1 Fishing impact on Kattegat cod, 2007-2017, induced by the Danish and Swedish Bottom trawl fisheries.

By

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1.1 Summary

Temporarily and permanent closed areas were introduced in 2009 to increase the spawning biomass of the Kattegat cod by protecting cod on historically important spawning grounds in the south-eastern Kattegat. This management measure was supplemented with mandatory use of trawls with a lower retention of cod and effort limitations. The Norway lobster fisheries (TR2 fleet segment) are the main demersal fishery in Kattegat and have the largest catches of cod. In this analysis, the reduction in fishing impact on cod is quantified from spatially modelled stock distribution and data on fishing pressure from VMS and gear selection data from the Norway lobster fisheries. The fishing impact (proxy for fishing mortality) on cod from Danish and Swedish fisheries has shown a reduction of around 70% from 2007 to 2017. This reduction in fishing impact is due to a combination of factors: changes in the spatial distribution of effort, use of more selective gears with a lower retention of cod and an overall decrease in effort. In the Danish fisheries, the closed areas and reallocation of effort have reduced the fishing impact on medium and large sized cod. Concurrently the dominant gears have changed from 90 mm trawl to the more selective gears SELTRA 270/300 which also has reduced the fishing impact on cod. The reduction of fishing impact by Swedish fisheries is almost exclusively due to shift to selective gears, i.e., to the standard grid which has very low retention of both large and small cod. For both countries the reduction in fishing impact has been strengthened by an overall reduction in effort. However, the downward trend in effort seems to have stopped and since 2014 there has been an increase in the Danish effort. Further, in 2017 there has been a shift from the standard grid to SELTRA 270/300 in Swedish fisheries which have increased the fishing impact on larger cod.

1.2 Introduction

This analysis was requested by Swedish Ministry for Rural Affairs and Ministry of Foreign Affairs of Denmark to summarize the changes in fishing pressure on cod in Kattegat since the introduction of closed areas in 2009 (Figure 1.2.1).

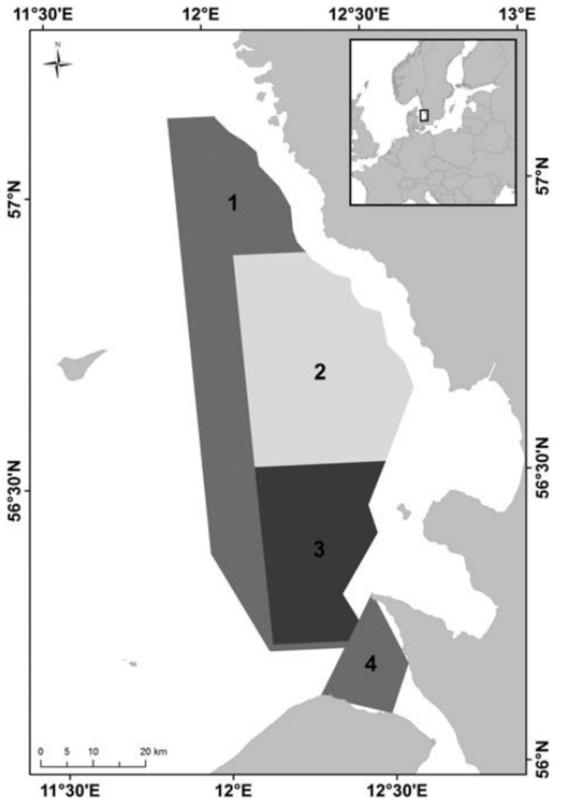

Figure 1.2.1. Present management areas in Kattegat

- **Box 1: seasonally closed area, closed from January 1–March 31, except for fisheries with selective gears;**
- **Box 2: partially closed area, closed for all fisheries in the period from January 1–March 31. Fisheries with selective gears are allowed from April 1–December 31;**
- **Box 3: permanently closed area, closed for all fisheries, including recreational fisheries.**
- **Box 4: seasonally closed area in the Northern Sound, closed from February 1–March 31, except for fisheries with selective gears**.

The stock status of Kattegat cod, ICES Advice 2018

The ICES assessment is considered uncertain, which leads to the ICES TAC advice is based on the trend in estimates biomass and not the absolute values for stock size, fishing mortality and recruitment. The high uncertainty in the ICES assessment is due to unaccounted mortalities caused by (historical) unreported catches, stock mixing and a possible increase in natural mortality from seal predation. The Kattegat area includes a mix of cod spawning in Kattegat and a component that is spawned outside Kattegat. There is an inflow into Kattegat of recruits from the North Sea which return to the North Sea when they mature. The assessment model does not presently take this migration into account which bias (overestimate) the estimate of fishing mortality. Likewise, unaccounted mortality from seal predation may also bias the estimate of fishing mortality.

The ICES stock assessment (Figure 1.2.2) thus presently include all cod in Kattegat and does as such not separate between cod spawned in, or outside Kattegat. The assessment shows that the biomass of cod in Kattegat has declined during the last years after an increase in the period 2010 to 2015. The current stock size is among the lowest observed. The SSB in 2018 mainly consists of the 2016 year class, a portion of which originates outside the Kattegat and might migrate back, making the spawning stock in Kattegat even more susceptible to overexploitation. The increase in SSB in 2013–2015 was due to the strong year classes of 2011 and 2012. SSB since 2015 is progressively declining under the lack of strong incoming year classes.

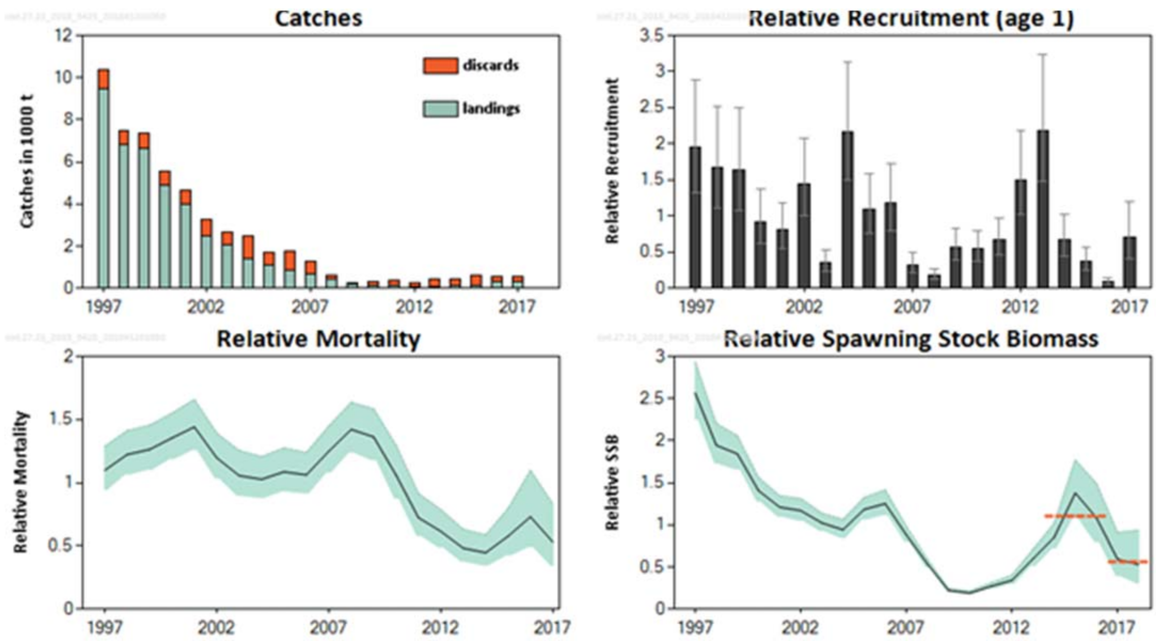

Figure 1.2.2. Summary of the stock assessment for cod in Kattegat. Catches (weights in thousand tonnes). Recruitment, mortality, and SSB are relative to the average of the time-series. Bottom right panel: relative SSB, regarded as an indicator of the recent development of the stock. The dashed lines in the relative SSB plot indicate the average values of the respective years. Relative recruitment, mortality, and SSB have confidence intervals (95%) in the plot. (Source, ICES 2018).

1.3 Overall approach

The fishing impact (proxy for fishing mortality) on cod in Kattegat is estimated as outlined in: “Quantifying relative fishing impact on populations based on spatio-temporal overlap of fishing effort and stock density” (Vinther and Eero, 2013). This approach combines a predicted spatio-temporal distribution of cod obtained from GAM analysis of survey CPUE data with the spatio-temporal distribution of fishing effort obtained from VMS. The fishing impact is calculated from sum of products of spatial stock distribution, spatial effort, and the retention probability of cod sizes for the applied gears:

$$Impact_{size,y,q} = \sum_{lon,lat} \sum_{gear} density_{size,q,lon,lat} * effort_{y,q,gear,lon,lat} * retention_{q,size,gear}$$

Where

size= cod size group (10-24 cm, 25-39 cm and ≥ 40 cm)
y = year
q = quarter of the year
lon = longitude
lat = latitude
gear = gear group
density = spatial distribution of cod
retention = retention likelihood of a cod size group by a gear
effort = fishing effort

This report presents the data input to calculating fishing impact and the resulting development in impact:

- Data and predicted *density* of cod are presented in section 1.4 Spatial stock distribution
- Data for *retention* of cod are presented in section 1.5 Cod retention by gear
- Data for *effort* are presented in section 1.6 VMS and effort data,
- Section 1.7 Fishing impact, presents the resulting *impact*

1.4 Spatial stock distribution

The method to estimate the stock distribution of cod follows the methodology presented in Vinther and Eero, 2013 with use of updated survey time series including first quarter in 2018. The updated analysis uses however the so-called delta-lognormal approach whereas the 2013 study used the negative binomial distribution. The delta-lognormal approach models data into two components: 1) the probability of a zero catch and 2) positive catch rates. The probability of a zero catch was modelled assuming a binomial distribution and the positive catch rates were modelled assuming a log-normal distribution. This approach was chosen as it was tested less sensitive to outliers (very high catch rates in a few hauls) than the former used negative binomial model. Quarter 2 have only data from 49 hauls from one year (2017). For this short time series with rather few observations, the negative binomial model performed best and was used.

Cod density is modelled individually by three size groups; 10-24 cm, 25-39 cm and ≥ 40 cm to reflect the differences in stock distribution of recruits, juveniles and the mature stock.

It is assumed that the spatial effects for each of the sub-models are the same for all years. Models which allows a gradually change in spatial effect were also tested and they resulted in slightly different stock distribution. However, the resulting fishing impacts estimated from the two model types were almost identical, and only the fishing impact estimated from models with fixed spatial effect are shown in this document.

Figure 1.4.1 shows the predicted distribution of cod, given a fixed spatial effect for all years for each combination of quarter and cod size class. It was not possible to predict the distribution for cod smaller than 40 cm in quarter 2, which only has 1 year of data, probably due to a scattered distribution of the smaller cod in combination with the low number of hauls. The densities shown by the colours are all relative to the maximum density of cod within the given map. This means that for situations with a quit uniform spatial distribution (e.g. quarter 1, 10-24 cm) the map shows the orange-yellow (highest density) marking for a rather large area, while situations where cod is concentrated in a rather small area (e.g. quarter 2, 40- cm) the orange-yellow marking is just used for rather limited area. As the scale for the coloration is different between maps the proportions of the stock number inside and outside the boxes are also shown. For example, 74 % of the 10-24 cm cod in quarter 1 is within area "b0" (outside the management boxes).

The permanently closed area (Box 3, "b3") has a high density and proportion (22 %) of the stock of cod ≥ 40 cm in quarter 1 (spawning period) while the density of this size group in box 3 is lower (4 %- 6 %) in the rest of the year (Figure 1.4.1). Box 2 has a rather high density of cod larger than ≥ 40 cm (18-39%) in all quarters. Cod smaller than 25 cm are generally found outside the management boxes.

The presented stock distributions in Figure 1.4.1 is predicted for 2017. Even though a fixed spatial effect is assumed for the present/absence and the present only models, the two models have each an independent year effect, such that the product of two model predictions will give a variable stock distribution between years (see Figure 1.4.2). Appendix 1 provides a more detailed description of input data, method and results for the spatial distribution of cod.

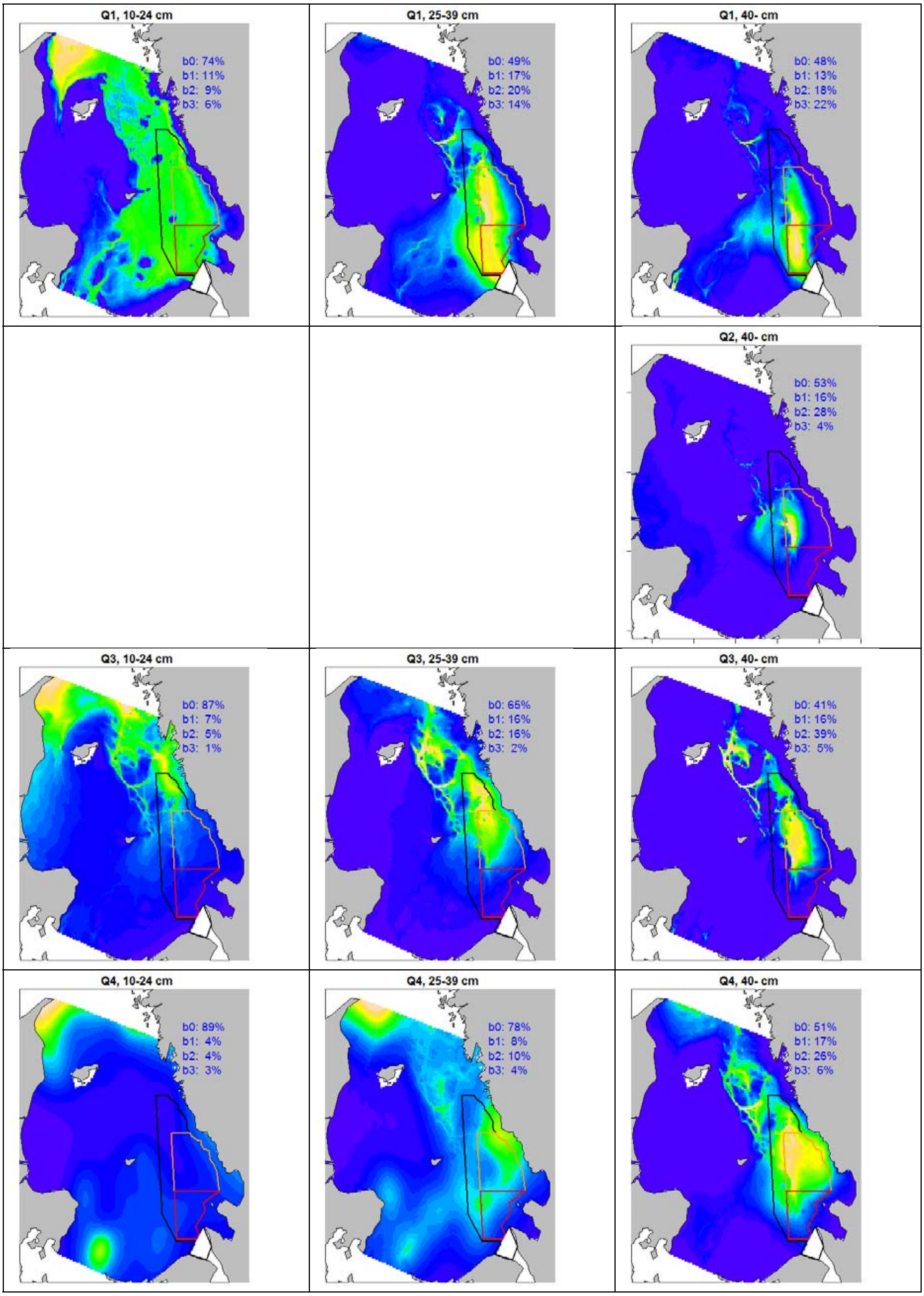

Figure 1.4.1. Predicted distribution of cod by quarter and size in 2017. The densities are scaled individually in each panel. Orange shows the highest, green the medium and blue the lowest density of cod. "b0" presents the proportion of the stock number outside the boxes. b1, b2 and b3 present the proportion in Box 1, 2 and 3, respectively (see Figure 1.2.1 for box definitions).

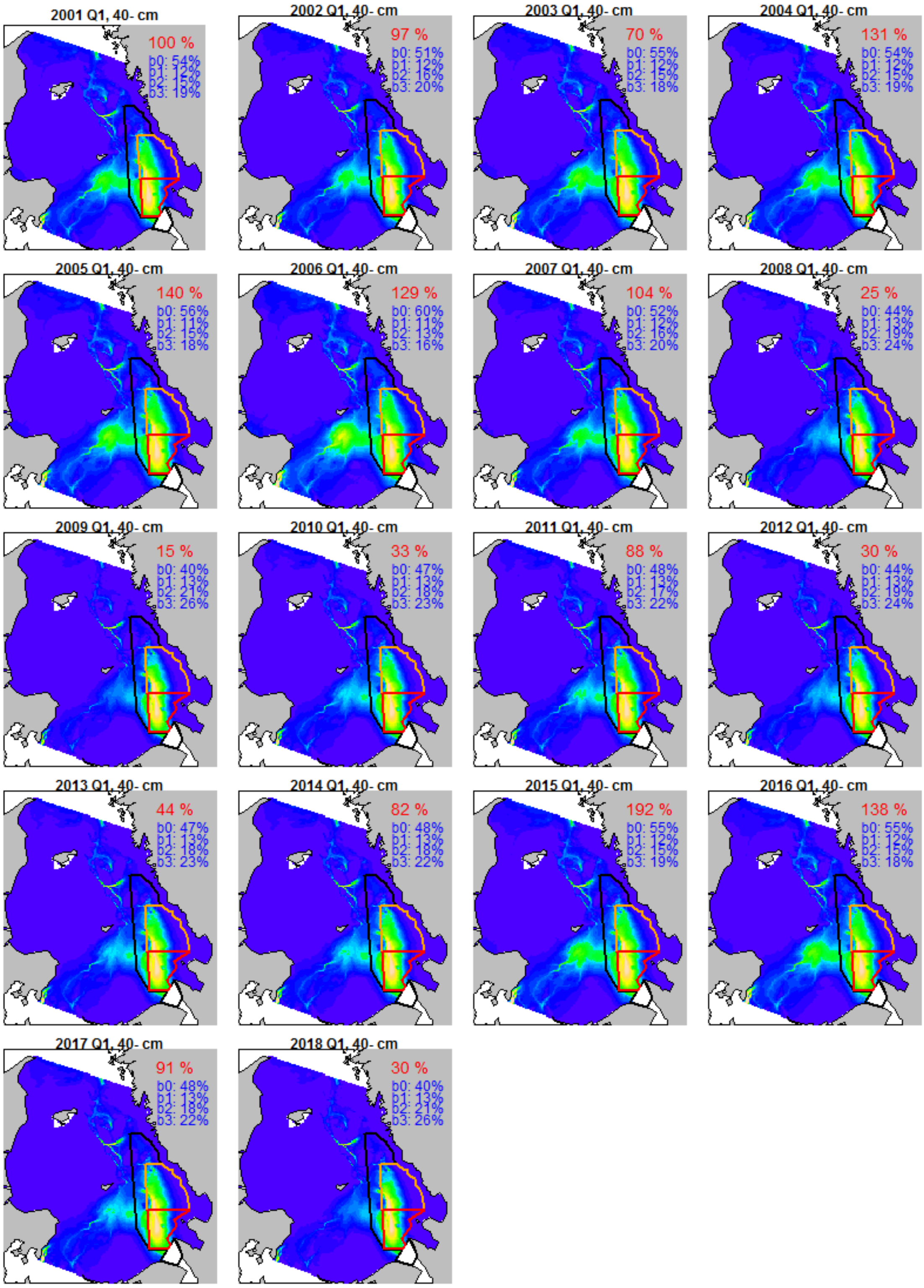

Figure 1.4.2. Predicted distribution of cod by quarter 1 and size ≥ 40 cm. The densities are scaled individually in each panel. Orange shows the highest, green the medium and blue the lowest density of cod. "b0" presents the proportion of the stock number outside the boxes. b1, b2 and b3 present the proportion in Box 1, 2 and 3 respectively. The red number is the total estimated stock numbers relative to stock numbers in 2007.

1.5 Cod retention by gear

A large number of selective gears have been applied by the fisheries in Kattegat, but Danish and Swedish scientists have previously concluded that adequate selective information for the used trawl alternatives is only available for SELTRA 270, 90 mm diamond mesh codend (90DMZ), 90 mm diamond mesh codend with a 120 mm square mesh panel (120SMP) and 70 mm square mesh codend with a 35 mm grid (Standard Grid) (Frandsen et al., 2013). Each gear type applied by the fisheries has been allocated to one of these 4 gear types. However, due to the lack of selectivity data for the SELTRA 300, this gear was assumed to have identical selectivity as SELTRA 270. The mean retention of cod by size class (Table 1.1) was calculated from the selection parameters for each of the 4 gear types and data on size distribution of cod in the sea. Cod larger than 40 cm are retained almost completely by the 90DMC and 120SMP gears, while hardly caught by the Standard Grid. Around two third of the 40+ cm cod are retained by the SELTRA270. For the smallest size group (10-24 cm) a rather small proportion is retained by all the gear types, but the 90DMZ and 120SMP gears have the highest retention.

Selection experiments conducted in 2017 (Valentinsson and Wernbo, 2018) comparing the selectivity of three different cod ends (120 mm diagonal, SELTRA 270 and SELTRA 300 as rigged by Swedish vessels, with floats and chains to increase SELTRA panel height) have provided updated information on the cod retention. The experiments showed that the SELTRA 270 and SELTRA 300 are very different in terms of cod selectivity, an example is that SELTRA 270 caught over 6 times more cod <30 cm. SELTRA 270 caught significantly more cod up to 68 cm. These results have not been taking into account in the present analysis where it assumed that selection is the same for SELTRA 270 and SELTRA 300, as the new data did not provide sufficient data to construct an absolute selection curves needed for this analysis.

Also important is the fact that the applied retention data are derived from experiments with a known configuration of the escape window and cod-end. However, the actual rigging of the trawl during commercial fishery may be different which hugely influence the selection parameters (e.g. Krag et al., 2008; Krag et al., 2016; and Valentinsson and Wernbo, 2018); most likely with a higher retention of cod in the commercial fishery than observed during the experiments.

Table 1.1. Mean retention (in number cod retained out of 1000 cod entering the gear) by cod size class, quarter of the year and gear, based on the selection property of the individual gear and mean size of cod within the size class derived from size distribution from surveys.

	Gear	10-24 cm cod	25-39-cm cod	40+ cm cod
Quarter 1	90DMC	185	809	994
	120SMP	160	647	981
	SELTRA270	47	405	685
	Standard Grid	63	116	1
Quarter 3	90DMC	134	793	994
	120SMP	121	625	981
	SELTRA270	34	388	685
	Standard Grid	46	128	1
Quarter 4	90DMC	66	822	994
	120SMP	88	667	979
	SELTRA270	17	420	670
	Standard Grid	19	106	1

1.6 VMS and effort data

Realised fishing effort from the TR2 fleet segment (and also the OTTER segment by Sweden) calculated from hourly VMS records (classified as fishing activity) and engine power of the individual vessels show an overall decline since 2007 for both countries (Figure 1.6.1). The general decline for both countries is confirmed by the reported nominal effort (kW days) (Figure 1.6.2). However, the nominal effort indicates an increase in 2016 for both countries, possibly due the changed management.

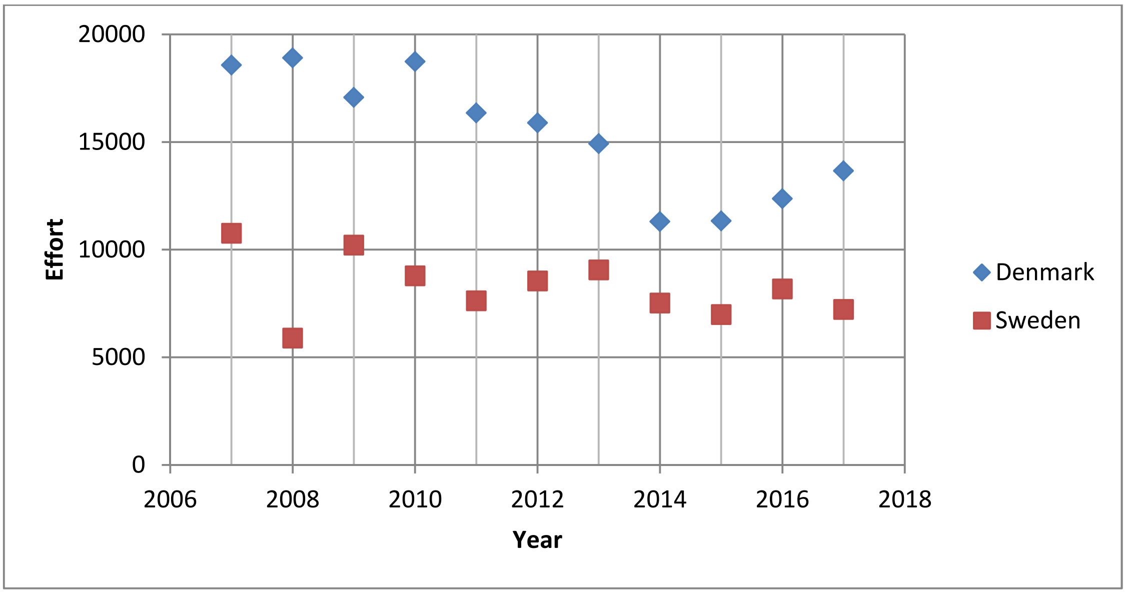

Figure 1.6.1. Fishing effort (arbitrary unit ~ no of hourly VMS fishing pings * kW * scaling) by country and year as used by the analysis. The low Swedish effort in 2008 is due to faults in the VMS database.

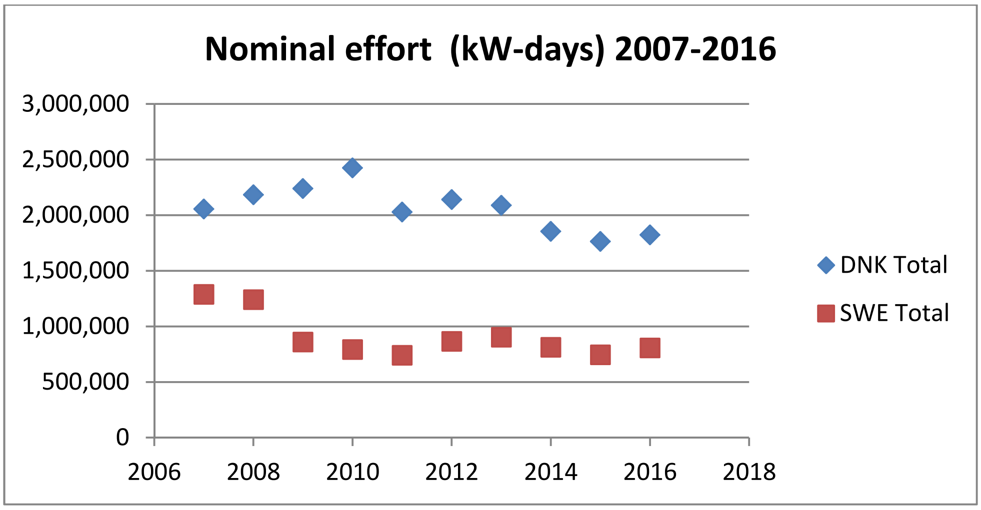

Figure 1.6.2. Nominal fishing effort (kW * days) 2007-2016 as reported to STECF for all vessels. Effort data on all TR2 gears in 3as (Kattegat) from 2003-2017, including gears with selection devices, e.g., the Swedish Nephrops grid. Data for the different vessel length categories (U10M, O10T15M and O15M have been aggregated in the graphs).

The effort distribution from VMS data shows a quite constant spatial distribution for the period after the introduction of the box closures in 2009 (Figure 1.6.3) with the most variable effort between years in Box 2 (Figure 1.6.4). The permanently closed Box 3 had some illegal Danish fishery in 2010.

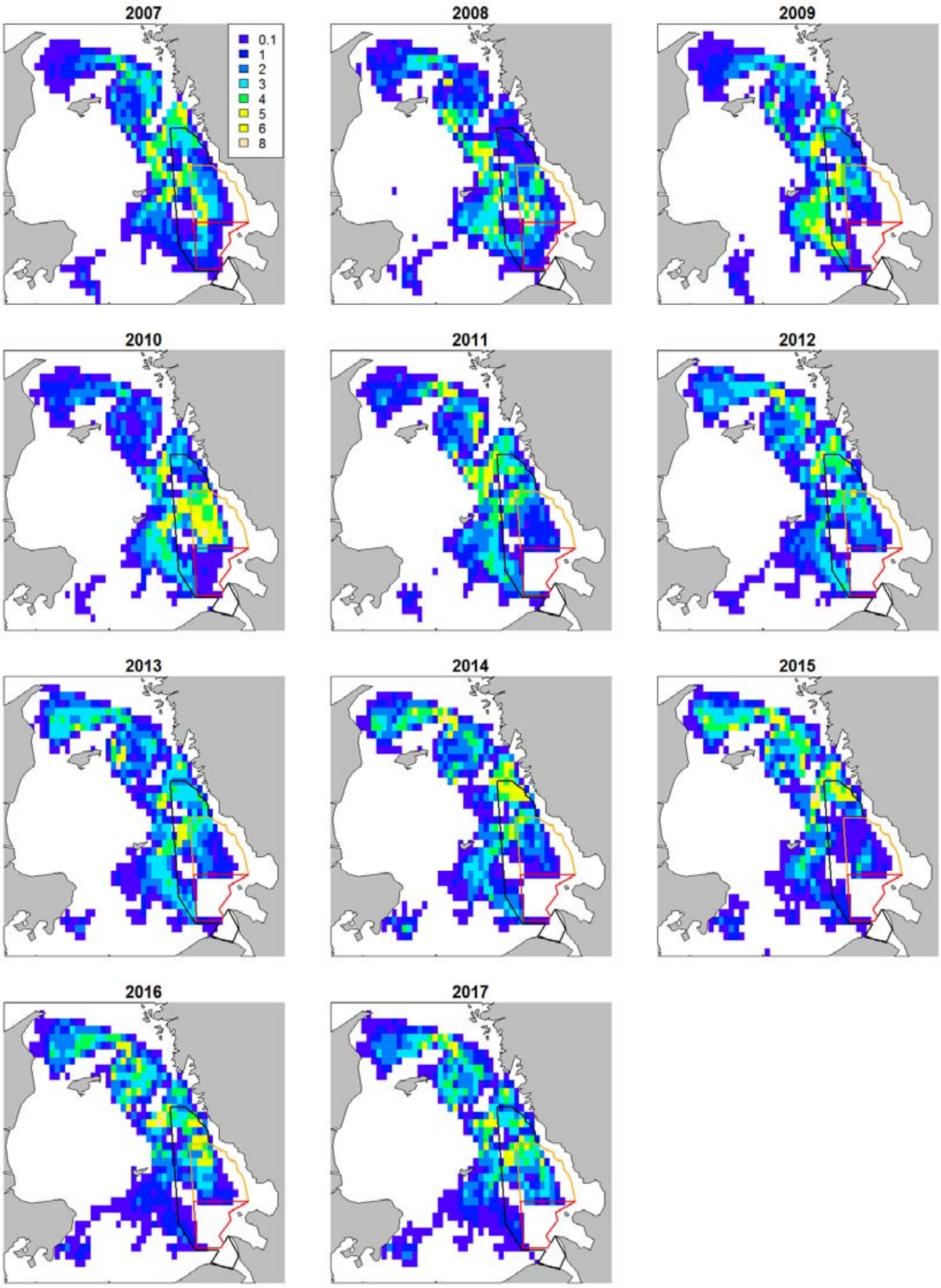

Figure 1.6.3. Distribution of combined Danish and Swedish fishing effort by 0.05*0.05 degree cell. The colour of the cells denotes the proportion of the total effort in ‰ in the cell in the particular year. Cells with less than 0.1 ‰ of the total effort have not been included. Please note that data 2007-2011 include the distribution of vessels ≥ 15 m while data 2012 – 2017 includes vessels ≥ 12 m.

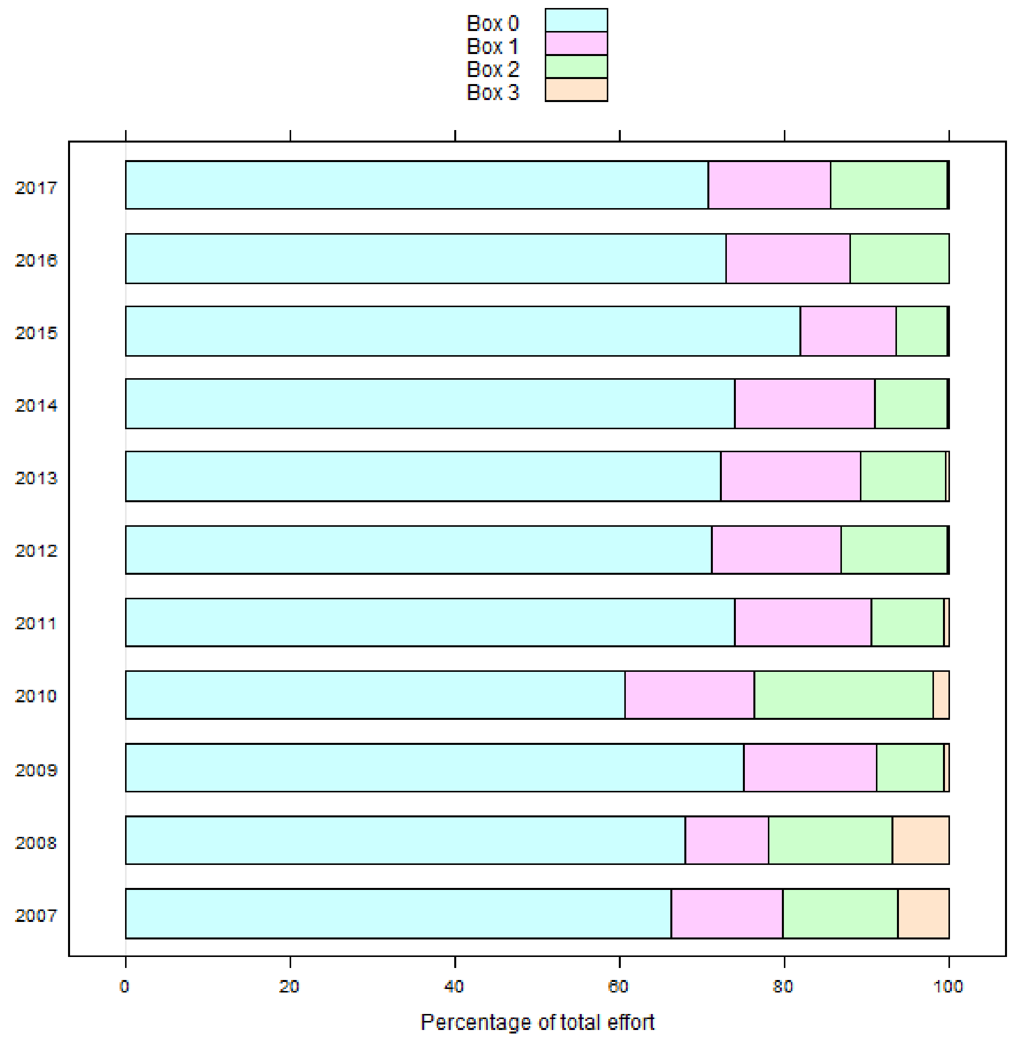

Figure 1.6.4. Proportion of total fishing effort by management boxes for individual years

1.6.1 Effort by gear group

The effort distributions by gear types (after reallocation to the four gear groups for which retention parameters are known) show a clear difference between the Danish (Table 1.2) and the Swedish fisheries (Table 1.3). The Standard Grid has hardly been used in the Danish fisheries. For 2010-2016 the Swedish fisheries used the Standard Grid for around 60% of the effort, however, following the removal of the effort regulation in 2017, the use of Standard Grid in Swedish fishery decreased from 61 to 40 % in 2017. SELTRA gears have been the dominating (>90% of effort) gear in the Danish fisheries for the last five years, while the proportion of SELTRA gears used by the Swedish fisheries has increased from 6% in 2013 to 57% in 2017 as the standard 90 mm gear was prohibited in 2016. The 90 mm with 120 SMP is not used by Swedish vessels.

Table 1.2. Distribution (percentage of total annual effort) of effort by gear group and year in the Danish fisheries. Some mis-recordings of the use of Standard Grid and, experimental fisheries using Standard Grid and VMS records without information on gear type have been allocated to the 120SMP gear type. The category SELTRA 270 covers both SELTRA 270 and SELTRA 300.

Year	90 mm with120 mm square mesh panel (120SMP)	Standard 90 mm (90DMZ)	SELTRA 270
2007		100.0	
2008	90.7	9.3	
2009	94.9		5.1
2010	79.4		20.6
2011	33.1		66.9
2012	7.7		92.3
2013	6.1		93.9
2014	4.0		96.0
2015	9.2		90.8
2016	9.9		90.1
2017	9.6		90.4

Table 1.3. Distribution (percentage of total annual effort) of effort by gear group and year in the Swedish fisheries. The category SELTRA 270 covers both SELTRA 270 and SELTRA 300.

Year	Standard 90 mm (90DMZ)	SELTRA 270	Standard Grid
2007	83.2		16.8
2008	78.9		21.1
2009	55.9		44.1
2010	40.5	0.0	59.4
2011	42.2	0.4	57.4
2012	35.6	0.7	63.7
2013	31.5	6.1	62.4
2014	21.1	10.9	68.0
2015	17.0	20.3	62.8
2016	3.8	35.7	60.6
2017	3.3	56.5	40.2

Appendix 3 provides more information on effort by gears used by the Danish and Swedish fisheries. See also section 1.5 for more information on the differences in selectivity for the SELTRA 270 and SELTRA 300 gears.

1.7 Fishing impact

Fishing impact is a proxy for fishing mortality and is calculated as the sum of product of spatial stock density, spatial effort and retention probability of cod sizes for the applied gears.

Fishing impact by the Danish and Swedish fisheries on all cod size groups has decreased considerably in the period 2007-2017 (Figure 1.7.1). Compared with the impact in 2007, the impact in 2017 is reduced by around 70% for both countries (Figure 1.7.2 and Table 1.4). The reduction shows a similar pattern between cod size group with a clear reduction in impact in the period 2007-2014 for all cod sizes followed by an increase in impact since 2014 for cod larger than 25 cm.

1.7.1 Effect of spatial closures, effort limitations and changed gears

The change in impact from one year to the next is due to the changes in total effort, spatial distribution of the effort and the applied gears. Two additional analyses were conducted to analyse the effect on each of these factors.

1) Spatial and gear effects only: It is assumed that the annual efforts have been the same in all years, so the change in the impact is just an effect the closed areas and gear changes. In the calculation of impact, the spatial distribution of effort in a given year remains as observed but the total annual efforts are scaled to be the same in all years.

2) Spatial effects only: Only the effect of changes in the spatial distribution of effort is quantified, by keeping the total effort constant (as in option 1) and assuming that the same gear has been applied in all years and fleet segments. This analysis shows the effects of changes in the spatial overlap of effort and cod densities and thereby whether the fisheries have allocated their effort to areas with lower or higher cod density.

The additional analyses show different results for the Danish (Figure 1.7.3) and Swedish fisheries (Figure 1.7.4). The impact of the spatial effects only (the mid panel, "Spatial effects", in Figure 1.7.3) contribute by around 20% reduction in fishing impact for the medium and larger cod in the period 2007-2017 in the Danish fisheries. This shows that the present Danish fisheries now fish in areas with lower cod densities than before the introduction of the closed areas. The shift to areas with lower cod densities cannot be seen for the Swedish fisheries. When the effect of both area closures and gear changes (but no effort changes) are taken into account the relative impacts in 2017 are similar for the Danish and Swedish fisheries. Both countries have an increase in impact since 2014 for the large cod. This increase for the Swedish fisheries is due to the decrease in the use of sorting grid. The increase in the fishing impact for the Danish fisheries is mainly due to the increase in total effort since 2014.

1.7.2 Discussion

As for all other analyses the results depends on the data used and the assumptions made. The spatial effects used for the modelling stock distribution may not be fixed for all years as assumed in the analysis, but models with a gradual change in spatial effects resulted in an almost identical estimate of fishing impact. This shows that the estimated fishing impact is robust to the choice of model for stock distribution. The change in minimum vessel length from 15 to 12 m in 2012 for mandatory use of VMS may have biased the results, as it was assumed that the smaller vessels had the same species fishing distribution as the ≥ 15 m vessels. Previous analysis showed a small difference in the spatial distribution of the smaller and larger Danish vessels in 2012-2014, but the effect on the estimated fishing impact before 2012 seems limited.

The most critical data and assumption in the analysis are probably the used cod retention estimated for four "standard" gears. These four gears do not fully cover all the gears actually used; the SELTRA 270 parameters have e.g. been applied for the SELTRA 300 gear, which bias the results. New experiments (Valentinsson and Wernbo, 2018) show a substantial difference in the selection for the two gears. This means that the decrease in impact might have underestimated, mainly in box 2, and in box 1 during quarter 1 where SELTRA 300 is required. Also important is the fact that retention data are derived from experiments with a known configuration of the escape window and cod-end. However, the actual rigging of the trawl during commercial fishery may be different which influence the selection parameters (e.g. Krag et al., 2008; Krag et al., 2016; and Valentinsson and Wernbo, 2018); most likely with a higher retention of cod in the commercial fishery than observed during the experiments. These issues may have overestimated the reduction in fishing impact due to the change to SELTRA gears.

1.7.3 Conclusion

The present fishing impact on cod has been reduced with around 70% compared to the fishing impact in 2007. The impact reduction is due to a combination of factors: changes in spatial effort distribution, use of more selective gears and an overall decrease in effort. It is not possible to fully separate the effects on the impact from each of these factors as they are linked, e.g. changes of gears may have occurred to get access to fishing grounds that would otherwise be closed. Some observations should nevertheless be commented upon. Introduction of the closed areas and reallocation of effort have reduced the fishing impact on medium and large sized cod in the Danish fisheries. Concurrently the dominant gears have changed from 90 mm trawl with 90DMZ/120SMP to the more selective gears SELTRA 270/300 which also has reduced the fishing impact on cod. The reduction of fishing impact by Swedish fisheries is almost exclusively due to shift to selective gears, i.e., to the standard grid which has very low retention of both large and small cod. For both countries the reduction in fishing impact has been strengthened by an overall reduction in effort. However, the downward trend in effort seems to have stopped and there has since 2014 been an increase in the Danish effort. Further in 2017 the Swedish fisheries shifted from the standard grid to SELTRA 270/300 which have increased the fishing impact on larger cod

The management objective of the closed areas is to reduce mortality of cod and to rebuild the stock. Cod is mainly taken as bycatch in the Norway lobster fishery. This implies that the mortality of the stock is strongly correlated with the effort directed to the Norway lobster fishery. The effort regulation system is no longer present and the Norway lobster TAC has increased substantially in recent years. This might lead to an increase effort in the Norway lobster fishery and therefore also an increase the fishing mortality for cod. Kattegat cod will be under the landing obligation from 2019, which may trigger shifts to gear with a lower retention of cod, provided adequate enforcement of the landing obligation. Use of gears with an effective and stable selectivity (i.e. sorting grid) will reduced catches of unwanted cod more than the use of SELTRA gears. Scenarios of different management measures within the closed areas were explored in 2014 (Hjelm et al. 2014). Effective scenarios to minimize fishing impact on cod were e.g. to only allow sorting grid in box 2. Less restrictive access to box 3 outside the spawning period also reduced fishing impact.

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Table 1.4 Relative fishing impact by cod size group and year totally and by country.

Denmark and Sweden

Year \ Size	[10,25)	[25,40)	[40,150)
2007	100	100	100
2008	81	79	89
2009	82	75	74
2010	79	63	83
2011	47	46	47
2012	36	38	43
2013	34	35	33
2014	27	24	22
2015	29	25	23
2016	31	33	30
2017	24	31	40

Denmark

Year \ Size	[10,25)	[25,40)	[40,150)
2007	100	100	100
2008	100	87	99
2009	88	72	69
2010	97	72	105
2011	48	47	51
2012	30	37	46
2013	28	32	34
2014	22	23	25
2015	26	25	24
2016	30	31	31
2017	25	31	39

Sweden

Year \ Size	[10,25)	[25,40)	[40,150)
2007	100	100	100
2008	52	65	69
2009	73	80	84
2010	54	48	42
2011	44	43	40
2012	44	39	36
2013	43	40	32
2014	34	26	17
2015	33	24	20
2016	34	35	29
2017	22	31	41

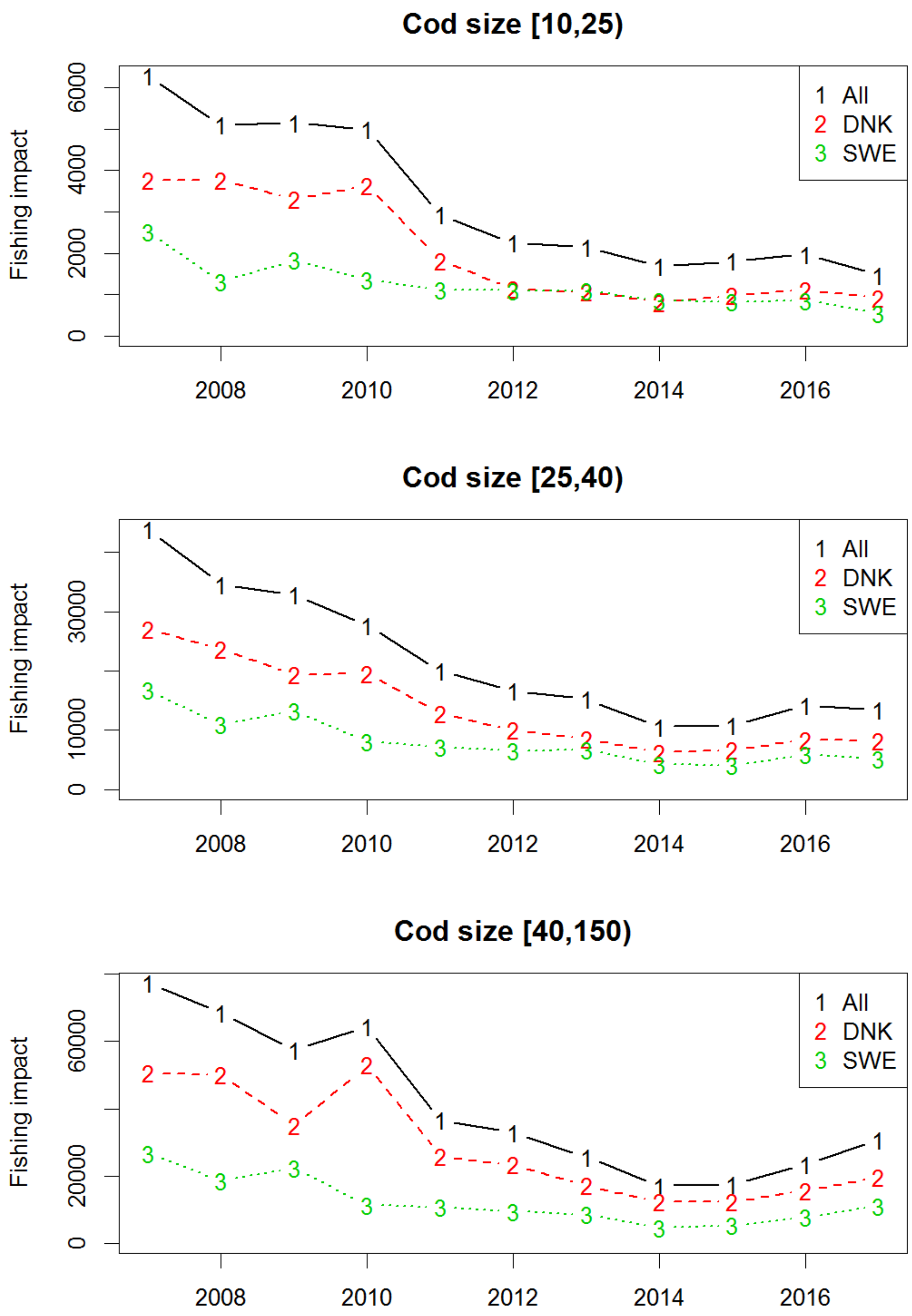

Figure 1.7.1 Absolute fishing impact (arbitrary unit) by cod size group and country.

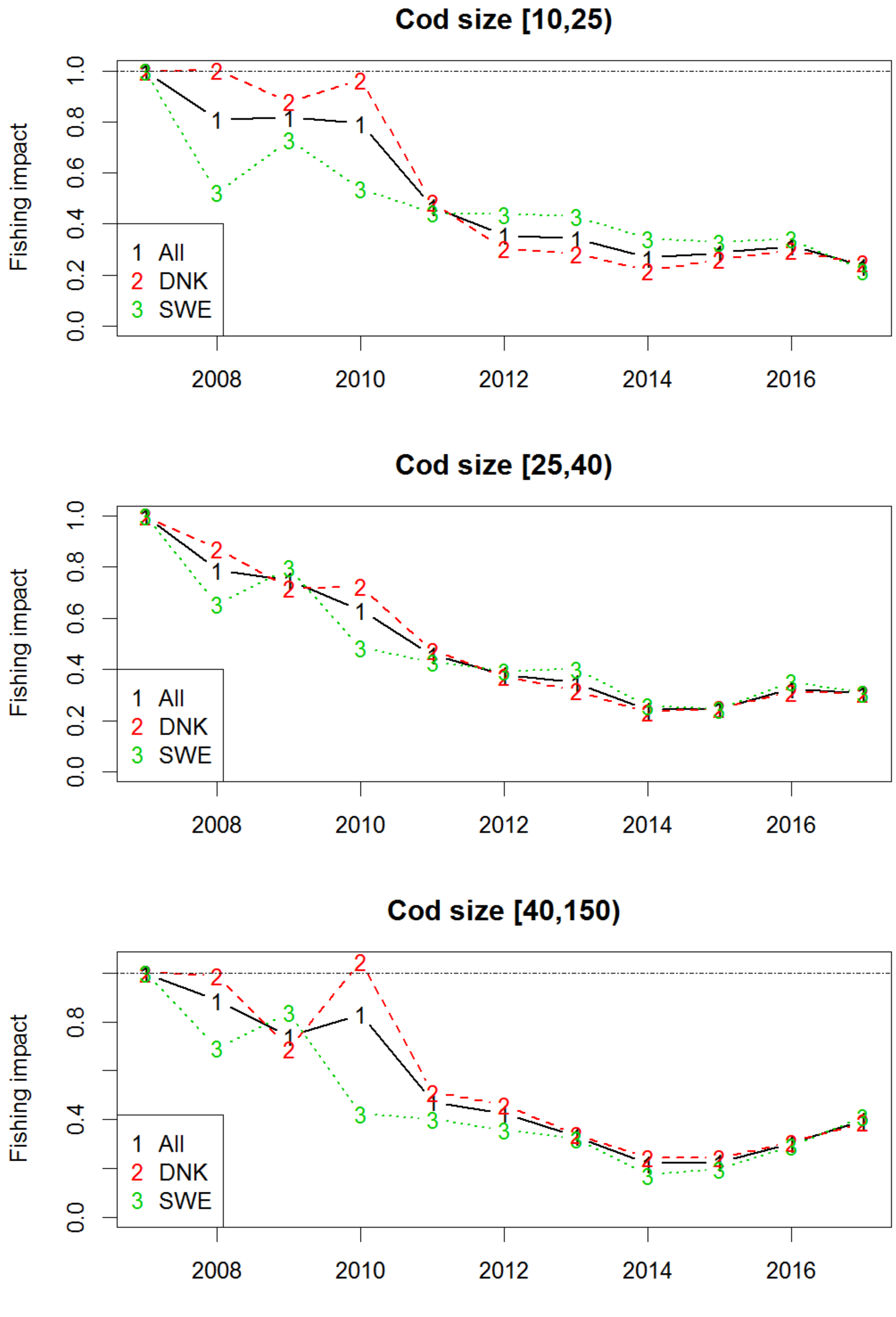

Figure 1.7.2. Relative fishing impact by cod size group and country.

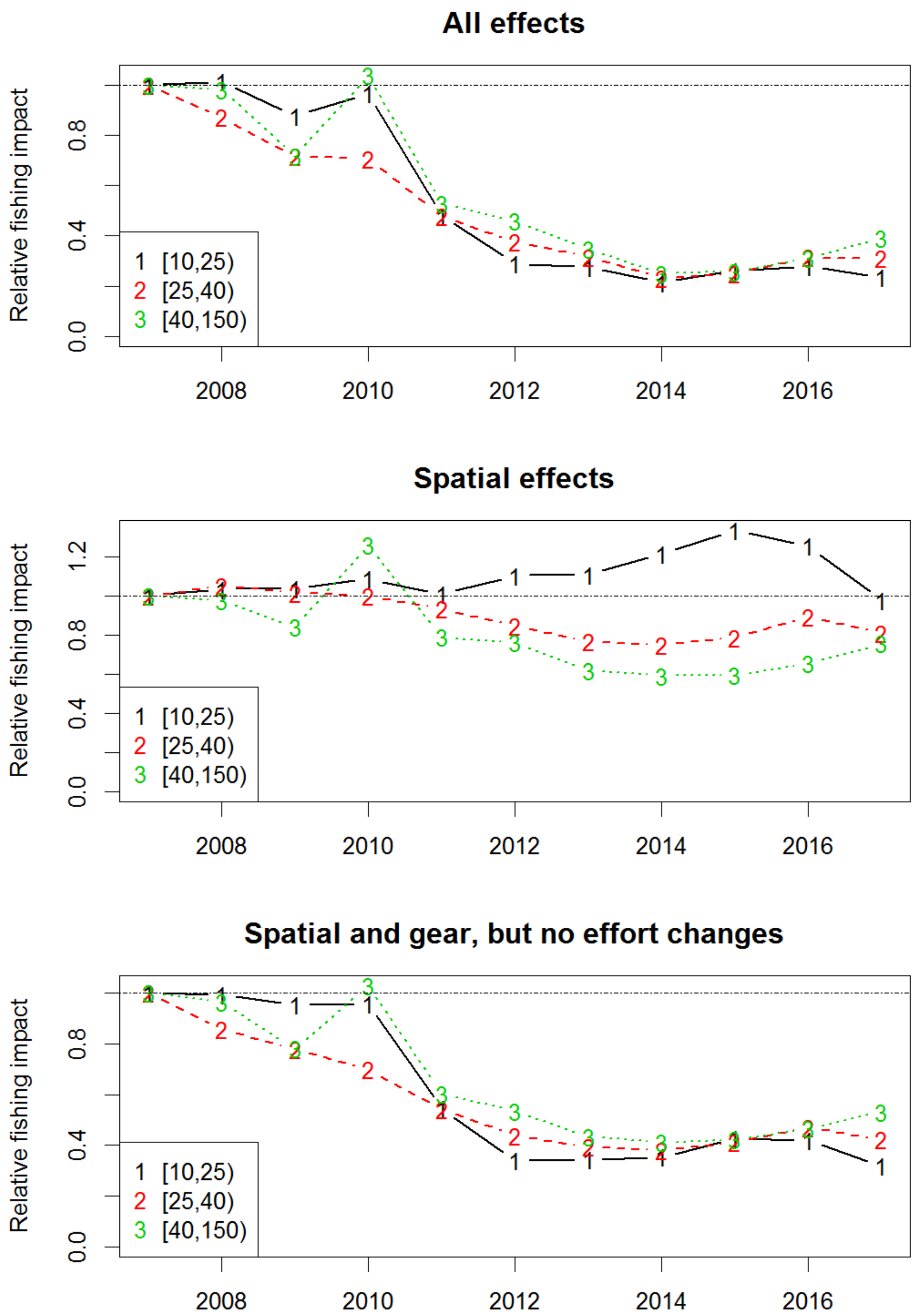

Figure 1.7.3. Additional analysis of Danish fisheries. Relative fishing impact by cod size group, for (top) all effects, (mid) effect of box closures only and (bottom) box closures and gear changes.

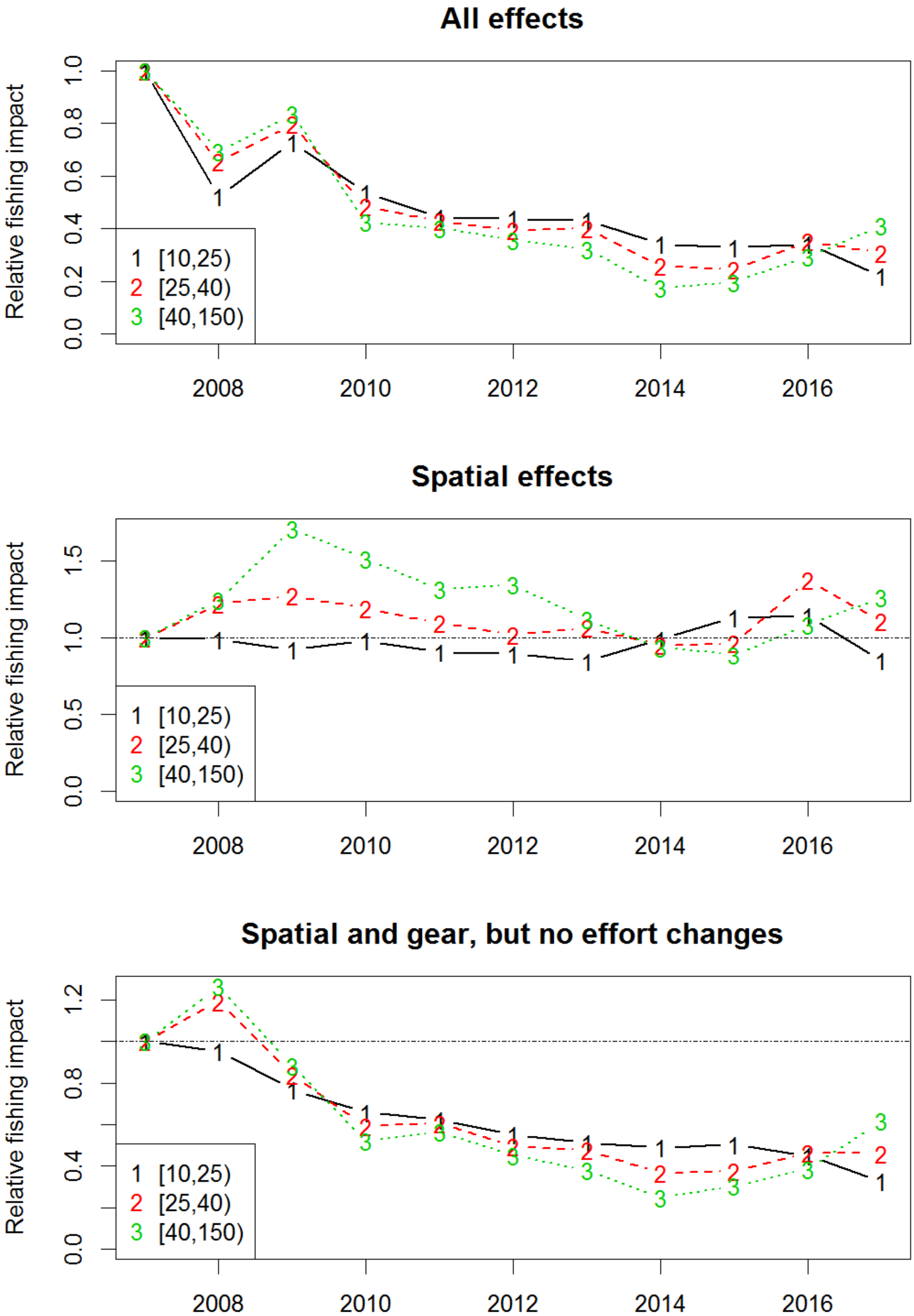

Figure 1.7.4. Additional analysis of Swedish fisheries. Relative fishing impact by cod size group, for (top) all effects, (mid) effect of box closures only and (bottom) box closures and gear changes.