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1 **Detection and quantification of differences in catch rates among research vessel gears and**
2 **commercial vessels**

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10 **ABSTRACT**

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

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

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

30 **1. INTRODUCTION**

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

39 Sampling with towed gears during fishery-independent surveys is a common method for a wide range
40 of target species, and commonly conducted by research vessels (Hilborn and Walters 1992). The catch
41 rate of a towed gear fishery-independent survey is typically expressed as the biomass or number of
42 individuals of the target species caught divided by the effort applied. Effort can be measured as the
43 time spent fishing, number of dredges or trawls used, or the area that the gear sampled (Hilborn and
44 Walters 1992). The size-structure of fishery-independent samples is usually expressed as counts or
45 proportions of measured animals at size intervals (Wileman et al 1996). A wide range of environmental
46 and technical factors influence catch rates (Fraser et al 2007). Environmental factors can include sea
47 state, depth, tidal flow, bathymetry, and substrate type (Dare et al 1993; Fifas and Berthou 1999; Fifas
48 et al 2004). Technical factors include gear operations, specifications, and vessel characteristics, which
49 can each interact to create unique catch rates for each vessel-gear combination (Byrne et al, 1981;
50 Fraser et al 2007; Weinberg and Kotwicki 2008). Vessel size has been shown to be a key driver of catch

51 rates (Basch et al 2002; Thorson and Ward 2014). A small and lighter vessel is more likely to roll and
52 pitch in poor weather conditions, and therefore will find it harder to maintain gear in the optimal
53 position or maintain desired speeds (Byrne et al 1981). In addition, a less powerful vessel may also
54 have difficulties maintaining speed in strong water currents.

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

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

71 Commercial vessels can be a cost-effective alternative to research vessels for conducting fishery-
72 independent surveys (Cadigan and Dowden 2010). In addition, using commercial vessels in fishery-
73 independent surveys helps engage fishers in the assessment process by improving communication
74 and reducing scepticism between scientists and fishers (Thorson and Ward 2014). To characterize any
75 potential effect that the use of commercial vessels may impart, the catch rates between research and

76 commercial vessels need to be quantified and compared as vessel attributes can affect the collected
77 samples. Previous research studying vessel effects have differed on whether commercial vessels
78 produce comparable catch rates to research vessels during fishery-independent surveys (Helser et al
79 2004; Thorson and Ward 2014), which implies the issue is complicated and should be investigated
80 further.

81 Typically, when size distributions are compared, it is common to have one non-selective gear that is
82 assumed to collect a representative sample of the target species (Millar and Walsh 1992; Munro and
83 Somerton 2001; Kotwicki et al 2017). However, it is often expensive and time consuming to assemble
84 a non-selective fishing gear, and useful catch comparisons can still be made when the gears involved
85 are all selective and the true population size-structure is unknown (Bethke et al 1999; Prchalova et al
86 2009; Reid et al 2012). In particular, the catch comparison rate, which is the ratio of the catch from
87 one vessel/gear to the total from both vessels/gears, can be estimated to describe the relationship
88 between the catch rates of the two vessels or gears (Halliday 2002; Krag et al 2014). Catch comparison
89 rates are often useful in stock assessments as a correction factor when survey vessels are changed or
90 when multiple vessels are used during a survey (Cadigan and Dowden 2010; Kotwicki et al 2017). The
91 catch comparison rate has been referred to by several other names, such as relative efficiency or
92 selectivity ratio (see Kotwicki et al 2017 for a full review of alternative terminology).

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

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

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

120 **2. MATERIALS AND METHODS**

121 *2.1 Catch comparison experiment*

122 The four vessels fished alongside each other in a parallel fishing experiment within areas where
123 scallops were expected based on previous survey data and fisher knowledge (Delargy et al 2019).
124 Scientific observers were present on all vessels for all hauls. The fishing was conducted in Cardigan
125 Bay in the eastern Irish Sea off the coast of Wales, UK, on 25th to 28th April 2021 (Figure 2). The

126 substrate was primarily gravelly sediment with a few small patches of sand and water depth in the
127 area ranged between 20 and 60 m (EMODnet 2021). Most hauls were conducted on commercially
128 fished grounds and the positions selected using a mixture of randomly generated survey locations and
129 locations chosen by fishers involved in the experiment, to ensure sufficient scallop catches would be
130 obtained for statistical analyses. In addition, permission was obtained to conduct five hauls within an
131 area closed to commercial scallop dredging since June 2009 (Scibberas et al 2013), as this closed area
132 was known to have higher scallop densities than the commercial grounds (Delargy et al 2019).
133 Sampling this closed area allowed assessment of catch comparison rates over a wider range of
134 densities than likely available on the commercial grounds. These five haul locations were randomly
135 generated as part of the annual survey design (Delargy et al 2019).

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

142 All dredges were spring-loaded Newhaven dredges with mouth width of 76 cm. The commercial vessel
143 dredges each had eight teeth of 110 mm length and belly rings of 90 mm diameter (Table 1). Two
144 commercial vessels each hauled eight dredges evenly split between two tow bars (four aside) (vessels
145 FV2 and FV3), while the third commercial vessel used six dredges split between two bars (three aside).
146 One commercial vessel (FV3) had two 76 mm wide skids fitted underneath the chainmail bag of each
147 dredge. These skids, which are akin to skis, are designed to raise the bag and reduce the area of the
148 dredge that contacts the seafloor (Catherall and Kaiser 2014). The research vessel hauled four dredges
149 from a single tow bar. Two of these dredges had nine teeth of 110 mm length and belly rings of 80
150 mm diameter, hereafter “research vessel king dredges” (RVK). The other two dredges had ten teeth

151 of 60 mm length and belly rings of 60 mm diameter, hereafter “research vessel queen dredges” (RVQ).
152 These two types of dredges have been used during the annual surveys, which the research vessel has
153 conducted since 2012 (Delargy et al 2019).

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

171 The research vessel and one commercial vessel had access to a motion-compensated balance and
172 recorded the subsample and total weights of king scallops (live weight in kg, including shell) from each
173 dredge to calculate a raising factor to estimate the total number of scallops caught in a dredge when
174 more than 90 scallops were caught. The other two commercial vessels used measuring sticks and
175 standardised baskets to record subsample and catch volume, and the subsample and catch weights

176 were approximated from weights of baskets recorded on the research vessel. For this method, the
177 measuring sticks were used to measure the height that the scallops reached within a basket. The
178 weight was then determined as the average weight from scallop samples of the same height in a
179 basket (rounded to nearest 5 mm) that had been weighed on the research vessel using identical
180 baskets. These approximated subsample and catch weights were then used to estimate the total
181 number of scallops caught, in the event that more than 90 scallops were caught in a single dredge.

182 *2.2 Data preparation*

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

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

200 *2.3 Statistical analyses*

201 Hauls were excluded from the analysis if both vessels had caught no scallops, however this was rare
 202 and for five of the comparisons no hauls were removed and only one haul was removed from the
 203 other four comparisons. Size structured CPUE between pairs of vessels represented the response
 204 variable included in the statistical models. This metric was defined as $\frac{n_{1h,l}}{n_{1h,l}+n_{2h,l}}$, where n_1 and n_2 are
 205 the CPUE from a single size class (l) at each haul (h) from two vessels (Krag et al 2014; Kotwicki et al
 206 2017; Brooks et al 2020). This catch comparison rate is useful because it allows for hauls to remain
 207 paired during the analyses and is a binomial variable, the modelling of which is supported in many
 208 statistical computer packages. When the catch comparison rate equals 0.5 then the two quantities are
 209 equal (Krag et al 2014). Two vessels or research vessel dredge types were compared at a time using
 210 the catch comparison rate (Table A.1).

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

$$214 \quad \phi_{h,l} = \frac{p_h s_{1,h,l} r_1(l)}{p_h s_{1,h,l} r_1(l) + (1 - p_h) s_{2,h,l} r_2(l)} \quad (1)$$

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

225 (Holst and Revill 2009). In addition, an offset was included to account for differences in subsampling
226 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
227 factors at each haul from each of the vessels in a comparison (Brooks et al 2020). Inspection of plots
228 of model fits were used to select the best number of degrees of freedom permitted in the shape of
229 the model-estimated curves, and AIC values were used to select between polynomial and basis spline
230 models after determining the best degrees of freedom (Akaike 1974; Brooks et al 2020).

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

236 **3. RESULTS**

237 *3.1 Initial statistics*

238 The range of mean distances between any two vessels across the comparisons was 377 to 545 m (Table
239 A.2). Large distances, such as greater than 1 km, occurred when the two vessels in a comparison
240 occurred at either end of the line formation that the vessels fished in. The research vessel conducted
241 35 hauls that at least one commercial vessel was present for (Table A.2). Vessel FV3 conducted 35 of
242 these, FV2 conducted 34 of these and FV1 conducted 21 of these (Table A.2). FV1 missed the entirety
243 of the fourth day as initial weather conditions prevented this smaller vessel from being able to travel
244 from port to the haul locations. The area swept during hauls was variable among vessels, and partly
245 determined by the number of dredges each vessel used (Figure 3). The sea state during the hours of
246 fishing ranged from smooth to moderate on the Douglas Sea Scale. The mean depths of hauls ranged
247 from 24.3 to 52.3 m.

248 Mean CPUE across the gear-vessel combinations from each haul ranged from 0.01 to 25.32 king
249 scallops per 100 m² (Figure 2). The estimated total number of king scallops caught across all vessels in
250 sampled dredges was 11,779, and 8,236 were measured for shell width. Raising of catch weights to
251 obtain an estimated count caught was required at one haul for all commercial vessels and RVK and a
252 second haul for just RVQ.

253 *3.2 Size-structured scallop catch*

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

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

272 **4. DISCUSSION**

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

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

299 1998; Needle 2001). Whilst it would not be ideal to change the survey to a more selective gear, there
300 are uncertainties about future survey funding (for both vessel time and new gear) and data on
301 commercially sized scallops only would be better than no data.

302 The differences in catch rates throughout this study are likely to have been driven by differences in
303 belly ring diameter, number of teeth per dredge, tooth length, vessel power and vessel size. Both types
304 of research vessel dredges had finer belly ring diameters (60 or 80 mm) than the commercial dredges
305 (90 mm) and both had significantly higher smaller scallop (< 105 mm) catch rates. Higher catch rates
306 of smaller scallops in dredges with finer belly rings is expected, as has been shown in research from
307 other scallop dredge fisheries using catch comparison studies, where both gears are selective (Bourne
308 1965; Brust et al 1995; Rudders et al 2000), and by selectivity studies, where a reference gear or
309 sampling method is assumed nonselective (Fifas et al 2004; Roman and Rudders 2019; Poirier et al
310 2021). Research focussed on spring-loaded Newhaven dredges has shown that belly ring size is a
311 significant driver of size-structured king scallop catch rates and is likely the most important component
312 of this gear for size-selectivity (Lart et al 2003). Therefore, it is likely that the differences in belly ring
313 sizes are the biggest drivers of the significant differences reported here.

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

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

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

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

346 The similarities between the catches of FV2 and FV3 indicate that the skids had limited effect on
347 scallop catch rates, which reflects the findings of initial trials of attaching skids to Newhaven spring-

348 loaded dredges (Catherall and Kaiser 2014). However, it is impossible to isolate the effects of these
349 dredges from potential vessel effects in the current study design. In addition, the current study was
350 not designed to assess other aspects of the skids, including the intended reduction of seafloor and
351 benthic community impacts or potential reductions in fuel consumption and bycatch catch rates
352 (Catherall and Kaiser 2014). Therefore, further trials of this dredge modification are required to better
353 assess its potential benefits.

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

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

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

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

398 accounted for by using the research vessel dredges on board commercial vessels and then conducting
399 a further catch comparison study to test for vessel effects.

400 These findings are highly important to the future of the local fishery-independent survey, but also
401 highlight the clear differences between fishery-independent samples when gears differ and from
402 different commercial vessels. Therefore, they are applicable to scientists or managers from other
403 fishery surveys that use multiple vessels, are considering a change in survey vessel, are attempting to
404 design a survey, or simply wish to understand how research vessel indices may compare to commercial
405 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/>.

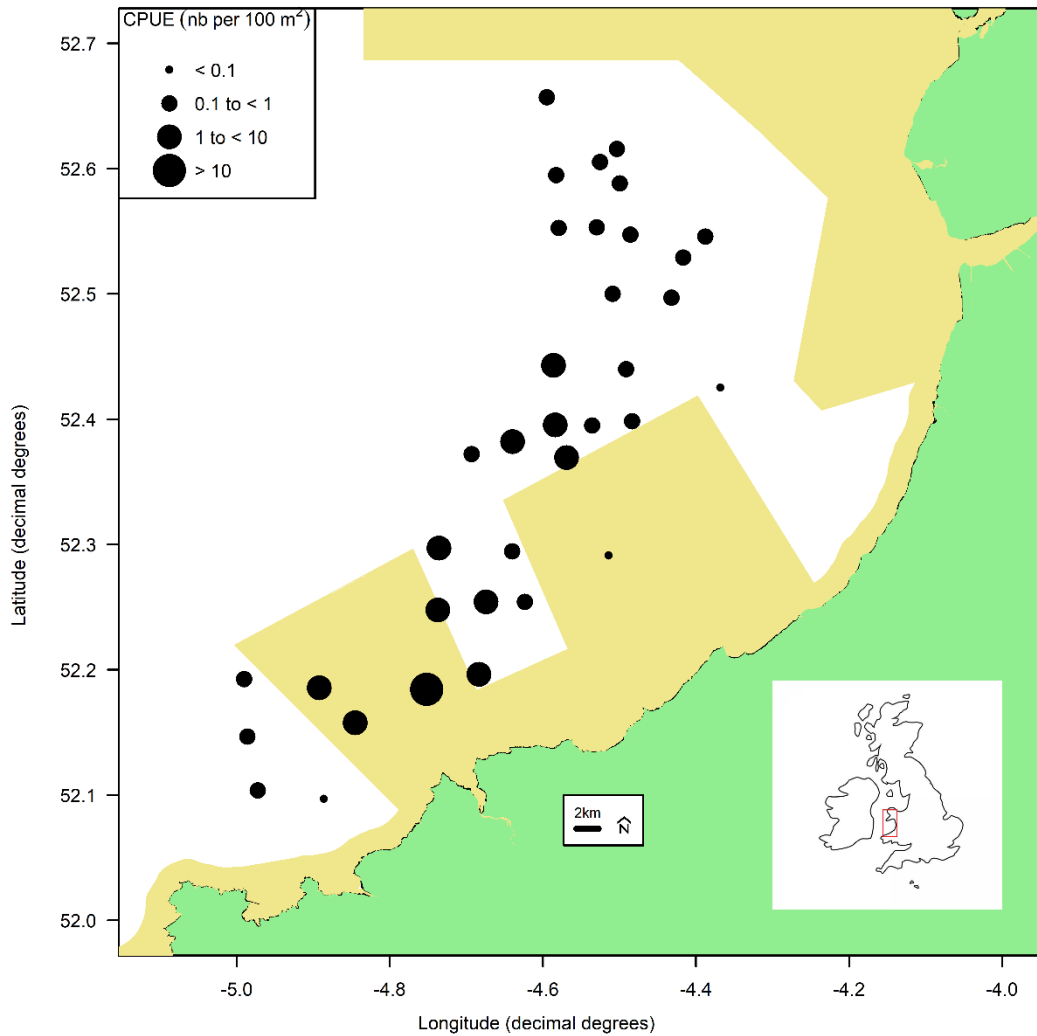


Figure 2: The start points of the hauls conducted by the research vessel (Prince Madog) during a comparison study of king scallop catch rates among three commercial vessels and the research vessel in April 2021. The size of each point is scaled by the mean catch-per-unit-effort across all the gears and vessels that fished each location (numbers of king scallops caught per 100 m² 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.

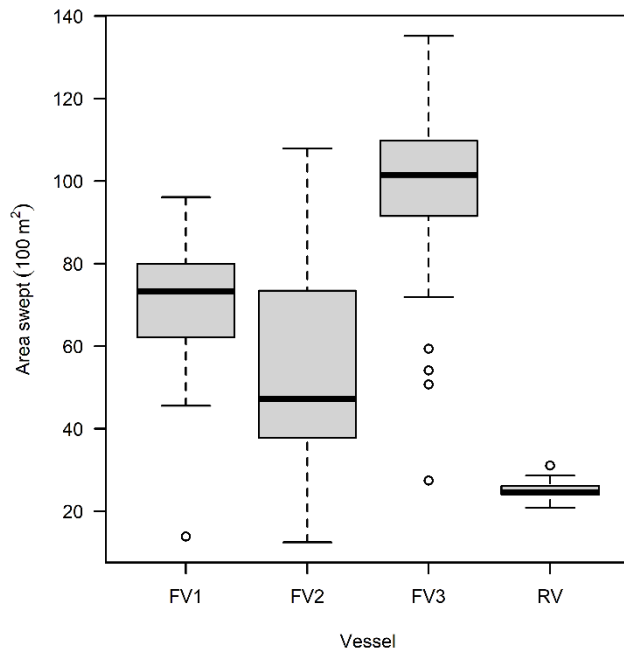


Figure 3: Swept area (100 m^2) of hauls conducted by the three commercial vessels and the research vessel used during the catch comparison experiment conducted in April 2021. The black line represents the median swept area for each lane, the upper and lower limits of the boxes represent the inter-quartile 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.

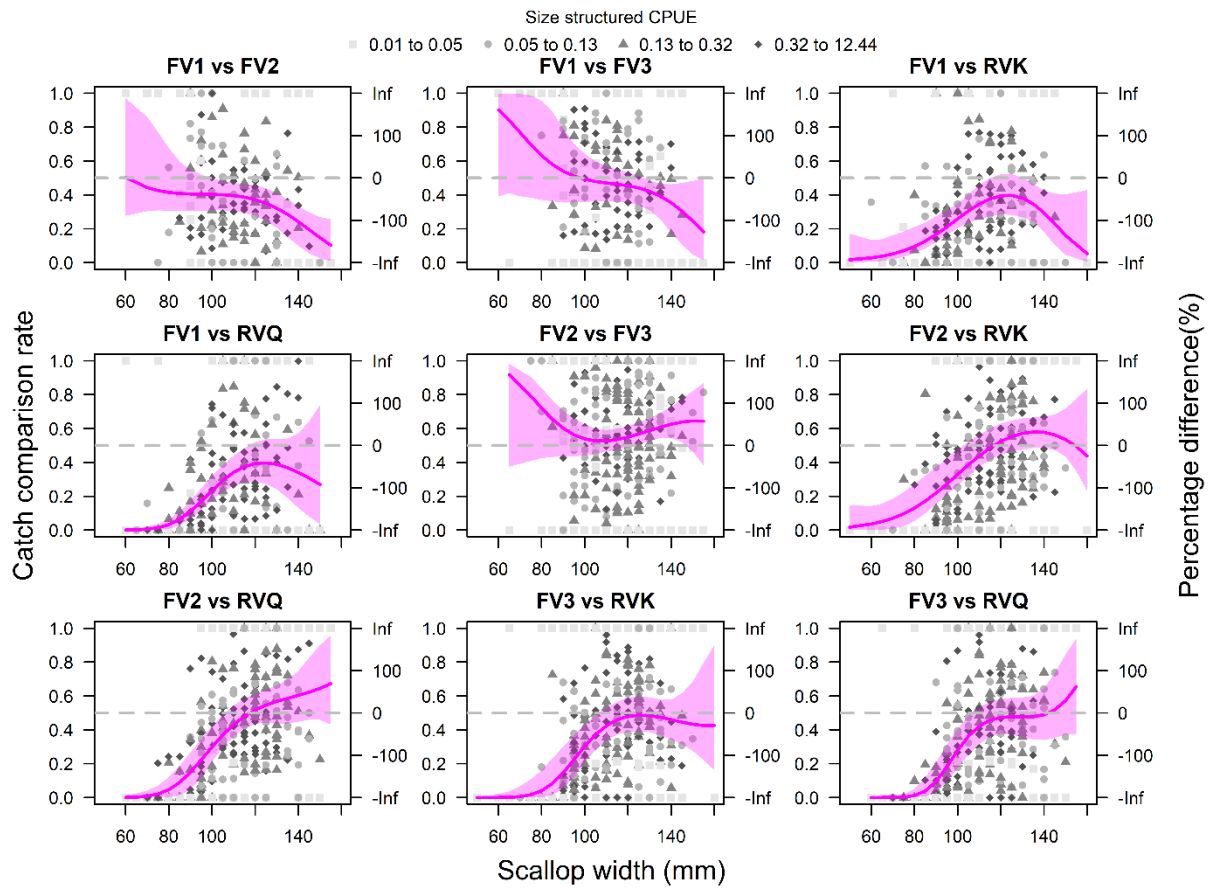


Figure 4: Plots of observed and model estimated size-structured king scallop catch comparison rates among vessels from a parallel fishing experiment involving three commercial vessels and a research vessel conducted in April 2021. Each panel represents a comparison between two vessels, with the first listed vessel in the panel title as $n1_{r,l}$ and the second listed vessel as $n2_{r,l}$ 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.