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1 **Using alternative biological information in stock assessment: condition-corrected**
2 **natural mortality of Eastern Baltic cod**

3
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11 Short Communication for ICES JMS

12
13 **Abstract**

14 The inclusion of biological and ecological aspects in the assessment of fish population status
15 is one of the bases for an ecosystem-based fisheries management. During the past two
16 decades the Eastern Baltic cod has experienced a drastic reduction in growth and body
17 condition that may have affected its survival. We used results from published experimental
18 literature linking cod condition to starvation and mortality, to estimate the annual proportion of
19 cod close to the lethal condition level in the Eastern Baltic cod stock. Thereafter we applied
20 these results to adjust the natural mortality (M) assumed in the analytical stock assessment
21 model. The results in terms of Spawning Stock Biomass (SSB), Fishing mortality (F) and
22 Recruitment (R) in the final year from the stock assessment using M values adjusted for low
23 condition were up to 40% different compared to the assessment assuming a constant M =
24 0.2. This method could be used for adjusting natural mortalities for other cod stocks where
25 changes in condition are observed.

26 Keywords: ecosystem-based fisheries management, fish nutritional status, natural mortality,
27 stock assessment

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32
33 **Introduction**

34 Ecosystem-based fisheries management relies on the use of biological and ecological
35 considerations in the management of exploited resources (Pikitch *et al.*, 2004; McLeod and
36 Leslie, 2009). In practice, this can be achieved either by the use of ecosystem information
37 directly as input in the assessment and/or forecast models (e.g. in form of climate-sensitive
38 stock-recruitment relationships; ICES, 2015a) or by their integration in the management
39 decision (e.g. environment-sensitive harvest control rules; Lindegren *et al.*, 2009).

40 In the Baltic Sea, recent examples of the inclusion of ecosystem information in stock
41 assessment are mainly confined to the pelagic stocks. Temperature and zooplankton are for
42 example used in the short-term forecasts of the Gulf of Riga herring (ICES, 2015a), whereas
43 the use of temperature has been attempted for Baltic sprat (ICES, 2007). Moreover,
44 predation mortalities by cod from multi-species models are incorporated in the single-species
45 stock assessment models for Baltic sprat and Central Baltic herring (ICES, 2015a). On the
46 other hand, for the Baltic cod stocks there has been a lack of practical applications of
47 ecosystem information into stock assessment. The only currently used application is the
48 inclusion of cannibalism in the single-species stock assessment of the Western Baltic cod
49 (ICES, 2015a).

50 During the past two decades, one of the main changes in the Eastern Baltic cod stock
51 (hereafter simply referred to as the Baltic cod) has been the drastic decrease in body

52 condition, and likely also growth, of individual fish (ICES 2015b; Eero *et al.*, 2012, 2015). An
53 association between poor condition/growth and natural mortality has been reported for a
54 number of species in the wild and experiment setups (Adams *et al.*, 1982; Henderson *et al.*,
55 1988; Post and Evans, 1989; Thompson *et al.*, 1991; Gislason *et al.*, 2010). Experimental
56 studies performed on Atlantic cod have also found a negative relationship between body
57 condition and mortality (Dutil and Lambert, 2000), which the authors argued to be one of the
58 causes of the lack of recovery of the Gulf of St. Lawrence stock despite the fishery
59 moratorium in the 1990s. Based on literature, therefore, an increase in natural mortality could
60 be expected also for the Baltic cod.

61 The aim of our paper was to use the findings by Dutil and Lambert (2000) to propose a
62 method to estimate the annual proportion of the Baltic cod that is expected to die due to low
63 condition, with an application into stock assessment. A comparison between the status of the
64 stock (spawning stock biomass, fishing mortality and recruitment) estimated by assuming
65 constant vs. condition-corrected natural mortalities is also presented using the settings of the
66 latest accepted analytical assessment of this stock (ICES, 2013).

67

68 **Methods**

69

70 Data and estimation of body condition

71 Data on total length (TL, cm) and total weight (TW, g) of individual cod were extracted from
72 the ICES DATRAS database, which contains biological information of cod caught during the
73 Baltic International Trawl Survey (BITS; ICES, 2014a) and covers the period 1991-2014. Dutil
74 and Lambert (2000) used gutted weights (GW) and fork length (FL) in their condition
75 estimates, and therefore TL and TW were converted into GW and FL for each fish.

76 The formulas used for the conversions are the following:

$$77 \text{FL} = 0.9306 * \text{TL} + 3.7471 \quad (\text{eq. 1})$$

$$78 \text{GW} = \text{TW} / (1.10 \text{ to } 1.23, \text{ length-class and quarter-specific}) \quad (\text{eq. 2})$$

79 The equation (1) was based on Pinhorn (1969), while the equation (2) was based on samples
80 from the Baltic Sea collected by Sweden and Denmark in ICES SDs 25 and 26 between
81 2006-2014 (totally 21 436 cod). No differences in the weight conversion formula were
82 observed between years and therefore an overall average by quarter and length-class was
83 used. After conversion, the condition for each fish in the DATRAS database was estimated as
84 Fulton's $K = \text{GW} / (\text{FL}^3) * 100$.

85

86 Estimation of K-corrected natural mortalities (IBIS)

87 Dutil and Lambert (2000) carried out a controlled experiment with cod (in the length range of
88 30-55 cm) in which one group of fish was fed and one group was not fed for 92-100 days.
89 While some fish died from starvation during the experiment, it was found that of the fish that
90 were alive at the end of the experiment, the fish that were not fed (starved) had $K=0.42-0.67$
91 and the fed fish had $K=0.83-0.98$ (Fulton's K , based on fork length and gutted weight). The
92 biological properties (e.g. liver energy and muscle energy) of some of the starved fish were
93 similar to those of dead fish, so the authors expected them to die shortly.

94 The following steps were followed to estimate the proportion of fish that would die due to low
95 condition and the new corresponding natural mortalities for wild Baltic cod:

96 1) Fish with $K \leq 0.65$ were considered as dying. The proportion of fish with $K \leq 0.65$ was
97 estimated for BITS Q1 and BITS Q4 surveys between 1991-2014. The estimation was
98 done by length-classes (20-29, 30-39, 40-49, 50-59 and 60-69 cm).

99

100 2) The proportions of fish with $K \leq 0.65$, by quarter and year, were translated into natural
101 mortality rates (M_K) using the following equation (Nygård and Lassen, 1997):

$$102 \text{"proportion fish with } K \leq 0.65\text{"} = (1 - (\exp(-M_K))) * 100 \quad (\text{eq. 3})$$

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3) The estimated natural mortality rates were added on the top of the constant $M=0.2$, traditionally assumed in the analytical assessment of the Baltic cod stock. By doing this, we made the assumption that the mortality = 0.2 is due to everything but condition. Therefore, the new M was estimated using the following equation:

$$M \text{ (K-corrected)} = 0.2 + M_K \quad (\text{eq. 4})$$

4) The K-corrected natural mortalities by length were translated into natural mortalities by age using an age-length-key in which ageing was done using only one country, i.e. Sweden. The use of only Swedish age estimations in the age-length-key would reduce the effect of the inconsistencies existing in Baltic cod age estimations among countries (ICES, 2015b).

The flowchart of the steps used in the estimation of the K-corrected natural mortalities is shown in Fig. 1.

Application of the K-corrected natural mortalities into stock assessment

We used the K-corrected natural mortalities as input in analytical stock assessment using SAM (ICES, 2013). Analytical stock assessment has not been used in practice for this stock since 2014 due to a number of issues with input data and in the model outputs (ICES, 2015b; Eero *et al.*, 2015). Our purpose here was not to produce a functioning stock assessment to be used as basis for ICES advice, but rather to illustrate how much K-corrected natural mortalities alone would change the perception of the stock in relative terms, regardless of the other uncertainties that might be present in the assessment.

Therefore, we applied the same settings and other input data as used in the latest accepted assessment (ICES, 2013) and only changed the natural mortality values. We compared the output (spawning stock biomass, SSB, fishing mortality, F , and recruitment, R) of the runs in which natural mortalities were set to 0.2 for all ages (ICES, 2013) with runs in which K-corrected natural mortalities estimated following our method were used.

We first looked at the effect of modified M values in 1991-2014 on the entire corresponding time series of SSB, F and R from stock assessment up to 2014. Secondly, we were interested in demonstrating the effect of M values on SSB, F and R in the final year of stock assessment, which is the basis for providing management advice. Therefore, we successively excluded one last year from the time series back to 2004 (known also as retrospective analyses), both in the assessment with constant M values and the one with K-corrected M s, to be able to compare the effect of M on the estimates in the final year in eleven cases (2004-2014). Thereafter we plotted the values of SSB, F and R for the final year of these eleven runs to show the differences between using constant M and K-corrected M values.

To demonstrate the potential effect of changes in M on management targets, maximum sustainable yield reference points (F_{msy} and MSY) were calculated both for the assessment with constant M (at 0.2) and with K-corrected M , using the standard method used in ICES (e.g. ICES, 2014b).

Results

A total of 244 258 fish records were extracted from the DATRAS database. An example of frequency distributions of K-values by quarter is shown in Fig. 2. While in 1994 nearly no fish had $K \leq 0.65$, in 2010 a significant proportion of fish was below this threshold in both quarters. The time-series of the proportion of fish with $K \leq 0.65$ by length-class and quarter is shown in Fig. 3. The smaller length-classes (20-29 and 30-39 cm) did not show large changes in any of the two quarters, while the larger length-classes showed an increase up to 15% in quarter 1 and 25% in quarter 4. The proportion of fish with $K \leq 0.65$ decreased towards the end of the time-series in quarter 4. The time-series of K-corrected natural

154 mortality rates by quarter and length-class are also shown in Fig. 3, and display the same
155 patterns as the proportion of fish with $K \leq 0.65$. The time series of K-corrected natural
156 mortality rate by age, estimated using a Swedish age-length-keys, are shown in Table 1.
157 Spawning Stock Biomass (SSB), Fishing mortality (F) and Recruitment (R) for the final year
158 using the constant natural mortalities (i.e. 0.2; ICES, 2013) and the K-corrected natural
159 mortalities are shown in Fig. 4. The differences between the runs ranged between 2-24% in
160 SSB, between 3-40% in F, and between 2-14% in R in the eleven years compared. SSB and
161 R were always higher and F was always lower in the runs with the K-corrected natural
162 mortalities, with increasing difference over time due to cumulative effect of a higher M
163 compared to the baseline value of 0.2.
164 The K-corrected M values resulted in ~ 40% higher Fmsy estimate compared to the Fmsy
165 estimated using constant M = 0.2 (in our example, Fmsy were estimated at 0.63 and 0.43,
166 respectively). Less difference was obtained for MSY, the value corresponding to K-corrected
167 M being about 5% lower than for constant low M (60430 tons and 63516 tons, respectively).

168 169 **Discussion**

170
171 One of the ways to foster a sustainable ecosystem-based management is to integrate
172 biological and ecological knowledge into stock assessment and management of the exploited
173 living resources.

174 In terms of natural mortality, the ecosystem effects that are considered in stock assessment
175 context are mainly related to predation (e.g.; Sparholt, 1990; Hollowed *et al.*, 2000; Tyrrell *et*
176 *al.*, 2008; EC, 2012). Age- or size-specific differences in natural mortality are in some cases
177 assumed or estimated using length or weight data (e.g. for plaice in Eastern Channel; ICES,
178 2015c). However, we are not aware of any examples where inter-annual variations in natural
179 mortality due to other drivers than predation have been formally included in fish stock
180 assessments. This is likely because natural mortality is generally difficult to estimate, which is
181 why it is often kept constant (Johnson *et al.*, 2014). Nevertheless, in cases where strong time
182 trends exist in some biological or ecosystem parameters that are expected to influence
183 natural mortality, efforts should be made to take this into account in stock assessment.

184 In the Baltic Sea, the drastic decrease in condition of cod during the past 2 decades has
185 raised a lot of concerns for the managers and the fishery (ICES, 2015a), including decrease
186 in the quality of the fish and consequently their prices, possibly contributing to increased
187 discarding and high-grading and to the impossibility to fill the annual quotas. The reasons of
188 the observed decrease in cod condition are outside the scope of our paper and are currently
189 under investigation in several projects. Recently published papers and reports point to the
190 lack of food and density dependence (Eero *et al.*, 2012), selective fishing (Svedäng and
191 Hornborg, 2014), increase in anoxic areas and increase in parasite infection (ICES, 2015b)
192 as potential causes for the decrease in cod condition.

193 Our study aimed at proposing a method to include information about the temporal variations
194 in cod condition in the estimation of cod natural mortality, to be applicable in stock
195 assessment. Analytical stock assessment has been used by ICES as base for Advice for the
196 Eastern Baltic cod up to 2013 (ICES, 2105b). Thereafter, due to issues discovered in the
197 analytical assessment (e.g. strong retrospective patterns), it was abandoned and a data-poor
198 approach (based on biomass trends from scientific surveys) was used as base for advice
199 (Eero *et al.*, 2015). The potential reasons of the failure of analytical stock assessment have
200 been summarized by Eero *et al.* (2015) and are represented by deteriorated ageing quality,
201 unaccounted natural mortality, uncertain discards and changes in survey catchability.
202 Therefore, our study represents an attempt to solve some of these issues. Moreover, our
203 study illustrates how much the M-correction alone would matter in the perception of the stock
204 in relative terms, regardless of all the other uncertainties that exist in the assessment.

205 Consequently, the results in terms of SSB, F and R presented in this study are only indicative
206 and should not be used for management purposes. Our proposed method to estimate K-
207 corrected natural mortalities can be applied (both in age- and length-based models) when the
208 other issues related to the analytical stock assessment will be solved.

209 Recommendations for fisheries management in terms of fishing mortality (F) often scale with
210 natural mortality (M), and may therefore be highly dependent on the value of M assumed
211 (Andrews and Mangel, 2012). Thus, misspecification of M may lead to over- or under-
212 estimates of critical management quantities (Johnson *et al.*, 2015). In our analyses, not taking
213 into account the increase in M due to low condition resulted in lower SSB estimates and
214 higher F estimates compared to the analyses that included K-corrected M. Thus, in this
215 particular example and present situation, one may argue that ignoring the increase in M and
216 applying a constant relatively low value of M would be more precautionary from a management
217 perspective, since it would decrease the catch advice. However, this could be different in a
218 situation when M is changing in the other direction, e.g. if the condition of cod will improve.
219 Furthermore, setting targets for fishing mortality at increasing M is not straightforward and
220 two opposing possibilities may be considered. One approach would increase the target
221 fishing mortality based on yield per recruit considerations, as the change in FMSY owing to
222 changing M in our study would also suggest. In contrast, another approach would lower the
223 target F to maintain the total amount of mortality the stock can withstand before productivity is
224 impacted constant (Legault and Palmer, 2015). In this context, Rätz *et al.* (2015) introduced
225 the concept of maximum sustainable dead biomass (MSDB) as a way to account for
226 variations in natural mortality and fishing mortality over time in management. The MSDB
227 approach would provide managers with the level of different natural mortality sources and
228 adjust the anthropogenic mortality accordingly.

229 In practice, thorough analyses would be needed to determine the most appropriate approach
230 via estimating targets for a range of stock–recruitment relationships and evaluating the trade-
231 offs between risk of overfishing and lost yield (Legault and Palmer, 2015). Our aim in this
232 paper was not to conduct such analyses, given the present lack of analytical assessment for
233 the Eastern Baltic cod, implying that also reference points cannot be reliably estimated.
234 However, we wish to point out that if time-varying natural mortalities are implemented in the
235 future, the estimation of the corresponding management targets would need careful
236 consideration.

237 In our analysis we focused solely on the impact of condition on natural mortality, to
238 specifically look at the effect of one specific factor on the assessment results. However, other
239 parameters used as input in stock assessment can be potentially affected by the condition of
240 the fish. Fish in low condition have a lower probability of being mature (Morgan, 2004) and
241 therefore a population dominated by slim fish is expected to have a lower SSB and
242 recruitment success (Balcombe *et al.*, 2013). These effects of condition on maturation, SSB
243 and recruitment could change the stock-recruitment relationship and affect the outcome of
244 the stock assessment and estimation of reference points. Moreover, the occurrence of slim
245 fish in the stock could be expected to change the selectivity of both commercial and scientific
246 surveys (ICES, 2015a).

247 Hereafter, we discuss our assumptions and the potential shortcomings of the method we
248 have proposed. Firstly, we assumed that the cod with $K \leq 0.65$ are all dying, while in the
249 experiment performed by Dutil and Lambert (2000) non-fed fish with $K \leq 0.65$ either died from
250 starvation or were still alive at the end of the experiment. However, the biological properties
251 (e.g. liver and muscle energy) of the starved fish still alive resembled that of fish that died,
252 and therefore the authors expected the starving fish to die shortly. In the wild, fish experience
253 harsher environmental condition than in controlled experiments. Especially, cod in the Baltic
254 Sea is at the limit of its distribution range, and is heavily affected by environmental stressors
255 such as large variations in the already low salinity and large extent of hypoxic areas.

256 Moreover, starved fish in the wild could be more prone to predation and fishing as well as
257 have increased difficulties in feeding on highly motile pelagic prey. Therefore, we consider
258 reasonable our assumption that all fish with $K \leq 0.65$ would die. Secondly, Dutil and Lambert
259 (2000) used in their experiment fish in the size range 30-55 cm, and therefore the limits for
260 mortality and starvation for the other size-classes are unknown. The size-class 20-29 cm
261 used in our calculations for the Baltic cod presents very little fish with $K \leq 0.65$ (around 1%)
262 and therefore a bias for those would produce only a very minor difference in our calculations.
263 On the other hand, although it is hard to believe that cod in the size-class 60-69 cm would
264 have a mortality (or starvation) limit very different from the one used in Dutil and Lambert
265 (2000), this could have been a source of bias. Thirdly, in our survey the cod that might have
266 already died due to low condition are of course not observed. This means that we could have
267 underestimated the proportion of the population that die because of low condition, or could
268 potentially compensate for the first assumption. Another source of uncertainty is associated
269 with the laboratory experiments originating from the northern Gulf of St. Lawrence (Dutil and
270 Lambert, 2000), while the thresholds for detrimental condition may be different in other cod
271 stocks. For example, the experiments were conducted at higher temperatures than those
272 normally experienced by the Baltic cod that could affect the threshold level of mortality due to
273 low condition. Fourthly, the length-age-key (ALK) we used to allocate length-classes into
274 ages can contain bias due to the known ageing problems for the Baltic cod. The use of only
275 Swedish ALK, although potentially being also inaccurate, would reduce these temporal
276 inconsistencies and bias. Fifthly, we assumed that the mortality due to low condition has to be
277 added to the background natural mortality of 0.2, which could be caused by diseases,
278 predation by seals and cannibalism for smaller individuals. In the 1990s there was nearly no
279 cod with $K \leq 0.65$, nevertheless an $M = 0.2$ was used in analytical stock assessment (ICES,
280 2013). This supports our choice to add the mortality due to low condition to 0.2. Finally,
281 various mortality effects may be compensatory, i.e. they may decline as other effects
282 increase. Natural mortality can either compensate for the anthropogenic mortality (i.e.
283 decrease of the natural mortality in exploited systems) or overcompensate for it (i.e. increase
284 of the natural mortality in exploited systems). If the exploitation is targeting individuals with
285 lower than average quality, the mortality from exploitation could be compensated by a
286 decreased natural mortality. Alternatively, if exploitation is targeting individuals with higher
287 than average quality, exploitation could be over-compensated by increased natural mortality
288 since the remaining individuals would be below average and thus more susceptible to die of
289 natural causes, as shown in both aquatic and terrestrial systems (Toigo *et al.*, 2007;
290 Sandercock *et al.*, 2011; Sedinger *et al.*, 2010; Rätz *et al.*, 2015). What are the main
291 mechanisms acting on the Baltic cod remain an open question. It could be argued that
292 trawling would be compensatory since cod with lower condition is more easily caught than
293 cod with a higher condition, leaving cod with good condition left in the system. Conversely,
294 slim cod could actually escape through the mesh of the trawl, proportionally removing cod in
295 good condition from the system.

296 We have proposed here a simple approach that can be considered to adjust the natural
297 mortalities from body condition data for stock assessment and management purposes, using
298 available information from existing experimental studies. We recognize that ideally a
299 validation of the resulting estimates for a given stock would be needed. However, at lack of
300 such validation, existing information from other stocks can be useful to explore the potential
301 consequences of changing M , also in the context of defining precautionary management
302 targets. Therefore, we consider the approach useful both for Baltic cod and for other cod
303 stocks, especially those experiencing large fluctuations in condition and growth.

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305

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310

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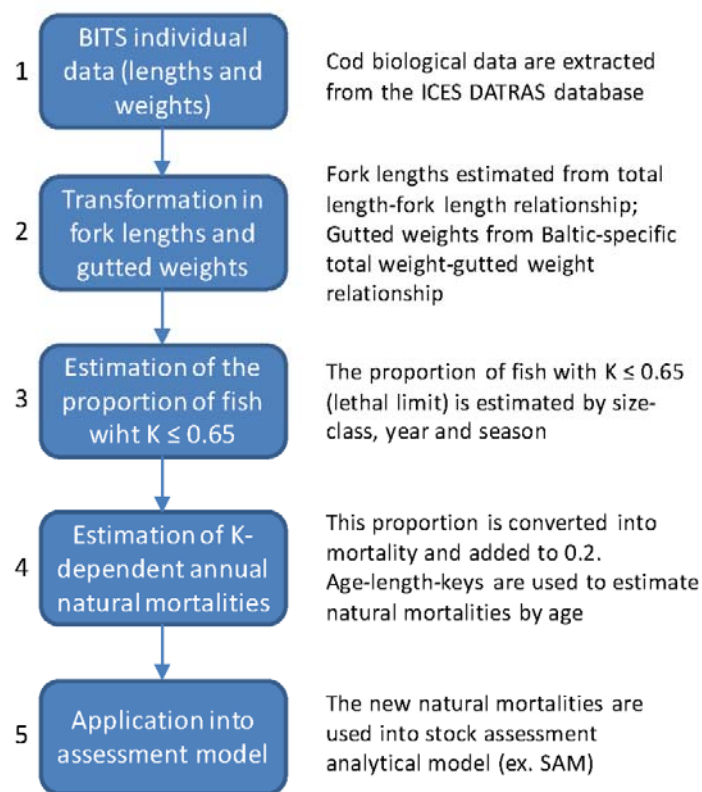
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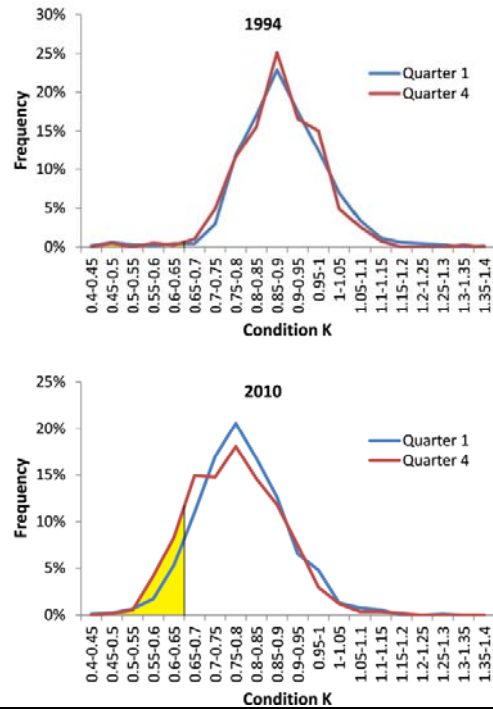
408 **Figures**



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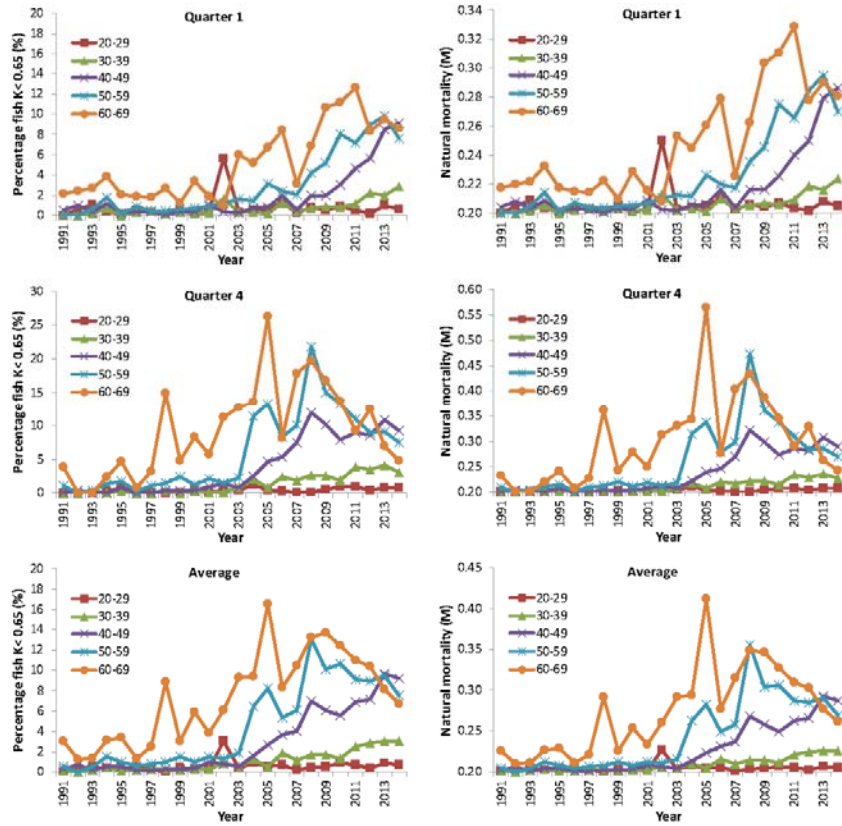
410 Figure 1. Flowchart of the steps used in the estimation of the K-corrected natural mortalities
 411 for inclusion in analytical stock assessment models. In step 4, the translation of natural

412 mortalities by length-classes into natural mortalities by ages is not necessary if a length-
 413 based stock assessment model is used.



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415 Figure 2. Examples of frequency distributions of condition (1994 and 2010) of cod in the size-
 416 class 50-59 cm, by quarter. The shaded area indicates the part of the distribution that is \leq
 417 0.65 and that was assumed to die.

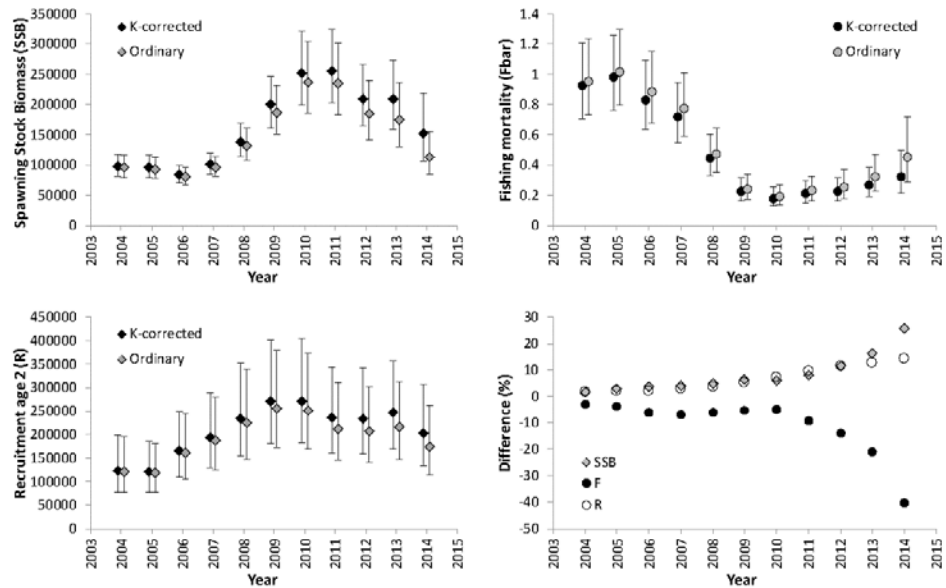


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419 Figure 3. Time-series of condition (left panel) and condition-corrected natural mortality (right
 420 panel) for different size-classes of cod, by quarter. Averages between quarters are also
 421 shown. Note the different scale of the Y-axes.

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Figure 4. Comparisons of Spawning Stock Biomass (SSB), Fishing mortality (F) and Recruitment (R) by year for the SAM runs with constant natural mortality of 0.2 (as regularly used for this stock) and the SAM runs with K-corrected natural mortalities. The symbols represent the final year estimate of 11 runs where we excluded step-by-step one year at a time back to 2004 (i.e. they represent the final year of 11 retrospective runs ending from 2004 to 2014). The relative differences in SSB, F and R using SAM runs with constant natural mortality of 0.2 and the SAM runs with K-corrected natural mortalities are also shown. Bars show 95% confidence intervals.