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## The use and performance of survey-based pre-recruit abundance indices for possible inclusion in stock assessments of coastal-dependent species

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### Abstract :

We reviewed the use of survey-based pre-recruit abundance indices in short-term recruitment forecasts for fish species relying on coastal habitats at the juvenile stage and that are assessed by ICES. We collated information from stock assessment reports and from a questionnaire filled out by the stock assessors. Among the 78 stocks with juvenile coastal dependence, 49 use short-term forecasts in stock assessment. Survey-based pre-recruit abundance indices were available for 35 of these stocks, but only 14 were used to forecast recruitment. The questionnaire indicated that the limited use of survey-based pre-recruit abundance indices was primarily due to sampling inefficiency, which may preclude reliable recruitment estimates. The sampling is inefficient because the juvenile coastal distribution is outside the geographical area covered by large-scale surveys or targeted coastal surveys are conducted on limited spatial and temporal scales. However, our analysis of the relationship between survey-based pre-recruit indices and assessment-generated recruitment indices revealed that survey-based pre-recruit abundance indices were sufficiently accurate to provide useful information for predicting future recruitment. We recommend expansion of the use of survey-based indices of pre-recruit abundance in stock assessment and recruitment forecasting, and consideration of how to include juveniles in ongoing and future surveys.

**Keywords** : coastal nursery, forecast, juvenile habitat, recruitment, stock assessment, survey

## 41 **Introduction**

42           Recruitment variability of many marine and coastal fish species is the main driver of  
43 fluctuations in population abundance and critically depends on the highly variable mortality  
44 rates of early life stages (Levin and Stunz, 2005; Juanes, 2007; Archambault et al., 2014).  
45 Forecasting future recruitment has long been a focus of fisheries management (Hilborn and  
46 Walters, 1992; Needle, 2001) and continues to be an essential part of evaluating fishery  
47 management strategies (Kimoto et al., 2007; Stige et al., 2013; Punt, 2019). Stochastic  
48 processes that occur at the egg and larval stages generate high mortality rates (typically 99.9%  
49 for eggs and larvae; Le Pape and Bonhommeau, 2015), which can also be density-dependent  
50 and can vary greatly from year-to-year, thereby generating large fluctuations in recruitment

51 (Houde, 2008; Cury et al., 2014; Szuwalski et al., 2015). Accordingly, egg and larval  
52 abundances estimated from ichthyoplankton surveys are often poorly correlated to future  
53 recruitment success. In contrast, after a “critical” stage or size (Cowan et al., 2000; Dingsor et  
54 al., 2007; Houde, 2008), juvenile fish experience considerably lower and more consistent  
55 mortality rates than eggs and larvae. Abundance, whether absolute or relative (index), can be  
56 estimated during the juvenile stage for many species (Le Pape and Bonhommeau, 2015),  
57 without major discrepancies arising from the highly variable mortality rates typical of earlier  
58 life stages. In stock assessment, pre-recruitment is considered the life stage after the transition  
59 from the highly variable early stages (eggs, larvae, and often early juveniles) to when natural  
60 mortality is largely stable (Lorenzen and Camp, 2019) but before individuals fully join the adult  
61 stock. Survey-based pre-recruit abundance indices could therefore provide reliable information  
62 on recruitment and future year-class strength (Helle et al., 2000; Zhang et al., 2010; Stige et al.,  
63 2013).

64 Indices estimating pre-recruit abundance can provide projections of recruitment and can  
65 inform fisheries management, especially for stocks whose exploitation is highly dependent on  
66 the juvenile stage. Such stocks depend on recruitment for determining harvest, due either to  
67 their biology (short-lived species, like small pelagics) or because high exploitation rates reduce  
68 the age of the fish harvested. For example, high exploitation rates of Atlantic cod *Gadus morhua*  
69 in the North Sea during the last five years (2012 to 2016) of the assessment resulted in immature  
70 fish constituting an average of 71% of the international landings in number (ICES, 2017c).

71 Coastal zones are biologically productive areas that serve as juvenile habitat for numerous  
72 marine species (Beck et al., 2001). For example, considering the species for which ICES  
73 provides advice, one-third are dependent on coastal habitats during their juvenile stage (Seitz  
74 et al., 2014), and these species account for 66% of the total landings of ICES-evaluated stocks  
75 (Brown et al., 2018a). Scientific surveys at the population scale are usually designed to estimate

76 density and age-structure of post-recruited fish. Many surveys focus on post-recruitment fish  
77 for specific management purposes and therefore are not designed nor appropriate for estimating  
78 pre-recruit abundance. Additionally, such post-recruitment surveys most often do not provide  
79 adequate coverage of coastal habitat on which juveniles rely (Ralph and Lipcius, 2014). When  
80 juveniles aggregate in coastal areas, survey designs that cover suitable shallow coastal habitats  
81 are required to produce reliable estimates of pre-recruit density. The timing within the year of  
82 the surveys is also important to give sufficient time for the recruits to settle in the juvenile  
83 habitats and to pass the early juveniles stages that incur highly variable survival (van der Veer,  
84 1986; Wennhage, 2002; Nash et al., 2007). Surveys designed for other purposes may not cover  
85 the time period that is optimal for estimating recruitment from pre-recruits. Even when the  
86 surveys focus on juveniles before recruitment, they tend to be spatially localized, thereby  
87 creating challenges to extrapolate the results to the broader spatial domain of the managed  
88 stock. A valid reason for why surveys are not used to generate pre-recruit indicators is simply  
89 that the surveys were well designed for other purposes and provide insufficient coverage of the  
90 spatial and temporal scales of the juveniles (Albert et al., 2001; Ralph and Lipcius, 2014).

91 This paper focuses on the use of survey-based pre-recruit abundance indices and the  
92 degree of agreement between survey-based and stock assessment estimates of annual  
93 recruitment for species with juvenile coastal dependence. Accurate short-term forecasts of  
94 recruitment could improve the management advice in the stock assessment of species with  
95 juvenile coastal dependence. We focused on those ICES-assessed species whose juveniles rely  
96 on coastal habitats (see definitions in Seitz et al., 2014) and reviewed the use of survey-based  
97 pre-recruit abundance indices for short-term forecasts. For all ICES-assessed stocks whose  
98 juveniles use coastal habitats, we collated information from stock assessment reports and from  
99 a complementary questionnaire, which we designed for completion by the lead fisheries  
100 scientist for each stock assessment. The goals of our analysis were to: (1) assess the frequency

101 of the use of survey-based pre-recruit abundance indices in recruitment forecasts in the  
102 framework of ICES stock assessment working groups; (2) identify factors that influence when  
103 survey-based pre-recruit abundance indices are used; (3) determine the level of accuracy  
104 (agreement with stock assessment estimates) when survey-based pre-recruit abundance indices  
105 are used to indicate recruitment; and (4) suggest possible factors that influence the accuracy of  
106 the survey-based estimates. Our focus was on goals (1) and (3) because we had relatively high  
107 confidence in the underlying information and they provide important results about the  
108 frequency of use of pre-recruit surveys and their overall performance. The reliability of  
109 information to achieve goals (2) and (4) was uncertain, as it is difficult to judge a survey  
110 program for generating pre-recruit information when the survey was designed for other  
111 purposes (goal 2) and our sample size of surveys was too small for assessing which factors  
112 influence accuracy (goal 4).

113

## 114 **Methods**

### 115 *Data collection*

116 Of the 61 species for which ICES carried out stock assessments in 2017 and 2018, 18  
117 species (Table 1) had juveniles with coastal dependence (Seitz et al., 2014). These 18 species  
118 encompass 78 distinct stocks. Information about the use of survey-based pre-recruit abundance  
119 indices for these ICES-assessed 78 stocks was collated. The information came from the ICES  
120 stock assessment working group (WG) reports (ICES, 2017a-c; ICES, 2018a-f), and the  
121 questionnaire completed by the lead fisheries scientists in charge of each stock assessment. The  
122 ICES WG reports, questionnaire responses, and follow-up communications with WG members  
123 provided the following information on the 78 stocks that rely on coastal habitat:

124 1. ICES DLS (data-limited stocks) category (ICES, 2012). The categories spanned from DLS  
125 category 1 (data-rich stocks with quantitative assessments) to DLS category 3 (stocks for

126 which survey-based assessments indicate trends) to categories DLS 4-6 (data-poor stocks  
127 without quantitative assessments).

128 2. Whether pre-recruit surveys were used for short-term estimation and prediction of  
129 recruitment. In ICES stock assessment WG terminology, recruitment estimation means  
130 projecting the youngest assessed year class strength for years  $y$  and  $y+1$ . The term  
131 recruitment prediction is used in WGs to calculate TAC advice when recruitment is projected  
132 two years ahead. In the present analysis, we pooled these two situations and considered the  
133 use of pre-recruit surveys both for recruitment estimation or prediction (hereafter called  
134 “short-term forecasts of recruitment”). Performing recruitment estimation is the minimum  
135 required and is mandatory for DLS category 1, but is highly unusual for the other categories.

136 3. Availability of survey-based abundance estimates for pre-recruits. The expertise of the lead  
137 fishery scientist involved with the assessment was the key source for these estimates. Indeed,  
138 WG reports only mention survey-based abundance indices when used in stock assessment.  
139 When they are not accounted for, expertise is the only means to investigate whether such  
140 indices exist.

141 4. When used, how were the short-term survey-based pre-recruit abundance indicators  
142 combined with the stock assessment? Survey-based pre-recruit abundance indices are  
143 typically used in two ways in ICES stock assessments: (i) post-hoc short-term forecasts of  
144 year-class strength by calibration-regression analysis of recruit index series (e.g., RCT3;  
145 Shepherd, 1997) and then used to account for future recruitment after a matrix model-based  
146 stock assessment is completed (e.g., Extended survivors analysis, XSA; Shepherd, 1999); or  
147 (ii) state-space modeling (e.g., SAM; Nielsen and Berg, 2014) that integrates the survey-  
148 based pre-recruit abundance indices directly into a stock assessment. We analyzed both uses  
149 of survey indices.

150 When survey-based pre-recruit abundance was available as an index (positive response to item  
151 3 above), additional information was collated for that subset of stocks:

152 5. Sampling gear (i.e., acoustic, trawl or net) used in the survey to derive the pre-recruit index.

153 6. Spatial scale of the survey as one of four possibilities: (i) stock scale that included juvenile  
154 habitats; (ii) stock scale that did not include juvenile habitats; (iii) stock spatial distribution  
155 partially covered with the area covered including juvenile habitats; and (iv) stock distribution  
156 partially covered and juvenile habitats not sampled.

157 7. Average number of samples in the annual survey.

158 8. Age-group represented in the survey-based recruitment estimate and the youngest age-group  
159 included in the stock assessment.

160 Finally, when responses indicated that a stock assessment included short-term forecasts of  
161 recruitment and a pre-recruit survey was available but not used to forecast recruitment:

162 9. The fisheries scientist for that stock assessment was asked why the survey was not used. Four  
163 possible responses were offered in the questionnaire: (i) the pre-recruit index time series was  
164 incomplete; (ii) the pre-recruit survey was carried out too late in the year to be available for  
165 the ICES stock assessment working group; (iii) the potential use of the survey-based pre-  
166 recruit abundance indices had not been evaluated; or (iv) pre-recruit survey-based indices  
167 were investigated (e.g., during the benchmark procedure) but a decision was made to exclude  
168 them from analysis.

169169

170 *Analysis: Availability and use of survey-based pre-recruit abundance indices for short-term*  
171 *forecasting in assessment*

172 The frequency of the use of short-term forecasts of recruitment in stock assessment, and  
173 the availability and the use of survey-based pre-recruit abundance indices to forecast  
174 recruitment, were estimated from the WG reports and questionnaires collated for each stock.



175 Starting with the 78 (18 species) ICES-assessed stocks, we categorized these by habitat  
176 (demersal, benthic, pelagic). These stocks were further subdivided into those that used short-  
177 term forecasts in their assessments and either did or did not use available pre-recruit survey-  
178 based indices. For the subset of stocks that did not use the survey-based pre-recruit indices, the  
179 reasons for disuse by the WG assessors were noted. Another subset of stocks, that relied on  
180 short-term recruitment forecasts and also used pre-recruit survey results to generate short-term  
181 forecasts, was further analysed for accuracy of the survey-based predictions.

182182

### 183 *Analysis: Accuracy of survey-based pre-recruit abundance indices to forecast recruitment*

184 Time series of survey-based recruitment predictions were obtained from ICES WG  
185 reports for each of the stocks that used survey-based pre-recruit indices for forecasting short-  
186 term recruitment in the assessment (ICES, 2017a-c; ICES, 2018a-f). For these stocks, time  
187 series of model-based recruitment short-term forecasts were obtained from the ICES database  
188 (ICES, 2018g). Complementary analyses were performed to assess the potential for  
189 autocorrelation between survey-based and model-based short-term forecasts of recruitment,  
190 because for some stocks the survey was also used within the assessment. When survey-based  
191 pre-recruit abundance indices were not used in the stock assessment modelling, but rather to  
192 make short-term forecasts post-assessment, the survey-based and stock-assessment-based  
193 indices were inherently independent and could be directly compared. However, when the  
194 survey-based pre-recruit abundance indices were used within the stock assessment, they  
195 influenced the assessment-based recruitment indices and could result in artificial agreement  
196 between the two short-term forecasts of recruitment because they were no longer independent.

197 Two alternative options were used to reduce or to remove this potential for artificial  
198 agreement between the two short-term forecasts (survey and assessment) of recruitment: (1)  
199 elimination of the last two years from the analysis, and (2) re-run of the stock assessment

200 without the survey index included to generate assessment-based recruitment not influenced by  
201 the survey results:

202 - The influence of survey results on assessment-generated estimates of recruitment can  
203 be significant, especially for the last years in a stock assessment (Hilborn and Walters, 1992).  
204 The influence of the survey results diminishes over time, as other sources of information in the  
205 stock assessment (e.g., catch-at-age and survey data on the older ages) inform the estimated  
206 recruitment values. To partially account for dependence between the survey- and model-based  
207 estimates, we eliminated the last two years of recruitment estimates for those stocks that used  
208 the survey-derived estimates as part of their stock assessment modeling. This elimination was  
209 done either manually or because the last two years were dropped when matching the two  
210 recruitment indices (i.e., there were no survey estimates available to match recruitment for the  
211 last two years of the assessment). To test the robustness of these modelling option, we employed  
212 two methods, both of which focus on the accuracy of the correlation results from stocks that  
213 used survey indices in their assessments: The first was a comparison between the four stocks  
214 with independent survey and assessment estimates of recruitment and the remaining 10 stocks  
215 that included the survey index in their assessment. The second was a windowing approach to  
216 compute correlations between survey and assessment estimates of recruitment, to assess the  
217 influence of the last years in correlations (see details in supp. Mat. 2).

218 - The best way to address this potential for artificial agreement is to re-run the stock  
219 assessments without the survey-derived indices, and then compare the new assessment-based  
220 estimated recruitments with the, now independent, survey-derived estimates of recruitment.  
221 Such an approach is obviously the most attractive in theory, but each assessment varies among  
222 the different stocks and cannot be tuned from the ICES database without the expertise of the  
223 stock assessment WG. To do so, the fisheries scientists in charge of these stock assessments  
224 were asked to re-run the stock assessments without the survey-derived indices, and some of

225 them kindly did so. These new time series of model-based recruitment were collated and used  
226 separately from the potentially correlated estimates in analyses. This subset of comparisons  
227 allowed us to evaluate the robustness of results based on the potentially correlated estimates.  
228 For standardization purpose, we also eliminated the last two years of the recruitment estimates  
229 from these series, either manually or naturally.

230 To assess the accuracy of the survey-based predictions of recruitment compared to  
231 assessment-based estimates, we computed the Pearson correlation coefficient ( $r$ ) between the  
232 survey-based recruitment estimates and the stock assessment model-based abundance for the  
233 youngest year group. This was done for all stocks ( $r_1$ , using model-based data from ICES  
234 database) and for the subset of 10 stocks that the assessment estimates were independent of the  
235 survey ( $r_2$ , from stocks whose assessment did not use survey or from re-run assessment models).  
236 We assumed that the model-based estimates were a realistic value and thus the closer the  
237 correlation of the survey-based prediction to the model-based value, the higher the accuracy of  
238 the survey-based value. Because the true value of recruitment is unknown, we refer to this as  
239 apparent accuracy. While agreement between the two estimates of recruitment suggest higher  
240 confidence in the survey-based estimates, without knowing the true values of recruitment we  
241 cannot access whether either is or both are biased.

242 For the stocks for which correlation coefficient  $r_1$  (model-based data from ICES  
243 database) and  $r_2$  (for rerun assessment estimates) were available, we first compared their  
244 respective levels to highlight potential lack of independence and caution about interpretation of  
245  $r_1$ . From this preliminary analysis ( $r_1$  versus  $r_2$  for rerun stocks only), we determined if we would  
246 use the  $r_2$  values (truly independent estimates on 10 stocks) rather than the  $r_1$  (14 stocks but  
247 only 4 truly independent estimates only) in subsequent analyses.

248 Another proxy ( $r_3$ ) was designed to approximate how short-term recruitment forecasts  
249 can be used in stock assessments that do not have a source of year-specific short-term forecasts.

250 The geometric mean of the model-based abundances for the youngest year class during the  
251 previous five years was computed. When year-specific forecasts of recruitment are not used,  
252 geometric mean of model-based recruitment estimates is frequently used in forecasting for  
253 ICES stock assessments. To estimate the improvement of the forecast linked to the use of  
254 survey-based pre-recruit abundance indices,  $r_1$  or  $r_2$  and  $r_3$  were compared. We used a one-way  
255 analysis of variance (ANOVA), after an arcsine transformation, to compare  $r_1$  or  $r_2$  to  $r_3$  values.  
256 The arcsine transformation is appropriate to normalize the data from the original [-1,1]  
257 distribution of correlation coefficients (Sokal and Rohlf, 1995). A higher value of  $r_1$  or  $r_2$  (for  
258 the survey-based estimates) compared to  $r_3$  (geometric mean of the assessment-based estimates)  
259 indicates that survey estimates agree with assessment values better than average recruitment  
260 agrees with the assessment values. In this way,  $r_3$  is an approximate proxy of the contribution  
261 of survey-based pre-recruit indices to estimate future recruitment over and above the use of a  
262 5-year average.

263 We explored whether various factors influenced the magnitude of  $r_1$  or  $r_2$ , including  
264 species vertical guild (Table 1), sampling gear, scale of the survey, number of samples in the  
265 survey, age group in the survey-based pre-recruit abundance indices, youngest age group in the  
266 stock assessment, difference between these two ages, and length of the time series.

267

## 268 **Results**

### 269 *Stocks of coastal dependent species*

270 ICES performed stock assessments for 185 stocks in 2017-2018 that spanned 61 species.  
271 Eighteen of these species (30%), which involved 78 stocks (42%), depend on coastal juvenile  
272 habitat (Table 2; supp. Table 1). These 78 stocks are widespread in the North East Atlantic  
273 (from Iberian waters to Greenland in latitude and from the North Sea to Greenland in longitude)  
274 and in the Baltic Sea (supp. Table 1). The habitat use of these species and stocks with juvenile

275 coastal dependence were: demersal (9 species; 39 stocks), benthic (6 species; 23 stocks), and  
276 pelagic (3 species; 16 stocks). Among these 78 stocks, most (87%) were well-assessed stocks  
277 (ICES categories 1 and 3), whereas 10% were data-poor stocks, all of which were demersal  
278 species (supp. Table 1).

279279

#### 280 *Use of recruitment forecasts and pre-recruit surveys in assessment*

281 Among the 78 stocks from species with juvenile coastal dependence, 49 (Table 2) used  
282 short-term recruitment forecasts (from any source) in their assessments. Most of these 49 stocks  
283 (46) were designated as DLS Category 1, with the remaining three stocks being DLS 3. Survey-  
284 based pre-recruit abundance indices were available (used and not used in the assessment) for  
285 35 (71%) of these 49 stocks, which were all designated as DLS Category 1 (Table 2; Figure 1).  
286 For these 35 (of 78) stocks with both survey-based pre-recruit abundance indices available and  
287 that use short-term recruitment forecasts in their assessment (Table 2), the pre-recruit indices  
288 were derived mainly (supp. Table 1) from trawl surveys for demersal species (12 of 18 stocks)  
289 and benthic species (9 of 9 stocks), and from acoustic surveys for pelagic species (5 of 8 stocks).  
290 While survey-based pre-recruit abundance indices were available for 35 of the 49 stocks that  
291 generated recruitment forecasts in their assessments, only 14 of these 35 stocks (40%; Table 2;  
292 Figure 1) actually used the indices in their assessments. For the majority of stocks (21 of 35),  
293 the indices were not used for short-term forecasts of recruitment. The underutilisation of survey-  
294 based indices was noteworthy for stocks of demersal species (12 of 18 stocks did not use the  
295 indices; supp. Table 1).

296 Six stocks with unused indices reported that the available time series were not yet  
297 sufficient or because the results would not be available in time for consideration by the WG  
298 (Table 3). But, the most commonly reported reason for not using the survey-based indices (11  
299 of 21) was that the use of the indices had not been thoroughly evaluated (Table 3; supp. Table

300 1). The remaining four stocks with unused indices had attempted to use the indices but a  
301 decision was made to not use them because the surveys were not designed to estimate pre-  
302 recruit abundance in the spatial domain of the stock (Table 3). A partial explanation for not  
303 using the survey-based indices when they were sufficient and available (15/21) was that these  
304 surveys were not designed to cover both the spatial scale of the stock and/or coastal juvenile  
305 habitats (Table 3).

306 Fourteen stocks used the survey-based pre-recruit indices in their forecasts. These 14  
307 stocks are distributed in the North East Atlantic (from Bay of Biscay to Greenland in latitude  
308 and from the North Sea to Greenland in longitude) and in the Baltic Sea (Table 4). For these 14  
309 stocks, seven of the indices were derived from surveys covering both the stock scale and coastal  
310 nurseries, four indices were from surveys that partially cover the stock's spatial extent and  
311 include coastal nurseries, and three indices were calculated from surveys done at the stock  
312 spatial scale but which do not include coastal juvenile habitat (Table 4).

313

#### 314 *Apparent accuracy of survey-based pre-recruit indices*

315 For 12 of 14 stocks (Table 4), pre-recruit abundance indices were used in the  
316 assessments. These were either derived from a single survey (8 stocks,) or were combined into  
317 a single recruitment index as part of the assessment by the ICES working group (4 stocks, North  
318 Sea cod and sole, Irish Sea plaice and Celtic Sea whiting; ICES, 2017c). Two (of 14) stocks  
319 used two survey-based pre-recruit abundance indices for short-term forecasting (Table 4):  
320 Iceland cod (ICES, 2018c) and North Sea whiting (ICES, 2017c). Our analysis of the  
321 relationship between the survey-based pre-recruit abundance indices and the model-based  
322 abundance for the youngest year class ( $r_1$  and  $r_2$ ) considered a single survey-based pre-recruit  
323 abundance index of recruitment per stock. For North Sea whiting, the lead fishery scientist  
324 (Miethe, pers. com.) for the stock assessment (ICES, 2017c) indicated that the index in Autumn

325 (IBTSQ3) is considered as the reference pre-recruit abundance index. For Iceland cod, we  
326 initially analysed both indices separately (surveys SMB and SMH had correlation coefficients  
327 of 0.75 and 0.8 with model-based indices, respectively); given the similarity of the results, the  
328 SMH index derived from the fall survey was selected (Table 4).

329 Among these 14 stocks, four use survey-based pre-recruit abundance indices only for  
330 forecasting and 10 used these indices in both stock assessment and forecasting (Table 4). Of  
331 these 10, only five required manual deleting of two recent years. The other five stocks, which  
332 used the survey indices in their assessments, had sufficient lag between the age of fish in the  
333 survey and the age of recruitment (youngest age) in the assessment. This meant that the two  
334 most recent years of recruitment from the stock assessment would not be auto-correlated with  
335 their survey index for our comparisons (i.e. “Natural removal”, Table 4).

336 From the 10 stocks utilising survey-based indices in both stock assessment and  
337 forecasting, fisheries scientists in charge of assessments agreed to rerun the stock assessments  
338 without the survey-derived indices for six stocks (Table 4,  $r_2$  in bold). For these stocks,  
339 correlations were higher for  $r_1$  than for  $r_2$  (Table 4, for the 6 stocks, average difference in  
340 Pearson correlation coefficient  $r_1 - r_2 = 0.077$  [0, 0.19]). These patterns confirmed the preliminary  
341 tests of robustness on the use of the correlation between the survey-based recruitment estimates  
342 and the stock assessment model-based abundance; i.e., low to moderate influence of  
343 autocorrelation when the last two years of the recruitment estimates are removed (detailed in  
344 supp. Mat. 2). However slight, these differences did indicate an overestimation of  $r_1$  through  
345 correlation induced by inclusion in the assessment. Hence, we selected  $r_2$  for further analyses,  
346 which reduced the number of stocks to 10 (4 whose assessment did not use the index and 6  
347 rerun assessments, Table 4).

348 When used, the survey-based predictions of recruitment ( $r_2$ ) had a reasonable apparent  
349 accuracy (Table 4; Figure 2; Figure 3). Survey-based pre-recruit abundance indices had

350 significantly higher correlations with the model-based recruitment estimates than the geometric  
351 means of the five previous years of model-based abundances (Figure 3;  $p < 0.001$ , after arcsine  
352 transformations of  $r_2$  and  $r_3$ ). No obvious patterns emerged from the factors (species habitat,  
353 survey design, Table 4) that could influence the accuracy of the survey-based pre-recruit  
354 abundance indices  $r_2$ , although the small size of the data set and the many potential influential  
355 factors made identification of associations difficult.

356

## 357 **Discussion**

358 We examined ICES-assessed stocks that both utilize coastal areas as juvenile habitat  
359 and use survey-based predictions of recruitment in their management assessments. Of the 78  
360 stocks involving 18 species with juvenile coastal-dependence, 49 also used short-term forecasts  
361 of recruitment in assessments. Most of these stocks (46 of 49) were designated as ICES DLS  
362 Category 1 stocks. Indeed, short-term forecasts of recruitment are mandatory in the ICES  
363 protocol for this category. We analysed the existence and aspects of surveys and derived survey-  
364 based pre-recruit indices and how they are presently used in assessments for the 78 stocks, using  
365 data collated from WG reports, responses to a questionnaire from the lead fishery scientists for  
366 each stock, and communications with lead members of various stock assessment WGs. We  
367 sought to explore how surveys are used to generate recruitment indices as part of assessments,  
368 possible reasons for their omission, and the accuracy of predicted recruitment from survey-  
369 derived values.

370 The responses to the questionnaire as to why the survey information was available but  
371 not used (i.e., survey data on pre-recruit abundance were not used for  $21/35 = 60\%$  of the stocks  
372 for which they are available) indicated that there are opportunities for determination of how the  
373 survey information, either as is or with some adjustments to the survey design, could be used  
374 in assessments. The most common response for why an available survey was not used was that



375 its utility had not been rigorously evaluated, followed by issues of whether enough data were  
376 available and that the survey results were not available in time for assessments. These three  
377 reasons accounted for why 17 of 21 stocks were not using available surveys to forecast  
378 recruitment for assessment, and suggest that surveys are available that, with proper evaluation,  
379 may be useful for generating recruitment indices.

380         Fishery-independent surveys are designed to answer specific questions and their lack of  
381 use for other purposes is not indicative of a poorly designed survey. For our proposed use, to  
382 forecast recruitment, the coverage of coastal habitats and the effective sampling of pre-recruit  
383 juveniles are critical. Both the stocks that did not use surveys to predict recruitment and those  
384 that did confirmed the (perhaps obvious) importance of the spatial scales of the surveys. Half  
385 of the survey-based pre-recruit indices used in assessments covered both the stock scale and  
386 coastal juvenile habitat, while the other half covered either stock scale or juvenile habitats. In  
387 contrast, none of the unused survey-based pre-recruit abundance indices covered both the stock  
388 scale and the coastal juvenile habitat. Most (87%) of the unused pre-recruit abundance survey-  
389 based indices covered only a fraction of the spatial extent of the stock, and 47% did not sample  
390 coastal juvenile habitat.

391         A major challenge for estimating pre-recruit abundance indices from surveys is to  
392 account for complex spatial and temporal variation in pre-recruit abundance (Denson et al.,  
393 2017; Potts and Rose, 2018). Variation in abundance across successive juvenile stages could be  
394 driven by small scale processes, leading to large spatial discrepancies among juvenile habitats  
395 (Scharf, 2000). The temporal (including inter-annual) variability in coastal habitat use of  
396 juvenile fish suggests that to estimate recruitment, it is necessary to survey several juvenile  
397 habitats (Chittaro et al., 2008). Both juvenile coastal distributions outside the geographical area  
398 covered by the surveys and regional patterns in recruitment variability (Denson et al., 2017)

399 may hinder estimation of reliable recruitment estimates (Albert et al., 2001; Ralph and Lipcius,  
400 2014).

401 The 17 stocks with available surveys not being used and which have not been evaluated  
402 for use would need to be evaluated. The evaluation should consider whether the sampling  
403 design can generate sufficiently accurate predictions of recruitment, and how easy it would be  
404 to maintain present sampling and make minor additions to better cover nursery areas (e.g., add  
405 stations in shallow juvenile habitat). Thus, there is an opportunity for further analyses to  
406 determine the feasibility and utility of these surveys for also generating short-term forecasts of  
407 recruitment, either as they are presently implemented or with minor changes that do not affect  
408 the use of the surveys for other purposes.

409 When survey-based predictions of recruitment were used in assessments, their apparent  
410 accuracy was reasonably high. The  $r_2$  values averaged 0.76 across all 10 stocks. Such degree of  
411 agreement was based on stocks with independent survey and assessment estimates and therefore  
412 was not influenced by lack of independence due to use of surveys within assessments. Indeed,  
413 for four stocks, survey-based predictions of recruitment were originally independent of the  
414 assessments (Table 4). For the six remaining stocks, models were rerun after removing survey-  
415 based indices from the assessment. For these six stocks differences between  $r_1$  and  $r_2$  depended  
416 at least partly on the availability of alternative information on recruitment strength used in stock  
417 assessment models. The difference was insignificant for North Sea plaice, for which several  
418 alternative data-based sources of information are used in the assessment model to infer pre-  
419 recruit abundance (including survey-based indices from other surveys; ICES, 2017c).  
420 Conversely,  $r_1$ - $r_2$  reached 0.19 for the western Baltic Sea cod, for which recruitment is mainly  
421 informed by the survey-based index in the assessment model for young stages (ICES, 2018b).  
422 This difference illustrates autocorrelation between survey-based and model-based short-term

423 forecasts of recruitment; i.e., for stocks where the survey-based recruitment indices informed  
424 the assessment models.

425         The degree of agreement between survey-based and survey-independent, model-based  
426 short-term forecasts was not due to a few influential points, as there was an average of 22 years  
427 in the various time series. Furthermore, the survey-based predictions out-performed the  
428 alternative using a 5-year geometric mean of model-based values.

429         Given the long history of attempts to predict recruitment in fisheries management, our  
430 results strongly suggest that juvenile surveys should be investigated for their potential use in  
431 assessments; a theme that has been emphasized by analysis of other stocks (Helle et al., 2000;  
432 Zhang et al., 2010; Caputi et al., 2014; Punt, 2019). Any possible use of survey results would  
433 need to be evaluated for the specifics of the survey data, the assessment methodology, and the  
434 life history of the species.

435         Deviations between survey-based and model-based short-term forecasts of recruitment  
436 may be due to several factors. First is the unknown estimation error in deriving recruitment  
437 estimates from surveys due to high spatio-temporal variation in abundance (Denson et al., 2017;  
438 Potts and Rose, 2018). Quantifying and understanding the causes of these errors is central to  
439 obtaining reliable recruitment estimates (Albert et al., 2001; Ralph and Lipcius, 2014). Second,  
440 our assumption that the model-based estimates are accurate ignores how process and estimation  
441 errors in recruitment arise from stock assessment models (Hilborn and Walters, 1992).  
442 Estimates of recruitment time-series are sensitive to model assumptions used in the assessments  
443 (Dickey-Collas et al., 2015). Third, there may be high, density-dependent and variable juvenile  
444 mortality (Nash et al., 2007; Le Pape and Bonhommeau, 2015; Haggarty et al., 2017) after the  
445 survey-based estimate of pre-recruit abundance. Given that these and other factors add noise to  
446 both survey-based and model-based short-term forecasts of recruitment, the degree of

447 agreement we found between both predictors across diverse stocks and sampling programs is  
448 encouraging.

449         The small (10 stocks) dataset precluded a comprehensive analysis of the driving factors  
450 of survey apparent accuracy. The correlation values did not indicate any obvious dependence  
451 on species habitat nor survey design. However, these and other factors, such as life history of  
452 the species, probably influence survey accuracy, which warrants analysis with more stocks.  
453 Two main issues complicated our ability to determine the factors that influenced the accuracy  
454 of survey-based pre-recruit estimates: (i) it is speculative to judge a survey program for  
455 generating pre-recruit information when the survey was designed for other purposes, and (ii)  
456 our sample size was too small for using the questionnaire results for assessing which factors  
457 influence accuracy. Given these caveats, the present analysis allows for some recommendations  
458 about survey design to ensure that the surveys provide sufficiently accurate pre-recruit  
459 abundance indices for advice about recruitment in stock assessment of species with juvenile  
460 coastal dependence:

- 461         - Surveys should sample coastal juvenile areas at appropriate times, to avoid the high and  
462         variable mortality during the early juvenile stages (Nash et al., 2007; Le Pape and  
463         Bonhommeau, 2015; Haggarty et al., 2017).
- 464         - Surveys should cover a large proportion of a stock's spatial domain to capture inter-  
465         annual variation in nursery habitat utilization (Albert et al., 2001; Ralph and Lipcius,  
466         2014).
- 467         - Surveys should be carried out annually to avoid missing values in the pre-recruit  
468         abundance time series.
- 469         - The juvenile portion of the survey should include an evaluation of the performance of  
470         the sampling gear (e.g., selectivities) and incorporate methods for quantifying  
471         variability.

472 - Where possible, juvenile surveys or the juvenile component of stock surveys should aim  
473 to be as consistent as possible with the survey of non-juvenile areas to provide  
474 commensurable data for combined analyses.

475 These conditions provide a general basis for examining how surveys can be initially  
476 evaluated for possible use for juveniles and pre-recruit indices. These recommendations can be  
477 applied to situations when surveys are being revised (surveys are presently done for multiple  
478 reasons) and new surveys are being designed.

479 Augmenting the survey-based pre-recruit abundance indices with other covariate  
480 variables, such as environmental drivers, may further improve the accuracy of recruitment  
481 predictions. Indices based on environmental drivers (e.g., ICES, 2018a for North East Arctic  
482 cod; Le Pape et al., 2003 and Lagarde et al., 2018 for Bay of Biscay sole; Denson et al., 2017)  
483 alone, or in combination with pre-recruit abundance indices (Zhang et al., 2010; Ralston et al.,  
484 2013), could provide helpful information about recruitment trends and variability in the near  
485 term. However, changes in total allowable catch (TAC) recommendations lead to gains only  
486 when environmental predictors and survey-based pre-recruit abundance indices are accurately  
487 assessed (Basson, 1999; De Oliveira and Butterworth, 2005). The increase in accuracy that  
488 survey-based pre-recruit abundance indices can provide to catch advice suggests that existing  
489 surveys should be evaluated for their potential use.

490 Predictions of future short-term recruitment can influence management advice both for  
491 the assessment year and for the TAC year (ICES, 2015). Our analysis showed that, while a  
492 limited number of the total possible stocks that can use survey-based predictions actually use  
493 them, when survey-based predictions are used in the assessment their apparent accuracy is  
494 reasonable. Survey-based pre-recruit abundance indices are being used for some stocks either  
495 explicitly in the stock assessment model (e.g., SAM model; Nielsen and Berg, 2014), or in a  
496 separate forecasting routine combined with stock assessment outputs (e.g., RCT3 routine post

497 XSA model; Shepherd 1997; Shepherd, 1999). These indices inform the expected recruitment  
498 in future years. The scope of the present paper was focused on the usefulness of survey-based  
499 pre-recruit abundance indices for advice about recruitment, not on the ways in which to utilise  
500 these indices in stock assessment procedures; this has been extensively discussed by others  
501 (Punt, 2019).

502 Tools for forecasting recruitment play an important role in fisheries management and  
503 decision-making, and all possible tools should be at least explored for their potential utility, if  
504 not utilised. When catches are highly dependent on recruitment (short-lived or over-exploited  
505 stocks; e.g., North Sea cod, ICES, 2017c), estimating recruitment and possible variability about  
506 the forecast is a priority to provide reliable information for management. However, the number  
507 of years for which short-term forecasts can benefit from survey-based abundance indices of  
508 pre-recruits obviously depend on the year-lag between the first age in the catch forecast and the  
509 age of the pre-recruit individuals in the survey. For the large proportion of stocks with only a  
510 1-year lag (Supp. Table 1), there is no observed recruitment survey index for more years ahead,  
511 and short-term forecast means a forecast for the next year only.

512 Even when they are not accounted for in stock assessment, survey-based pre-recruit  
513 abundance indices could be considered as quantitative evidence supporting or opposing  
514 predictions derived using average previous recruitment, and used to provide a measure of the  
515 uncertainty in predicted recruitment. Indeed, when the survey-based pre-recruit abundance  
516 indices are not available during an assessment (e.g., Sandeel stocks, sup. Table 1; Table 3),  
517 some procedures allow their results to be considered *a posteriori*. For example, the advice for  
518 the main flatfish and round fish stocks in the North Sea has a procedure for reopening after the  
519 surveys are conducted in autumn (ICES, 2008; ICES, 2015). Re-evaluating management advice  
520 after surveys are completed and pre-recruit abundance indices are estimated to differ  
521 significantly from assessment derived indices should make the advice more robust (ICES,

522 2008). This procedure of re-evaluating management advice clearly shows the validity and  
523 importance of the recruitment indices. We recognize that these approaches introduce additional  
524 work for those delivering advice; thus, exploratory analyses to assess their potential benefits to  
525 assessments are a good first step. While our focus was on species that use coastal habitats, our  
526 evaluation approach is applicable to most species, including those that do not depend on coastal  
527 juvenile habitats (Kimoto et al., 2007; Ralston et al., 2013).

528         We focused our analysis on using existing surveys for stocks that use recruitment  
529 forecasts in their assessments. In addition to the use of survey-based pre-recruit abundance  
530 indices for forecasting recruitment, fishery-independent surveys can be evaluated for their  
531 potential use with other management goals. Examples include quantifying juvenile habitat for  
532 informing an ecosystem-based approach to fisheries management (Browman et al., 2004),  
533 deriving indices of environmental drivers for further forecasting (Hidalgo et al., 2016), and for  
534 informing dynamic marine spatial plans that respond to changes in coastal habitats (Kininmoth  
535 et al., 2019). Surveys can also be used to provide alerts on the impacts of anthropogenic  
536 disturbances affecting survival of juveniles. A large proportion of coastal-dependent species is  
537 impacted by human activity other than fishing mortality when juveniles utilize coastal habitats  
538 (Brown et al., 2018a). Regular monitoring of juvenile habitats to provide data for assessment  
539 can generate spatially-explicit evidence for local productive areas to inform environmental  
540 management. Surveys can provide information on juvenile responses to both environmental  
541 drivers (Hermant et al., 2010; Caputi et al., 2014; Lagarde et al., 2018; Brown et al., 2019) and  
542 anthropogenic pressures (Rochette et al., 2010; Archambault et al., 2018), which can influence  
543 future stock dynamics (Stige et al., 2013). Habitat degradation can result in either overly  
544 optimistic or overly conservative assessments of stock status (Brown et al., 2018b). Preserving  
545 or restoring the capacity of juvenile habitat is of major importance for improving adult biomass  
546 of populations relying on coastal juvenile habitat (Van de Wolfshaar et al., 2011; Le Pape and

547 Bonhommeau, 2015; Archambault et al., 2018). Existing and planned surveys should be  
548 examined for possible leveraging of their results, in addition to their primary motivation and  
549 goals, thereby integrating fisheries and ecosystem-based management (Kraufvelin et al., 2018).  
550550

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563 **Supplementary Material** is available at ICES JMS online

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799

800 **Tables legends**

801 Table 1: The 18 species assessed by ICES in 2017-2018 whose juveniles rely on coastal  
802 habitats, and their general vertical habitat use (after Seitz et al., 2014 and updated in Brown et  
803 al., 2018a).

804

805 Table 2: The number of species and stocks assessed by ICES in 2017-2018 based on progressive  
806 sub-setting: coastal-dependent, use short-term recruitment forecasts in assessment, existence of  
807 surveys with possible estimate of pre-recruitment, and use the survey values as the predictor of  
808 recruitment in the assessment.

809

810 Table 3: The reasons for rejection, and spatial scale of the survey for the 21 stocks of species  
811 that rely on coastal habitats and for which survey-based pre-recruit abundance indices exist but  
812 are not presently used in short-term forecasts in ICES assessment.

813

814

815 Table 4: Characteristics of the 14 stocks of species relying on coastal habitats at juvenile stage,  
816 for which survey-based pre-recruit abundance indices are used in short-term forecasts in ICES  
817 stock assessments. Characteristics shown are: description of the stock, name and information  
818 on survey design (\*: the selected survey indices for the 2 stocks for which 2 were available),  
819 age of pre-recruit in survey-based abundance indices, youngest age in the associated stock  
820 assessment, length of the time series, assessment model used, whether the pre-recruit survey-  
821 based indices were used in the stock assessment or only for short-term forecasts, the method to  
822 eliminate the last two years of the recruitment estimates (either “manually” or “natural, i.e.,  
823 natural elimination because the last two years were dropped when matching the two recruitment  
824 indices”), value of the correlation coefficients  $r_1$  and  $r_2$  ( $r_2$ : **rerun models** (in bold) and *stocks*

825 *for which survey-indices are not incorporated in the assessment (in italic).*

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830 Figure legends

831

832 Figure 1: Number of stocks by DLS Category that used short-term forecasted recruitment in  
833 their assessment, categorized by whether a pre-recruit survey exists or not, and if it exists,  
834 whether it was used to predict recruitment. A total of 49 stocks were used that were species that  
835 rely on coastal habitats and for which ICES assessments used short-term forecasted recruitment.  
836

837 Figure 2: Scatter plot of survey-based (x axis) and assessment-based (y axis) recruitment (both  
838 in the unit used in the stock assessment WG) for the 14 coastal-dependent stocks for which  
839 survey-based pre-recruit abundance indices are used as short-term forecasts of recruitment in  
840 ICES assessments. Stock codes are defined in Table 4.

841

842 Figure 3: Box plot of the correlation coefficients between model-based recruitment indices and  
843 (left panel) the geometric mean of the model-based recruitment indices during the last five years  
844 ( $r_3$ ), and (right panel) the survey-based pre-recruit abundance indices ( $r_2$ ). Each plot is based on  
845 the 10 stocks that rely on coastal habitats at juvenile stage and for which the ICES assessments  
846 are truly independent from survey-based pre-recruit abundance indices but use these survey-  
847 based pre-recruit abundance indices for short-term forecasts of recruitment (thick line, median;  
848 box, from the 0.25 quartile to the 0.75 quartile; whiskers, 1.5 times the distance between the  
849 quartiles).

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851

Table 1: The 18 species assessed by ICES in 2017-2018 whose juveniles rely on coastal habitats, and their general vertical habitat use (after Seitz et al., 2014 and updated in Brown et al., 2018a).

<b>Species</b>	<b>Vertical position</b>
Ammodytes	Demersal
Anguilla anguilla	Demersal
Clupea harengus	Pelagic
Dicentrarchus labrax	Demersal
Engraulis encrasicolus	Pelagic
Gadus morhua	Demersal
Limanda limanda	Benthic
Merlangius merlangus	Demersal
Mullus surmuletus	Demersal
Platichthys flesus	Benthic
Pleuronectes platessa	Benthic
Pollachius pollachius	Demersal
Pollachius virens	Demersal
Psetta maxima (historic name)	Benthic
Scomber scombrus	Pelagic
Scophthalmus rhombus	Benthic
Solea solea	Benthic
Sprattus sprattus	Pelagic

Table 2: The number of species and stocks assessed by ICES in 2017-2018 based on progressive sub-setting: coastal-dependent, use short-term recruitment forecasts in assessment, existence of surveys with possible estimate of pre-recruitment, and use the survey values as the predictor of recruitment in the assessment.

<b>Category</b>	<b>Number of species</b>	<b>Number of stocks</b>
ICES evaluated	61	185
& coastally-dependent juveniles	18	78
& with short-term forecast		49
& with potential existing survey based pre-recruit indices		35
& using survey-based indices in forecast		14

Table 3: The reasons for rejection, and spatial scale of the survey for the 21 stocks of species that rely on coastal habitats and for which survey-based pre-recruit abundance indices exist but are not presently used in short-term forecasts in ICES assessment.

<b>Reason to reject</b>	<b>Number of stocks</b>	<b>Scale of the survey</b>
Incomplete time-series	2	
Too late to be used	4	
Not investigated, nor tested	11	Stock scale, not including nurseries (2) Stock distribution partially covered, including coastal nurseries (6) Stock distribution partially covered, not including coastal nurseries (3)
Investigated and rejected	4	Stock distribution partially covered, including coastal nurseries (2) Stock distribution partially covered, not including coastal nurseries (2)



Stock Description	Stock code	area of juvenile survey	Survey name	Method of survey	Nb samples	age group of the recruitment indice	youngest age group in the stock assessment	Length of the time series	Assessment method	Incorporated in assessment and not in forecast only
Anchovy ( <i>Engraulis encrasicolus</i> ) in Subarea VIII (Bay of Biscay)	ane.27.8	Stock scale, including nurseries	Juvena	Accoustic	80	0	1	15	Specific SAM like	Yes
Cod ( <i>Gadus morhua</i> ) in Division Va (Iceland grounds)	cod.27.5a	Stock scale, not including nurseries	SMH* and (SMB)	Trawl	800	1	3	21	specific XSA like	No
Cod ( <i>Gadus morhua</i> ) in NAFO Subarea 1, inshore (Inshore west Greenland cod)	cod.21.1	Stock distribution partially covered, including nurseries	West Greenland inshore gill-net survey	Net	100	1	1	28	SAM	Yes
Cod ( <i>Gadus morhua</i> ) in Subarea IV and Divisions VIId and IIIa West (North Sea, Eastern English Channel, Skagerrak)	cod.27.47d20	Stock scale, including nurseries	IBTS-Q1 + IBTS-Q3 combined	Trawl	200	1	1	35	SAM	Yes
Cod ( <i>Gadus morhua</i> ) in Subdivisions 22-24 (Western Baltic Sea)	cod.27.22-24	Stock scale, including nurseries	BITSQ4	Trawl	100	0	1	17	SAM	Yes
Herring in Subarea IV and Divisions IIIa and VIId (North Sea autumn spawners)	her.27.3a47d	Stock scale, including nurseries	IBTS (mik)	Trawl	567	0	0	27	FLSAM	Yes
Herring in Subdivisions 25 - 29 (excluding Gulf of Riga) and 32	her.27.25-2932	Stock scale, not including nurseries	BIAS	Accoustic	49	0	1	24	XSA	No
Mackerel in the Northeast Atlantic (combined Southern, Western and North Sea spawning components)	mac.27.nea	Stock scale, including nurseries	IBTS	Trawl	1820	0	0	18	SAM	Yes
Plaice in Division VIIa (Irish Sea)	ple.27.7a	Stock scale, not including nurseries	BTS combined	Trawl	58	1	1	24	SAM	Yes
Plaice Subarea IV (North Sea)	ple.27.420	Stock distribution partially covered, including nurseries	UKBTSQ4	Trawl	100	1	1	22	AAP	Yes

Sole in Subarea IV (North Sea)	sol.27.4	Stock distribution partially covered, including nurseries	DFS combined	Trawl	630	0	1	26	AAP	No
Sprat in Subdivisions 22 - 32 (Baltic Sea)	spr.27.22-32	Stock scale, including nurseries	BIAS	Accoustic		0	1	23	XSA	No
Whiting in ICES Division VIIb, c, e-k	whg.27.7b-ce-k	Stock distribution partially covered, including nurseries	IGFS+EVHOE Combined indice	Trawl	180	0	0	14	XSA	Yes
Whiting Subarea IV (North Sea) and Division VIIId (Eastern Channel)	whg.27.47d	Stock scale, including nurseries	IBTSQ3* and (IBTSQ1)	Trawl	310	1	1*	26	XSA	Yes

2 last years removed	Value of correlation coefficient (r1)	Value of correlation coefficient without survey-based index in stock assessment (r2)
	0.7	
	0.8	<i>0.8</i>
Manually	0.62	
Manually	0.91	
Manually	0.89	<b>0.7</b>
Manually	0.94	<b>0.84</b>
	0.92	<i>0.92</i>
Natural	0.64	<b>0.58</b>
Natural	0.67	
Manually	0.77	<b>0.77</b>

	0.83	<i>0.83</i>
	0.85	<i>0.85</i>
Natural	0.79	<b>0.68</b>
Natural	0.67	<b>0.67</b>

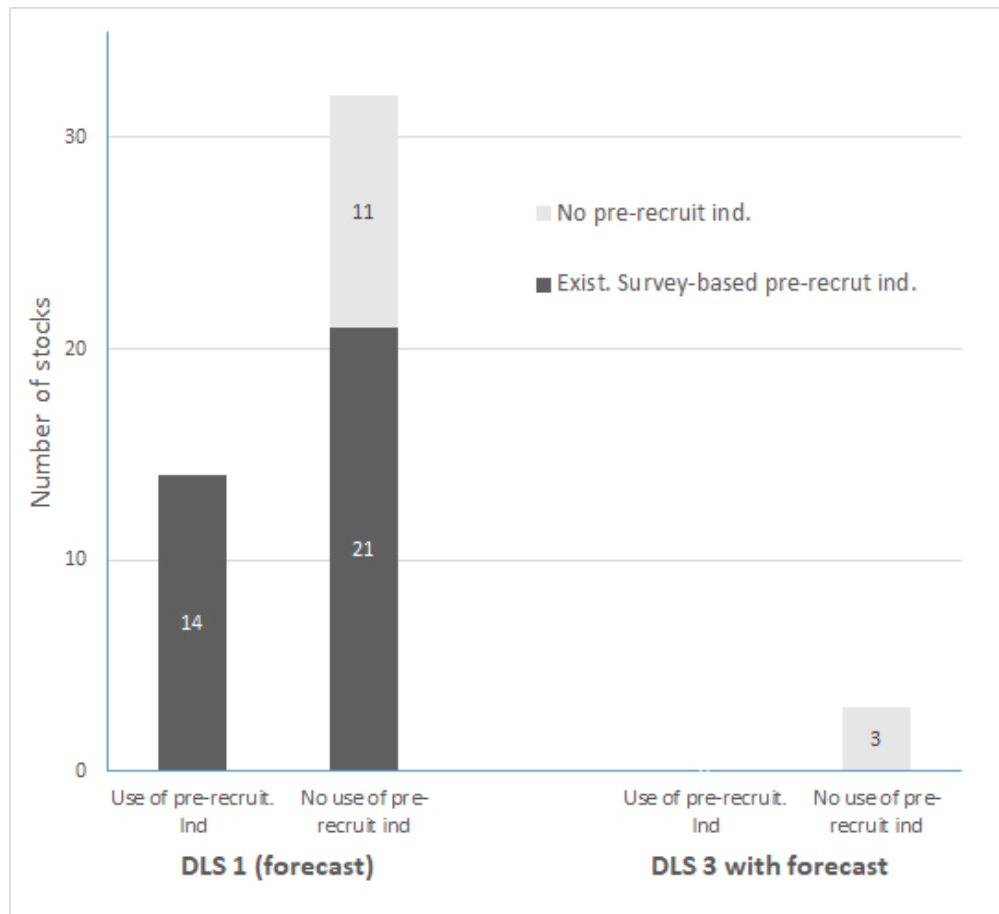


Figure 1: Number of stocks by DLS Category that used short-term forecasted recruitment in their assessment, categorized by whether a pre-recruit survey exists or not, and if it exists, whether it was used to predict recruitment. A total of 49 stocks were used that were species that rely on coastal habitats and for which ICES assessments used short-term forecasted recruitment.

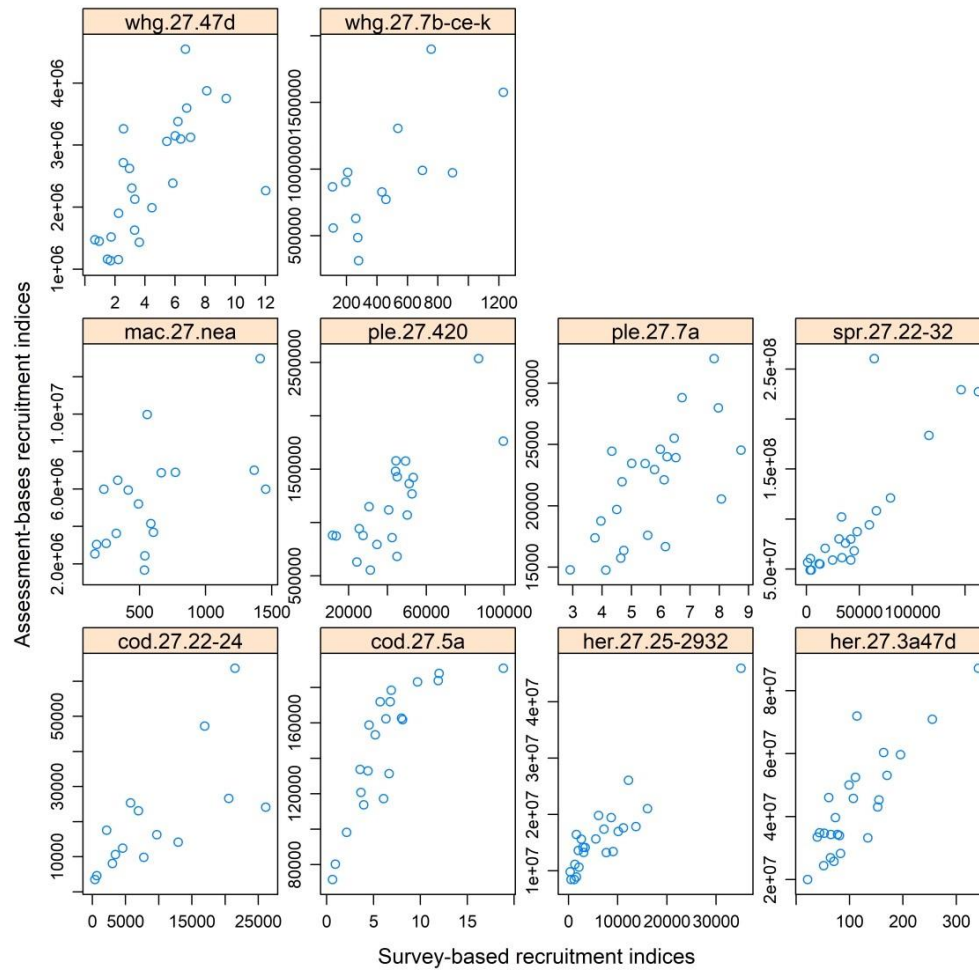


Figure 2: Scatter plot of survey-based (x axis) and assessment-based (y axis) recruitment (both in the unit used in the stock assessment WG) for the 14 coastal-dependent stocks for which survey-based pre-recruit abundance indices are used as short-term forecasts of recruitment in ICES assessments. Stock codes are defined in Table 4.

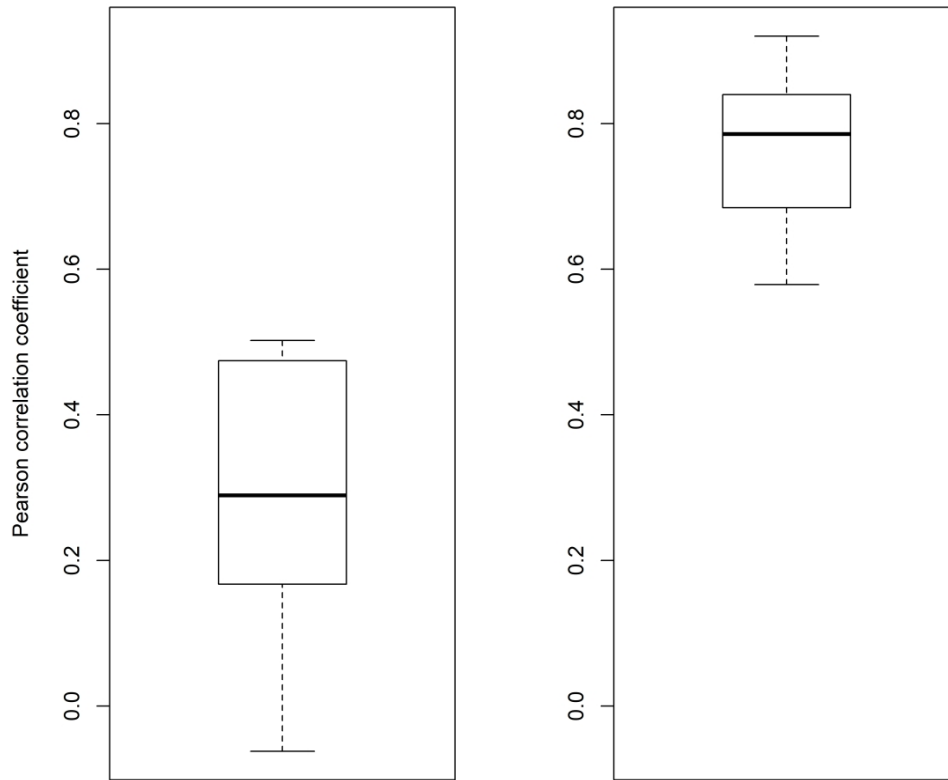


Figure 3: Box plot of the correlation coefficients between model-based recruitment indices and (left panel) the geometric mean of the model-based recruitment indices during the last five years ( $r_3$ ), and (right panel) the survey-based pre-recruit abundance indices ( $r_2$ ). Each plot is based on the 10 stocks that rely on coastal habitats at juvenile stage and for which the ICES assessments are truly independent from survey-based pre-recruit abundance indices but use these survey-based pre-recruit abundance indices for short-term forecasts of recruitment (thick line, median; box, from the 0.25 quartile to the 0.75 quartile; whiskers, 1.5 times the distance between the quartiles).