sea surface). Sea state was periodically recorded throughout the four days using visual assessment of wave height on the Douglas Sea Scale (Owens 1984). The mean of the start and end depths was obtained to provide a single depth value for each haul. The start and end positions of hauls were recorded by scientific observers on each vessel so that the swept area could be calculated. After each haul, observers measured the shell width (nearest mm) of up to 90 king scallops from as many dredges as possible (until the next haul) to obtain size distributions. If more than 90 king scallops were caught in a dredge, then a random subsample was obtained by hand. Dredges were selected for sampling following pre-prepared random number tables. These protocols are consistent with the annual survey methods (Delargy et al 2019).

The research vessel and one commercial vessel had access to a motion-compensated balance and recorded the subsample and total weights of king scallops (live weight in kg, including shell) from each dredge to calculate a raising factor to estimate the total number of scallops caught in a dredge when more than 90 scallops were caught. The other two commercial vessels used measuring sticks and standardised baskets to record subsample and catch volume, and the subsample and catch weights were approximated from weights of baskets recorded on the research vessel. For this method, the measuring sticks were used to measure the height that the scallops reached within a basket. The weight was then determined as the average weight from scallop samples of the same height in a basket (rounded to nearest 5 mm) that had been weighed on the research vessel using identical baskets. These approximated subsample and catch weights were then used to estimate the total number of scallops caught, in the event that more than 90 scallops were caught in a single dredge.

### *2.2 Data preparation*

Scallops were summed by 5 mm size groups across all dredges by haul for each commercial vessel, and by 5 mm size group and dredge type for each haul conducted by the research vessel. Size groups were labelled so that '110 mm' contained scallops 110 to 114 mm in size. Raising of these size-structured data was accounted for at the modelling stage to prevent raising from influencing the size-structure. This was achieved using an offset in the statistical model (Holst and Revill 2009). Scallops were sorted into these size groups to reduce the influence of observation error on the nearest mm measured scale. The number of scallops in each 5 mm group was divided by the swept area to obtain CPUE. The swept area of each haul, by each vessel, was calculated as the product of the haul length (m), the width of a dredge (m) and the number of dredges hauled. Haul length was estimated from the observed start and end coordinates by assuming the vessels had travelled in a straight line.

The distances between pairs of vessels for each haul (m) was calculated as the straight-line distance between haul starting coordinates. The distances between pairs of vessels were not directly incorporated into the statistical analysis and as described in the next subsection, steps were taken in the statistical models to help reduce the effects of inter-haul variability, which could have increased with increased distance between the vessels. Haul pairs were not excluded based on the distance between vessels, as all distances were considered sufficiently close. Plots of catch variation with distance between vessels were inspected.

### *2.3 Statistical analyses*

Hauls were excluded from the analysis if both vessels had caught no scallops, however this was rare and for five of the comparisons no hauls were removed and only one haul was removed from the other four comparisons. Size structured CPUE between pairs of vessels represented the response variable included in the statistical models. This metric was defined as $\frac{n1_{h,l}}{n1_{h,l}+n2_{h,l}}$, where $n1$ and $n2$ are the CPUE from a single size class ($l$) at each haul ($h$) from two vessels (Krag et al 2014; Kotwicki et al 2017; Brooks et al 2020). This catch comparison rate is useful because it allows for hauls to remain paired during the analyses and is a binomial variable, the modelling of which is supported in many statistical computer packages. When the catch comparison rate equals 0.5 then the two quantities are equal (Krag et al 2014). Two vessels or research vessel dredge types were compared at a time using the catch comparison rate (Table A.1).

Catch comparison rate ($\emptyset_{h,l}$) was modelled by a logit link (Eq 1), based on the ratio of swept area of one vessel relative to the other ($p_h$), size of scallop ($s_{i,h,l}$) and size retention model of each vessel's gear ($r_i(l)$) (Brooks et al 2020).

$$\emptyset_{h,l} = \frac{p_h s_{1,h,l} r_1(l)}{p_h s_{1,h,l} r_1(l) + (1 - p_h) s_{2,h,l} r_2(l)} \quad (1)$$

Holst and Revill (2009) demonstrated that fitting a random intercept for each haul incorporates the effects of $p_h$ and helps account for inter-haul variability, and this approach was implemented here. The retention models ($r_i(l)$) are a measure of a gear's ability to retain scallops of a given size compared to another gear and are constrained to the range of zero and one by a link function (Brooks et al 2020). In this study the retention models are relative because the absolute retention of any of the gears was unknown. Multiple methods for modelling these retention models were fitted for each comparison: third and fourth order polynomials (Holst and Revill 2009) and basis splines (Miller 2013) with three, four and five degrees of freedom. Weighting factors for the catch comparison rates were calculated as the summed CPUE across the two vessels for each haul and each 5 mm size group and were included in the model to give greater influence to catch comparison rates estimated from a larger sample size

(Holst and Revill 2009). In addition, an offset was included to account for differences in subsampling at each haul (Holst and Revill 2009). The offset was defined as $\ln\frac{q_2}{q_1}$, where $q_1$ and $q_2$ are the raising factors at each haul from each of the vessels in a comparison (Brooks et al 2020). Inspection of plots of model fits were used to select the best number of degrees of freedom permitted in the shape of the model-estimated curves, and AIC values were used to select between polynomial and basis spline models after determining the best degrees of freedom (Akaike 1974; Brooks et al 2020).

The bootstrapping method developed by Millar (1993), which resamples at both the haul and individual scallop levels, was implemented to further account for overdispersion and estimate confidence intervals around model estimates. Model residuals were inspected, and model estimates were compared to observations to inspect model fit. These models were implemented using the 'selfisher' R package (Brooks et al 2020).

## 3. RESULTS

### *3.1 Initial statistics*

The range of mean distances between any two vessels across the comparisons was 377 to 545 m (Table A.2). Large distances, such as greater than 1 km, occurred when the two vessels in a comparison occurred at either end of the line formation that the vessels fished in. The research vessel conducted 35 hauls that at least one commercial vessel was present for (Table A.2). Vessel FV3 conducted 35 of these, FV2 conducted 34 of these and FV1 conducted 21 of these (Table A.2). FV1 missed the entirety of the fourth day as initial weather conditions prevented this smaller vessel from being able to travel from port to the haul locations. The area swept during hauls was variable among vessels, and partly determined by the number of dredges each vessel used (Figure 3). The sea state during the hours of fishing ranged from smooth to moderate on the Douglas Sea Scale. The mean depths of hauls ranged from 24.3 to 52.3 m.

Mean CPUE across the gear-vessel combinations from each haul ranged from 0.01 to 25.32 king scallops per 100 $m^2$ (Figure 2). The estimated total number of king scallops caught across all vessels in sampled dredges was 11,779, and 8,236 were measured for shell width. Raising of catch weights to obtain an estimated count caught was required at one haul for all commercial vessels and RVK and a second haul for just RVQ.

### *3.2 Size-structured scallop catch*

Small scallop CPUE (< 105 mm wide) was significantly lower from the three commercial vessels than either of the research vessel dredge types, although the margin of difference decreased with increasing scallop size (Figure 4). Significant differences were inferred when the average model estimates and the 95% confidence intervals did not overlap 0.5, which is the response value that indicates CPUE was equal between any two gear-vessel combinations (Krag et al 2014). Medium-sized scallop CPUE (100 to 125 mm) was significantly lower from FV1 than RVQ and almost all sizes of scallop CPUE were significantly less from FV1 when compared to RVK (Figure 4). The FV1 results were the only examples of significant differences in the CPUE of scallops larger than 105 mm between the commercial vessels and either of the research vessel dredge types in the size-structured analyses (Figure 4).

The CPUE of scallops larger than 100 mm from FV1 was significantly lower than FV2, with the margin of difference increasing with increased scallop size (Figure 4). The same trend was apparent between FV1 and FV3, but with significant differences not occurring until scallops were 125 mm wide or more (Figure 4). The CPUE of scallops between 120 and 150 mm wide was significantly higher from FV2 than FV3 (Figure 4). The CPUE of all other size ranges of scallops were not significantly different between the commercial vessels. Residuals from the models were large on some occasions but were satisfactory overall (Figure A.1; Figure A.2). Model parameters are presented in Table A.3. There was no trend between distance between vessels and catch comparison rates (Figure A.3).

## 4. DISCUSSION

This study had scientific observers on four vessels that were fishing in parallel, which has provided a detailed understanding of differences in catch rates between scallop vessels used within the fishery. Whilst two of the commercial vessels had generally similar catch rates, significant differences existed across catch rates of scallops ranging from 120 to 150 mm. These differences, combined with the clear differences with the third vessel (FV1), highlight that whilst the catch rates of some commercial vessels can be similar, considerable differences can also occur, which agrees with studies focussed on the same gear or other fisheries (Basch et al 2002; Thorson and Ward 2014; Delargy et al 2022). This is an important consideration that should be corrected for if fishery-independent surveys use different commercial vessels among years or use multiple vessels to carry out a single annual survey (Delargy et al 2022). In contrast, the knowledge that the two similarly sized vessels had mostly similar catch rates could indicate that it would be appropriate to charter multiple vessels of similar size for the fishery-independent survey with limited corrections required.

The catch rates of commercial-sized king scallops were generally similar between each of the commercial vessels FV2 and FV3 and the research vessel dredge types. Therefore, changing the Welsh scallop survey vessel in the future to either of the commercial vessels FV2 and FV3 would result in similar catches of commercial-sized scallops. However, if the survey was switched to the more selective commercial gears, then there would be a considerable loss of information about smaller scallops (< 105 mm shell width) and lower total scallop catch rates would be observed. The loss of information would be even greater if the other commercial vessel, FV1, was used, as significantly lower catch rates were detected up to 125 mm in scallop size when compared to RVQ and for all sizes when compared to RVK. These findings imply that correction factors would need be applied to allow direct comparison of catch rates from these commercial vessels to the catch rates previously collected by the research vessel (Miller 2013). Target species individuals smaller than the harvestable size are an important data component of a fishery-independent survey, as the information for smaller individuals is often used to infer the future recruitment into the harvestable portion of the population by length-frequency plots or through inclusion in stock assessment models (Pennington and Stromme

1998; Needle 2001). Whilst it would not be ideal to change the survey to a more selective gear, there are uncertainties about future survey funding (for both vessel time and new gear) and data on commercially sized scallops only would be better than no data.

The differences in catch rates throughout this study are likely to have been driven by differences in belly ring diameter, number of teeth per dredge, tooth length, vessel power and vessel size. Both types of research vessel dredges had finer belly ring diameters (60 or 80 mm) than the commercial dredges (90 mm) and both had significantly higher smaller scallop (< 105 mm) catch rates. Higher catch rates of smaller scallops in dredges with finer belly rings is expected, as has been shown in research from other scallop dredge fisheries using catch comparison studies, where both gears are selective (Bourne 1965; Brust et al 1995; Rudders et al 2000), and by selectivity studies, where a reference gear or sampling method is assumed nonselective (Fifas et al 2004; Roman and Rudders 2019; Poirier et al 2021). Research focussed on spring-loaded Newhaven dredges has shown that belly ring size is a significant driver of size-structured king scallop catch rates and is likely the most important component of this gear for size-selectivity (Lart et al 2003). Therefore, it is likely that the differences in belly ring sizes are the biggest drivers of the significant differences reported here.

Research has also demonstrated that tooth spacing on spring-loaded Newhaven dredges can play a key role in the size-selectivity of king scallop catches, albeit to a less consistent extent than belly ring size, as scallops can pass between the spaces between the teeth on the seafloor (Lart et al 1997; Lart et al 2003). These studies found significantly fewer smaller king scallops (up to 125 mm shell width in one case) in dredges with nine teeth compared to those with ten. However, no significant differences were detected when dredges with eight teeth were compared to those with nine (Lart et al 2003). The present study compared dredges with ten to eight and nine to eight teeth, and therefore it is possible that the differences in the number of teeth could be contributing to the significant differences observed here as the dredges with the lower number of teeth caught significantly less smaller scallops.

Although there is little research studying the direct impacts of tooth length, vessel size and engine power on king scallop catch rates from spring-loaded Newhaven dredges, these factors may also contribute to the significant differences observed here (Basch et al 2002; Fifas et al 2004; Thorson and Ward 2014). FV1 was smaller, lighter, and less powerful than all other vessels and had significantly lower catch rates. The vessel may have rolled and pitched more than the other vessels when the sea state was moderate during the experiment due to its smaller size (Byrne et al 1981; Basch et al 2002). FV1 was also a much newer vessel than the other two commercial vessels, which meant the skipper had less years working on this vessel compared to the other commercial vessels, and this may have contributed to the lower catch rates observed. However, newer vessels can be more efficient due to technological improvements (Basch et al 2002).

The effects of vessel size and engine power could also apply to the differences in catch rates between each of the other two commercial vessels and the research vessel. In addition, the research vessel hung all dredges from a single tow bar, whereas the commercial vessels hung their dredges from two tow bars deployed on either side. It is possible that this difference in configurations influenced catch rates in an unknown manner (Carrothers 1981). However, as FV2 and FV3 had similar catch rates to the research vessel dredge types for larger scallops it is likely the differences in catch rates for smaller scallops were instead driven by the belly ring diameter and number of teeth on the dredges.

The two commercial vessels that were highly similar by length, weight, and engine power (FV2 and FV3) had the fewest significant differences between scallop catch rates. There were limited differences in catch rates between these vessels, however FV2 caught significantly more scallops between 120 mm and 150 mm shell width. Therefore, this highlights that even highly similar vessels can still produce significantly different catch rates that would need to be accounted for in stock assessments.

The similarities between the catches of FV2 and FV3 indicate that the skids had limited effect on scallop catch rates, which reflects the findings of initial trials of attaching skids to Newhaven spring-loaded dredges (Catherall and Kaiser 2014). However, it is impossible to isolate the effects of these dredges from potential vessel effects in the current study design. In addition, the current study was not designed to assess other aspects of the skids, including the intended reduction of seafloor and benthic community impacts or potential reductions in fuel consumption and bycatch catch rates (Catherall and Kaiser 2014). Therefore, further trials of this dredge modification are required to better assess its potential benefits.

The catch comparison rates from this study could vary with several factors including substrate type and sea state, as these are two factors known to affect catch rates of these gears (Dare et al 1993; Fifas et al 2004). The hauls from the present study were restricted to similar gravelly substrates and smooth to moderate sea states. In addition, vessel-specific catch rates are likely to fluctuate over time (Helser et al 2004; Wilberg et al 2010; Thorson and Ward 2014). Therefore, future research would be beneficial to verify if the catch comparison rates presented in the current study are consistent under other conditions or over time.

This study was unable to rotate gears around the vessels to separate vessel effects from gear effects. This was an unfortunate consequence of Covid-19 restrictions at the time, and there was reluctance to incur further delays to the field work due to constant uncertainties about the future. Being able to rotate the gears would have allowed for a more thorough investigation of each gear type and each vessel performance, although the study is likely to have required more hauls to have sufficient replicates of the gear types across the four vessels. Consequently, the study is limited to discussing vessel-gear combination units. Future research that isolates gear and vessels effects would be useful for comparing how scallop catch rates of commercial vessels using the survey dredges perform in case this is considered as an option for future surveys. This could involve a similar parallel fishing experiment where either the vessels change gears at the end of each day, or all vessels use duplicates of the survey gear. More small vessels would also be useful to test whether the significantly lower catch rates from the smallest vessel in the study are driven by vessel size.

The annual Welsh scallop survey also collects data on king scallop age-structure, queen scallop CPUE and CPUEs of bycatch species from each of the hauls. This study was unable to compare the age-structure of king scallop catches among vessels because scallop aging is time consuming and there were large catch volumes. However, there is no reason to suspect the age-structure among vessels would be any different beyond the differences caused by length-structure, as the vessels operated in proximity. Comparisons of queen scallop and bycatch species-level catches were not considered during this study due to small quantities caught across vessels and hauls, which involved many zero catches. This is largely a product of this comparison study being conducted in the parts of the survey area that have higher king scallop catch rates and lower queen scallop and bycatch catch rates. Therefore, the effect of changing the vessel-gear combination of the annual survey on the queen scallop and bycatch data remains unknown but the commercial gear is likely to result in lower catch rates of both due to the wider belly rings. To investigate this, future comparison trials would need to be conducted in areas likely to experience higher catch rates of queen scallops and bycatch.

This study has highlighted that catch rates among commercial vessels can differ significantly, and this could be linked to vessel size. Furthermore, despite two similarly sized vessels generally catching similar amounts, there were still significant differences in catch rates for a key component of the commercial catch (120 to 150 mm). This shows that catch rates from commercial vessels cannot be assumed to be the same. In addition, the research vessel had significantly higher catch rates of smaller scallops (< 105 mm shell width) whilst, in most cases, the catch rates of commercial-sized scallops did not significantly differ between the research vessel and the commercial vessels. These findings indicate that a significant amount of information would be lost by changing the annual survey vessel from the research vessel to any of the commercial vessel options trialled here, likely driven by a combination of vessel size and power and the number of teeth and belly ring diameter on the dredges. Therefore, correction factors would need to be applied to correlate previous survey catch rates with any future surveys using these commercial vessel options. Alternatively, gear effects could be accounted for by using the research vessel dredges on board commercial vessels and then conducting a further catch comparison study to test for vessel effects.

These findings are highly important to the future of the local fishery-independent survey, but also highlight the clear differences between fishery-independent samples when gears differ and from different commercial vessels. Therefore, they are applicable to scientists or managers from other fishery surveys that use multiple vessels, are considering a change in survey vessel, are attempting to design a survey, or simply wish to understand how research vessel indices may compare to commercial catch rates.

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## APPENDIX: SUPPLEMENTARY MATERIAL

The supplementary material contains a table displaying the comparisons made between pairs of vessels and a table displaying the number of hauls conducted, the number of these excluded from the analyses, the mean distance between vessels and the maximum distance between vessels. These data are presented for each vessel comparison combination. There is also a table containing the model parameter estimates for each comparison. The supplementary material also includes a figure that shows model residuals plotted against scallop width for each comparison and a figure showing model residuals plotted against model fitted values. Lastly, there is a figure showing the relationship between the distance between vessels and the catch comparison rates.

## AUTHORSHIP CONTRIBUTION STATEMENT

**AJD:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – Original draft, Visualization, Project administration. **NH**: Conceptualization, Methodology, Investigation, Resources, Writing – Review & Editing, Supervision, Project administration, Funding acquisition. **CH, RPC, KB, CNC, ABMM:** Investigation, Writing – Review & Editing. **HL**: Resources, Writing – Review & Editing. **IDM**: Writing – Review & Editing, Funding acquisition. **JGH**: Validation, Writing – Review & Editing, Supervision.

## DATA AND COMPUTER CODE AVAILABILITY STATEMENT

The data and R scripts are available at: https://github.com/a-delargy/Catch-comparison-data


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## TABLES

*Table 1: Specification of the vessels and dredges used during the fishing comparison experiment.*

| Vessel | Length (m) | Gross registered tonnage | Engine power (kW) | Dredge configuration | Number of teeth per dredge | Tooth length (mm) | Belly ring diameter (mm) | Other |
|---|---|---|---|---|---|---|---|---|
| Fishing vessel one (FV1) | 9.8 | 7.94 | 148.4 | Three aside | 8 | 110 | 90 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Fishing vessel two (FV2) | 14.95 | 47.05 | 221 | Four aside | 8 | 110 | 90 | |
| Fishing vessel 3 (FV3) | 14.96 | 59.48 | 214 | Four aside | 8 | 110 | 90 | Vessel with skids |
| Research vessel king dredges (RVK) | 34.9 | 390 | 1080 | Two dredges hung on same bar as RVQ | 9 | 110 | 80 | Same vessel as RVQ |
| Research vessel queen dredges (RVQ) | 34.9 | 390 | 1080 | Two dredges hung on same bar as RVK | 10 | 60 | 60 | Same vessel as RVK |

## FIGURES

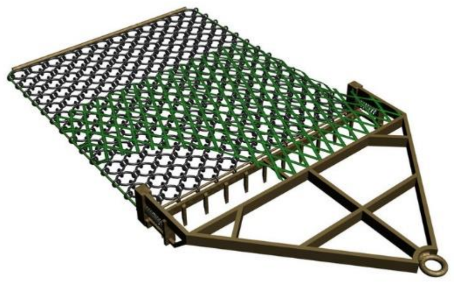

*Figure 1: An illustration of a single Newhaven spring-loaded dredge. Image obtained from the Seafish Asset Bank on 11th March 2022 https://seafish.assetbank-server.com/.*

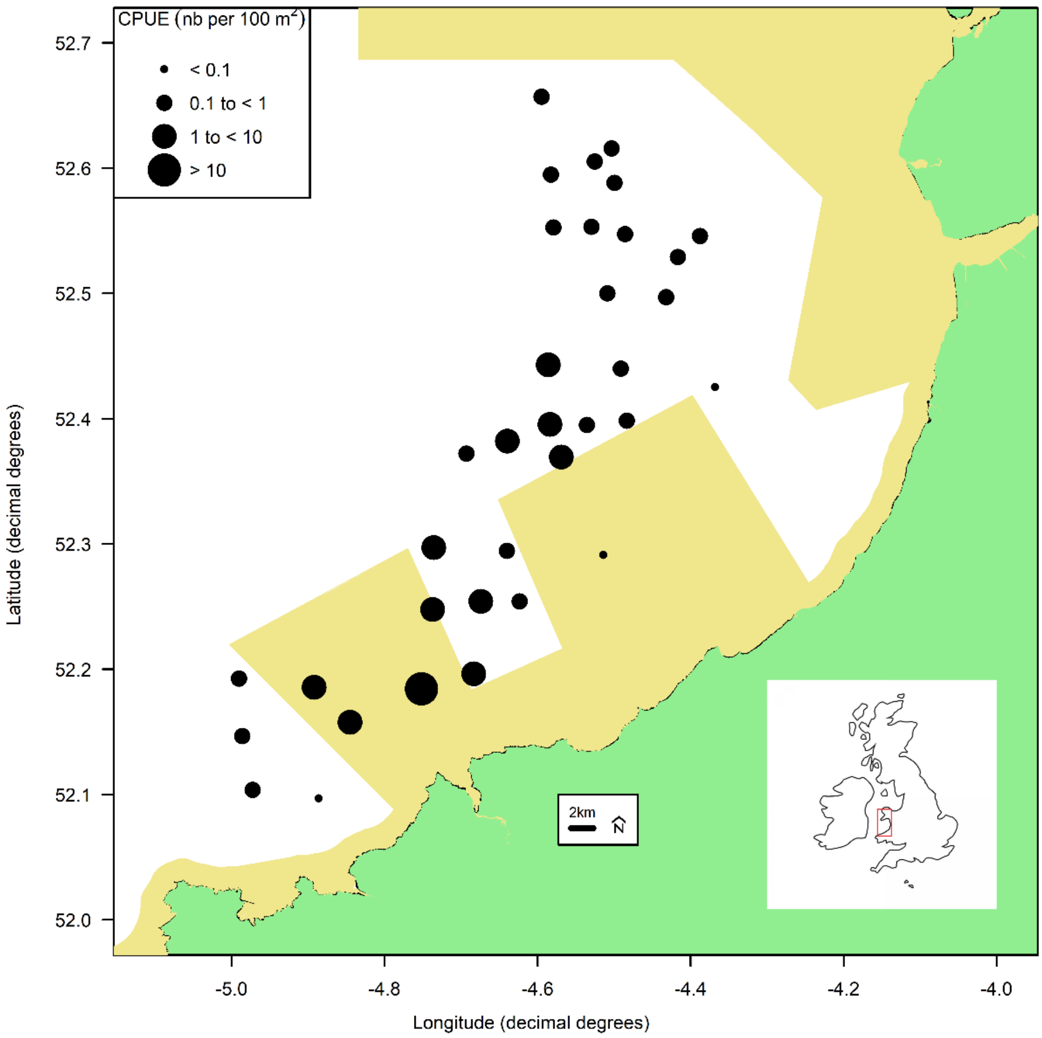


*Figure 2: The start points of the hauls conducted by the research vessel (Prince Madog) during a comparison study of king scallop catch rates among three commercial vessels and the research vessel in April 2021. The size of each point is scaled by the mean catch-per-unit-effort across all the gears and vessels that fished each location (numbers of king scallops caught per 100 m$^2$ of seabed fished). Green is land (part of Wales), beige is areas of sea closed to commercial scallop dredging and white is areas of sea open to commercial scallop dredging. The red box in the inset map indicates the position of the larger map within the British Isles.*

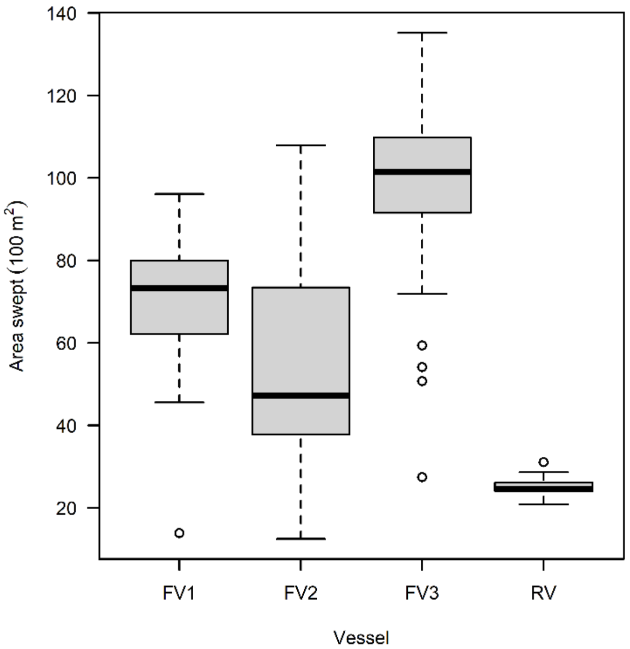


*Figure 3: Swept area (100 m$^2$) of hauls conducted by the three commercial vessels and the research vessel used during the catch comparison experiment conducted in April 2021. The black line represents the median swept area for each lane, the upper and lower limits of the boxes represent the inter-quartile range, the whiskers represent the upper quartile plus 1.5 times the inter-quartile range and the lower quartile minus 1.5 times with inter-quartile range. Points falling outside the whiskers are represented individually by circles. The research vessel swept area (RV) is presented for one type of dredge, and because both dredge types had identical mouth widths, the swept area in this figure can be assumed the same for both dredge types.*

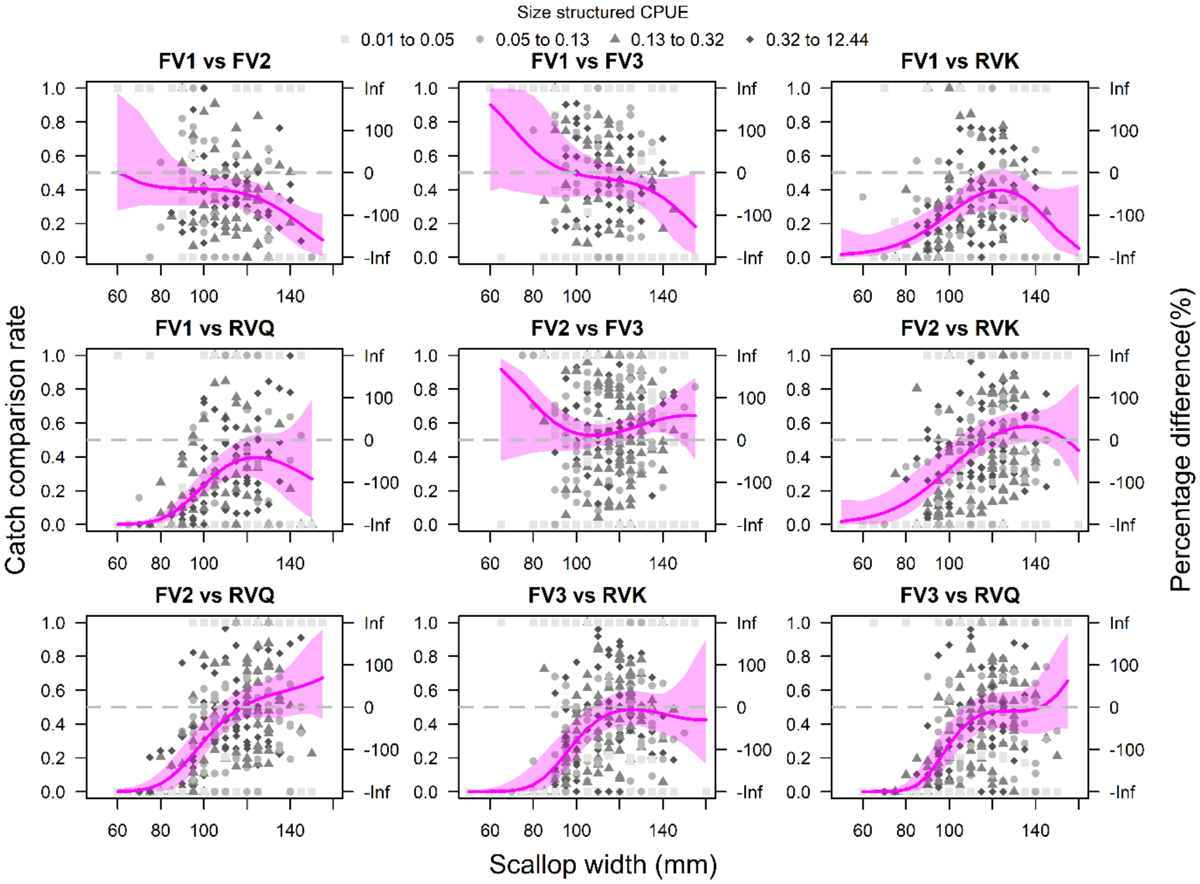


*Figure 4: Plots of observed and model estimated size-structured king scallop catch comparison rates among vessels from a parallel fishing experiment involving three commercial vessels and a research vessel conducted in April 2021. Each panel represents a comparison between two vessels, with the first listed vessel in the panel title as* $n1_{h,l}$ *and the second listed vessel as* $n2_{h,l}$ *in the catch comparison rate on the y-axis. The x-axis is scallop size, as shell width in 5 mm size groups. Points are observations and are coloured by the sum of the CPUE (numbers per 100 m²) across the two vessels for each size group and haul. The magenta lines are average model estimates, and the red shaded areas are 95% confidence intervals. The dashed line is at 0.5, which represents equal CPUE between the two vessels.*