Evaluation of a multi-annual plan including an index based HCR for North Sea horse mackerel

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Summary

For most pelagic fish stocks that are exploited in EU waters, long term management plans are established and used for TAC setting. North Sea horse mackerel was classified by ICES as a data-limited stock (DLS) in category 5 with only landings data available in 2012. This led to the advice for 2013 being a TAC which represented a reduction of 20% of recent landings as a precautionary measure. In response, the main stakeholder in the fishery - the Dutch Pelagic Freezer-trawler Association (PFA) - sought collaboration with IMARES to develop a multi-annual plan for this stock. The plan should specify a rationale for establishing TACs through a Harvest Control Rules (HCR) and it should stipulate how the stock could be 'moved up the ladder' of the DLS categories; ultimately aiming to progress it to become a data rich (category 1) stock in the medium term.

As a DLS, no stock assessment has previously been adopted as a basis for advice for North Sea horse mackerel. In recent years, some explorative work on data availability for the stock has been done by the ICES Working Group on Widely Distributed Stocks (WGWIDE), and this work has been taken further in this report to produce two potential indices of stock size from the IBTS Q3 survey data. A thorough analysis of the IBTS data for North Sea horse mackerel is also presented.

A modelling framework was developed (the JAXass model) to obtain plausible estimates of stock size using the indices created from the IBTS data. There are numerous difficulties fitting an assessment model for this stock: unclear stock boundaries, difficulty aging horse mackerel, lack of strong cohort signals in the catch at age data, no targeted survey of abundance for North Sea horse mackerel, and the available survey data not covering one of the main fishing grounds for the stock (ICES Subarea VIId). In addition there are some conflicting signals between the catch and index data, especially since the mid-2000s. Hence no single 'best' assessment model has been provided. Rather a suite of plausible models are used together to test the robustness of the stock to potential future management options.
Fishing mortality reference point values were calculated by running long term projections at varying levels of F. FMSY (the fishing mortality providing the maximum yield at equilibrium) is estimated to be in the range 0.08-0.24, depending on the choice of stock recruit relationship. A more precautionary and better estimated robust proxy for FMSY is proposed: F35 (the fishing mortality that leads to SSB at 35% of virgin biomass at equilibrium). Values for F35 range from 0.1-0.14 depending on the choice of stock-recruit relationship.

The available data suggest that the North Sea horse mackerel stock is currently at a low biomass in relation to levels in the late 1990s. Recent IBTS surveys have had a high proportion of 0 hauls and low CPUEs. Alternative methods of calculating the index from the raw data (e.g. delta-lognormal method, GLM analysis or simple mean CPUE of all hauls) indicate that the stock is near the lowest level observed. As a result, all exploratory assessment models fit to these data estimate that current SSB is near the lowest observed. Fishing mortality has been above fishing mortality levels suggested for Fmsy (proxies), especially in the recent past and a reduction in catches in the short term is therefore required to allow for recovery of the stock.

The special request sent to ICES asked "to assess whether the proposal as presented in Appendix A is precautionary and if it will deliver Fmsy by 2015 or 2020 at the latest". It was decided at the WKHOMMP meeting that with simulations including a constant catch or a constant F, the focus of the evaluations should rather be on what level the catch could be in the short term in order to reverse the declining trend in the stock than on the performance of the HCRs. To this end, the following procedure was followed: 1. Scenarios of constant catch and constant F were examined to see what level of catch or F would allow for recovery of the stock in the short term. 2. On the basis of these runs, viable short term management options are presented. 3. An initial examination of the potential HCR options is also presented, but to allow for a meaningful comparison of these some stock recovery is required first.
HCR performance statistics were tailored to short term considerations to give an idea of the short term prospects for the fishery and the short term recovery of the stock (by 2020). A recovery of the stock

above SSB2012 (lowest observed, candidate for Blim) is considered the first priority. This recovery is unlikely by 2015, but should be expected at least by 2020. A re-evaluation of potential HCRs looking at longer term management considerations should be undertaken in 3-5 years, unless anything changes in our understanding of the stock in the meantime that would require a re-evaluation of management options.

In terms of providing an estimation of what level of catch the stock could take in the short term, the MSE results are highly sensitive to the choice of stock-recruit relationship (SRR). However, regardless of the choice of SRR, the results from the exploratory assessment model runs and the evaluation of expected future performance of the stock are rather pessimistic. Depending on the SSR scenario (segRick or decLim), the suggested level of catch in the next few years which could allow for a reversal in the declining trend in SSB and bring SSB to above the SSB2012 level ranges from 2.5kt to 10kt. Recent catches of this stock have been in the range of 20-25kt, so this represents a significant reduction in fishing opportunities.

Determining what levels of TACs will lead to this level of catch is problematic, because of the consistent underutilisation in the TAC observed in recent years due to the absence of the Danish fishery. In order to reduce the fishing opportunities for those fleets who do utilise their quota not more drastically than necessary, this underutilisation could be taken into account when establishing the level of the TAC. In addition, a reduction in TAC would naturally only be effective if the TAC would be restrictive to the collective of all countries exploiting the stock, i.e. including Norway, which has caught highly variable but occasionally substantial quantities.

Investigation of how the HCRs performed in comparison to each other in the long term, was investigated as a hypothetical exercise however. The current evaluation results, suggest that the HCR based on a log-linear regression interpretation of the slope with a lambda value of 0.5 performs relatively well. It showed a lower interannual variability than when a 5 year slope was used but still responded most quickly to changes in the trend of the index. This is most likely because, at the time when the declining trend in the SSB starts to reverse and in fact is level for a few years, the 3-year slope HCR keeps the TAC also stable, while the 5-year HCR continues longer with declines, after which quickly changes to increases again. At the same time it indicated more recovery in SSB than the DLS rule or the HCR including a 20% constraint in TAC change.

There is some anecdotal evidence suggesting that one or more relatively strong year classes may have been produced in recent years in the North Sea: pelagic fishers have reported substantial quantities of juvenile horse mackerel in the Southern North Sea during their fishery, a near shore survey conducted in the 'Voordelta' area by IMARES caught a large number of juvenile horse mackerels in the summer of 2013, and the bycatch quota provided to the Dutch demersal fleet was exhausted approximately mid-year in 2013, which was considered very early in comparison to other years. If these are a true reflection of actual events, then this may lead to a more rapid recovery of the stock than the results of the current study suggest. This should then be measurable in the IBTS survey data in upcoming years, in which case management measures can be revised accordingly.

Generally speaking, any long-term management plan is most effective when its measures apply to all fisheries exploiting the stock and when catches can be identified as originating from that stock with some certainty. Considering the potential of mixing between Western and North Sea horse mackerel occurring in area VIId, better insight in the origin of landings from that area will be a major benefit, if not crucial, for improvement of the quality of future scientific advice and thus management of the North Sea horse mackerel stock. One way of possibly distinguishing between individuals of the two stocks is with the GCxGC-MS (Gas chromatography x Gas chromatography–mass spectrometry). A pilot project aimed at determining whether this technique could be used for distinguishing between Western and North Sea horse mackerel is currently underway.

1 The assignment

For most pelagic fish stocks that are exploited in EU waters, long term management plans are established and used for TAC setting. Such a management plan is lacking for North Sea horse mackerel. No stock assessment has previously been adopted as a basis for advice and as a consequence, ICES advice on catch limits has for over a decade consistently been along the line that catches should not be more than the 1982-1997 average in order to avoid an expansion of the fishery until there would be more information available (ICES 2007). In recent years, some explorative work on data availability for the stock has been done by the ICES Working Group on Widely Distributed Stocks (WGWIDE), which is responsible for assessing the status of the stock and the provision of annual TAC advice.

The Institute for Marine Resources and Ecosystem Studies (IMARES) in the Netherlands was asked by the Dutch pelagic fishing industry (Pelagic Freezer-trawler Association) to prepare a proposal for a multi-annual plan for horse mackerel in the North Sea (see appendix A), which would ensure sustainable management of the stock, as well as identify how improvement of the knowledge base to underpin scientific advice could be improved. In a collaborative process with stakeholders, a proposal was prepared and presented and discussed in the Pelagic RAC meeting early February 2014. It proposes a HCR that should help recover the stock, while in the meantime work on strengthening the knowledge base is conducted and preparation for an evaluation by 2019 at the latest (if necessary leading to amending the plan) is undertaken.

On 14 March 2014, ICES received a special request from the Dutch Ministry of Economic Affairs, Agriculture and Innovation to evaluate the HCR. This request stipulates "to assess whether this proposal is precautionary (does it comply with ICES criteria), and if it will deliver Fmsy by 2015 or 2020 at the latest". The current report presents the results of the collaborative project between IMARES and the PFA, which lead to the proposal of the index-based HCR as well as the results from the evaluation by ICES, which was conducted in preparation to and during a dedicated two day workshop held on 17 and 18 June 2014 in IJmuiden (see appendix B).

2 Background information

Scientific knowledge of the state of the horse mackerel stock in the North Sea has been rather limited. In contrast to, for instance, the Western horse mackerel stock, there has been no established scientific survey for the specific purpose of monitoring stock abundance trends. As a consequence, ICES advice on catch limits has for over a decade consistently been along the line that catches should not be more than the 1982-1997 average in order to avoid an expansion of the fishery until there would be more information available (ICES 2007). The predominant reason for this historic 'lack of attention' for developing a scientific knowledge and management basis for the stock has probably been its relatively minor economic importance to the pelagic fishing industry. Due to a number of circumstantial changes, the improvement of a scientific basis for management has become more relevant in recent years.
One such circumstantial change was a European Council decision on new management area boundaries between the three (Western, Southern and North Sea) horse mackerel stocks, which came into effect on the 1st of January 2010. The management area boundaries previously did not match the biological stock boundaries that ICES utilised for its advice. In addition, the results of a research project (HOMSIR) suggested that a change in the management area boundaries would be appropriate (HOMSIR project, 2003). This particular decision by the European Council, which included a redistribution of quota among EU Member States, had a substantial impact on the operating conditions for fisheries targeting horse mackerel.

Another recent development that impacted the industry's fishing opportunities was the by ICES introduced new approach for the underpinning of Total Allowable Catch (TAC) advice for data limited stocks (DLS) (ICES 2012a and ICES 2012b). ICES was commissioned to develop such a systematic approach by the European Commission in 2011, after which ICES organised a number of workshops – which were open to stakeholder participation – in order to work out the principles and protocols that should operationalise the DLS approach. The main objective for this new DLS approach was to halt the sustenance of exploitation levels for stocks where it is unknown whether these are sustainable. In other words, no longer would roll-over TACs be applied in the absence of reasons to decrease the TAC. It should now become customary to take precautionary action by reducing the TAC if no information is available for action to be taken otherwise. This should both promote more sustainable exploitation levels in stocks for which little information is available as well as stimulate EU Member States to take action in improving the knowledge base for all commercially exploited fish stocks that their fishing industries have stakes in.

In 2012, ICES identified 122 stocks for which no quantitative forecast could be provided. North Sea horse mackerel was classified as a DLS in category 5 with only landings data available . This led to the advice for 2013 being a TAC which represented a reduction of 20% of recent landings as a precautionary measure. In response, the main stakeholder in the fishery - the Dutch Pelagic Freezer-trawler Association (PFA) - sought collaboration with IMARES to develop a multi-annual plan for this stock. The plan should specify a rationale for establishing TACs through a Harvest Control Rules (HCR) and it should stipulate how the stock could be 'moved up the ladder' of the DLS categories; ultimately aiming to progress it to become a data rich (category 1) stock in the medium term.

3 The fishery

3.1 Management of the fishery

In 2009, the European Council decided on new management area boundaries between the three (Western, Southern and North Sea) horse mackerel stocks, which came into effect on the 1st of January 2010. The management area boundaries previously did not match the biological stock boundaries that ICES utilised for its advice. In addition, the results of a research project (HOMSIR) suggested that a change in the management area boundaries would be appropriate (HOMSIR project, 2003). This particular decision by the European Council, which included a redistribution of quota among EU Member States, had a substantial impact on the operating conditions for fisheries targeting horse mackerel.
The Eastern Channel, area VIId, has been an important area for the fisheries. Before 2010, the fisheries conducted there would be limited by quota for the Western horse mackerel stock. Since the TAC for Western horse mackerel was considerably higher than that for North Sea horse mackerel, area VIId provided for successful fishing opportunities. It also meant however, that fishing mortality on the North Sea stock due to catches of North Sea horse mackerel in area VIId, was not effectively managed. The redefinition of management areas resolved this.

The results of the HOMSIR project have been debated in terms of whether they with certainty legitimised a change in management boundaries. It is argued that mixing of both stocks (Western and North Sea) occurs in VIId and that catches there in fact are not solely of the North Sea stock. From an ecological perspective, it is very plausible that the delineation between VIId and VIIe does not coincide with any boundary in the eyes of fish since both areas are very similar in biological and geographical conditions. It is therefore quite likely that mixing indeed occurs. The current management boundary therefore does not *per se* allow for management of the effects of fisheries on the two neighbouring stocks separately, but rather should be viewed as a precautionary management choice which provides protection to the smallest stock that is caught in the mix.

The understanding that mixing may very well occur poses a challenge in the context of establishing a stock assessment and evaluating management measures, since the catch data to be included may be biased. Generally speaking, when catch data are consequently under- or overestimated, this has a scaling effect on the stock assessment results but it does not change the impression on the overall trend in abundance of the stock. When the bias is not consistently of the same magnitude however, e.g. when mixing ratios fluctuate, then the trend in stock abundance may be affected especially when regarded from one year to the next. Considering that it is currently not possible to obtain (annual) estimates of the amount of mixing in the past, the current evaluation assumes zero mixing, which forms a limitation to this study. For future improvement of the knowledge base for management of this stock, it would be valuable if information on mixing would be available. (See also discussion section on a pilot study currently conducted at IMARES aimed at this.)

3.2 Landings by the pelagic fleet

Horse mackerel catches taken in Divisions IVa and IIIa during the first and second quarter of the year and catches in divisions IVb, IVc and VIId (all year) are regarded as part of the North Sea stock. The majority of catches of North Sea horse mackerel in the 1970s and 1980 were taken by the Danish industrial fleet for the purpose of reduction into fishmeal and fish oil. Catches were taken in the fourth quarter mainly in Divisions IVbc and VIId. The 1990s saw a drop in the market value of industrial resources, limited fishing opportunities and steep increases in fuel costs, which lead to decreased efforts by the Danish fleet in catching horse mackerel in the North Sea. In 2001, an individual quota scheme was introduced in Denmark, which resulted in a rapid restructuring of the fleet. Since then, the fleet size was radically reduced to less than 20% compared to the 1980s and Danish North Sea horse mackerel catches have diminished.

Since the late 1990s, an increasing portion of catches has been taken in a directed horse mackerel fishery for human consumption by the Dutch freezer-trawler fleet. Landings by other countries have substantially reduced and in recent years, only Germany and Norway have landed some considerable quantities of horse mackerel from the North Sea area. The Norwegian fishery in recent years appears rather opportunistic in nature, since landings shows large fluctuation between 0 and approximately 10 kilotons (kt) of landings (Figure 3.1).
The opportunistic nature of the fisheries is likely due to the fact that North Sea horse mackerel fishing may involve comparatively long periods of searching time (which may have increased with a reduction in abundance of the stock).

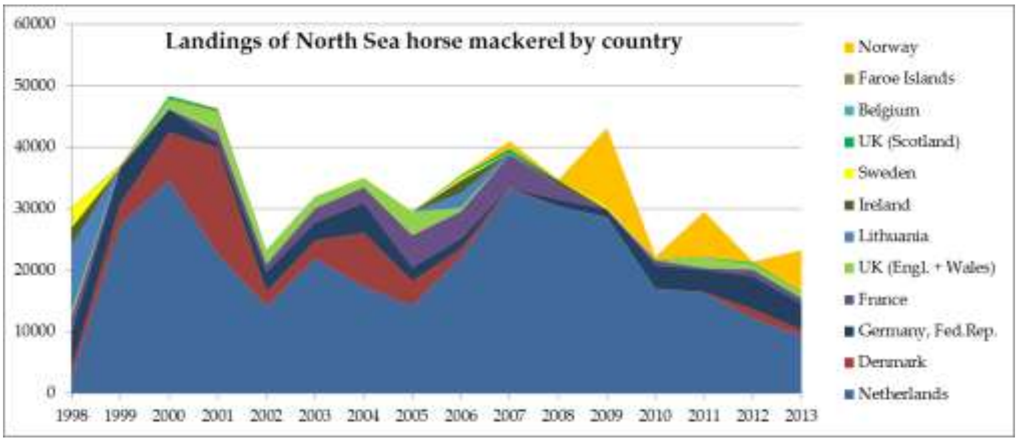

Figure 3.1. North Sea horse mackerel landings per country in the period 1998-2013 (2013 being a preliminary estimate).

Denmark has traded parts of its quota with the Netherlands for fishing opportunities for other species, however because of national arrangements in Denmark, only a limited amount of quota is made available for swaps with other countries. The fact that Denmark is the largest quota holder, but presently only very limitedly consumes its quota and also does not make its quota fully available to other countries through swaps largely explain the consistent underutilisation of the EU quota (approximately 50% in 2010-2013) in recent years (Figure 3.2).

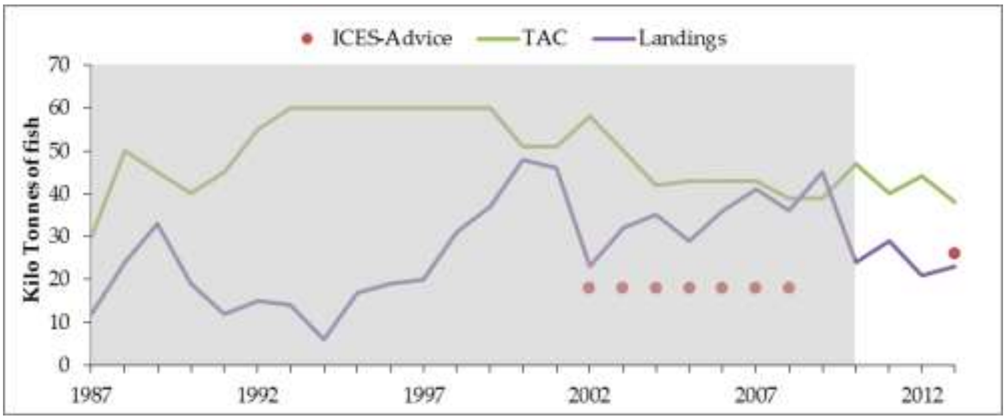

Figure 3.2. TAC, landings and ICES advice from 1987 until 2013. The grey shaded area indicates the period before the alignment of management areas. In this period TAC and landings are difficult to compare, since landings were not in fact restricted by the North Sea TAC, but rather by the Western TAC. Note that the 2013 landings figure is taken from preliminary catch statistics submitted to ICES, which likely presents an overestimate, since catches of area IVa and IIIa of all quarters are included in this preliminary estimate.

The focus area of the fisheries shifted from ICES subdivision IVbc in the 1980s and 1990s to VIId in the 2000s (Figure 3.3). Skippers with years of experience in the horse mackerel fishery, with which a workshop was organised, confirmed that the fishery in the North Sea had proved increasingly difficult over time, while the fishery in VIId remained more successful. One can imagine that the difficulty in finding schools of fish in the North Sea might have led to underutilisation of North Sea horse mackerel quota. This underutilisation was less noticeable in the 2000s and when asked, the skippers confirmed that some misreporting of landings from area VIId into area IVbc has taken place in the past. The spatial shift in the fishery therefore may have occurred earlier than Figure 3.3 suggests. In terms of validity of the catch data included in the assessment and evaluation here, the misreporting itself is assumed not be a major problem since area VIId is regarded as part of the distribution area of North Sea horse mackerel anyway. And so, even though part of the landings may have been registered under the wrong area, they can be considered to still be from the same stock. The skippers also confirmed that there have been no reasons or incentives for misreporting anymore since the management area boundary was revised in 2010, making area VIId part of the North Sea management area. See also Section 2.1.4 for further considerations on spatial aspects of the fisheries and management of the stock.

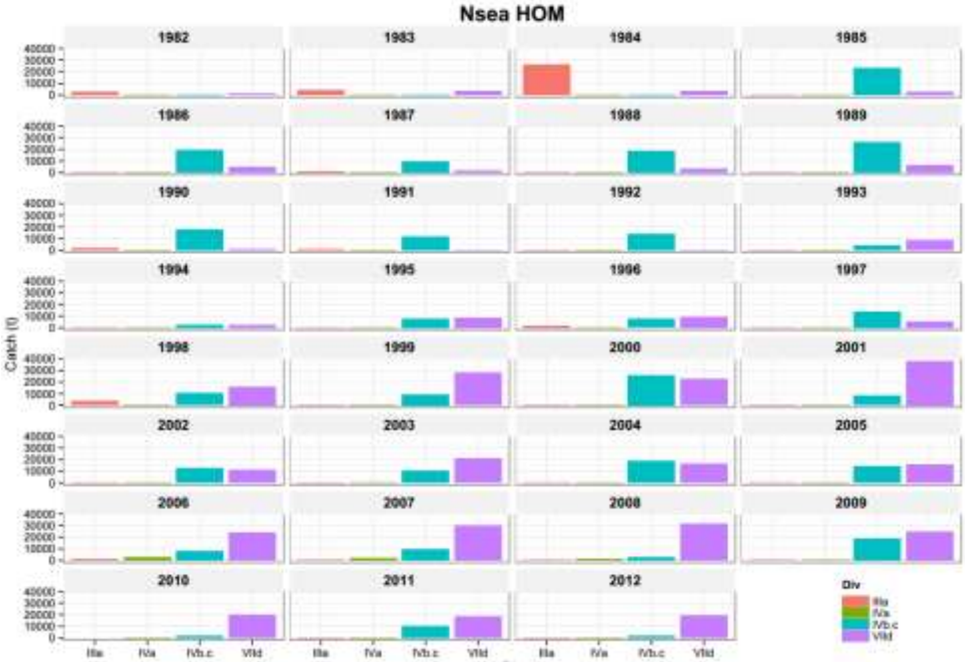

Figure 3.3. North Sea horse mackerel catches by ICES subdivision, showing a shift from area IV to area VIId over time (From: WGWIDE report 2013).

3.3 Discards by the pelagic fleet

Availability of discards data in pelagic fisheries is limited, possibly partly due to low percentages of discards in (Dutch) pelagic fisheries. The Netherlands and Germany conduct monitoring programmes in which catches are sampled on board. For a number of pelagic species, discard estimates are available. The total fractions of horse mackerel catches being discarded in all sampled areas together are very low. For 2011 and 2012, they were estimated as 0% and <1% by Germany and the Netherlands respectively (Overzee et al, 2013). Figure 3.4 shows the length distributions of landings and discards as measured during sampling trips in the Dutch and German monitoring programmes. The authors of this CVO report confirm that the observed discard fractions in 2011 and 2012 were consistent with earlier years.
Since the discards estimates from the Dutch and German programmes are so low, and since these countries are together responsible for approximately 70% of the landings of North Sea horse mackerel (on average over the period 1998-2012), it is considered that the total quantities of discards in the fisheries catching North Sea horse mackerel are negligible and they are thus excluded in the analyses in this report.

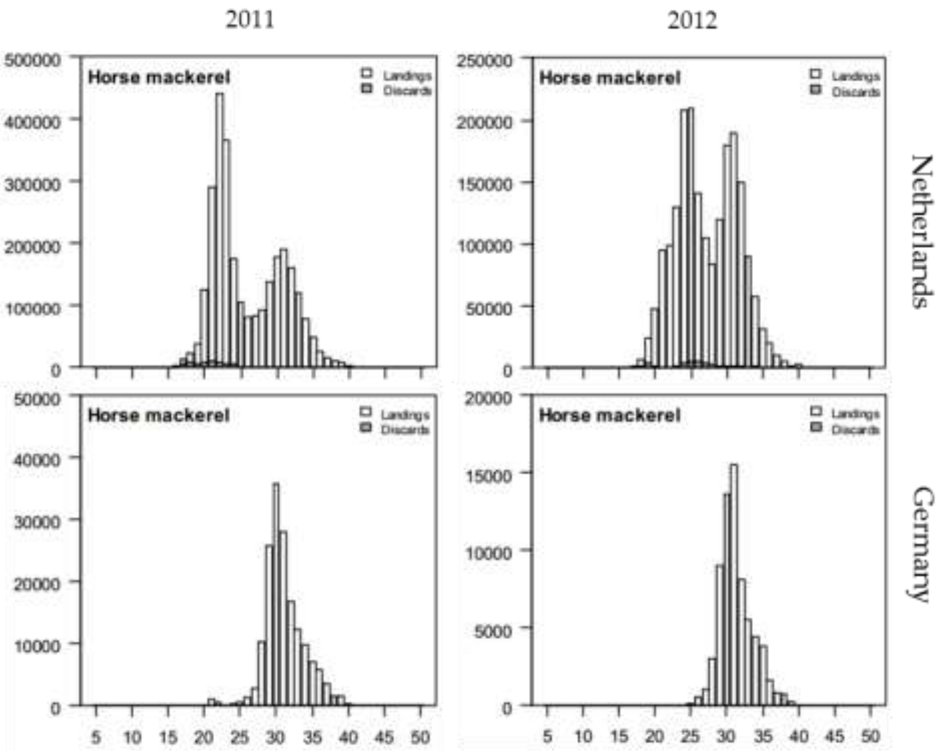

Figure 3.4. Length distributions (numbers of fish per cm length class) of landed and discarded horse mackerel in the Dutch and German pelagic fleet in 2011 and 2012 (from: Overzee et al, 2013).

3.4 Bycatch by demersal fisheries

Horse mackerel are also caught as a bycatch species in demersal beam trawl fisheries. In the Netherlands, the demersal fleet each year receives part of the national quota for horse mackerel as a bycatch quota. Landings by the demersal fleet (beam trawlers, otter trawlers and seines together) have being around 0.3 kt annually on average in the period 1995-2012. In terms of total quantities landed, this fishery is thus unsubstantial (around 1%) and these landings are thus not included in the current study.

4 Assessment models

In order to be able to develop a work bench with which an evaluation could be carried out of specific harvest control rules, some form of an assessment model needed to be developed. A number of options were explored: XSA, A4A and JAXass, a simple statistical catch at age (SCA) model. The final assessment model framework incorporated in the evaluation work bench was written in AD Model Builder (Fournier et al. 2012). All models showed similar trends in stock development over time, not surprising given the limited data available to fit the models to. Only the results of the model that was finally chosen to be used, the JAXass model, are presented in this report[1].

The JAXass model is an extension of the model first created by Sparre at the WGHANSA working group in 2007 (ICES 2007). It is a simple age based model that utilizes available data of catch (total catch and catch proportions at age) and, since the survey data is only length based, and given the difficulty in assigning older fish to distinct age classes based on length at age keys, a single biomass index for the older fish (age 2+). The index, calculated from the raw data using different methods, is compared to the total biomass of age 2+ fish in the stock.

The North Sea horse mackerel stock has not been benchmarked by ICES i.e. there is no agreed assessment model in place to use in the provision of advice. Much work has been done in the last two years that has significantly improved our understand of this stock and provided new information and data that could be used in an assessment. It is also likely that in the short term changes to the assessment methodology and the addition of other useful data will lead to an alternative assessment for this stock. In the interim, the JAXass model can be used to create plausible fits to the currently available data, none of which are proposed as a 'final' assessment, but all of which are based on available data and reasonable assumptions given our current understanding of the stock.

A reference set combining a number of plausible assessment models allows us to test the robustness of proposed index-based HCRs or levels of (constant) catch in the near future, even in the absence of a 'best' assessment model. However, it does not allow the evaluation of assessment-based advice for this stock in a full feedback evaluation (i.e. running an assessment model every year of the projection).

4.1 Catch data

Catch at age data is available since 1995. A considerable number of age samples are available from commercial catches, mostly from the Dutch fleet since they take the majority of the catches (Table 4.1). This age data is provided to ICES, where together with age data from other countries, catch-at-age numbers are computed each year at the WGWIDE group. The most recent catch-at-age table available (from the 2013 WGWIDE meeting) was used in the assessment model.
For comparison, Table 4.1 also includes the available age data from the IBTS survey in two short periods. In order to prepare a survey index selecting only 2-year old fish and older, it was necessary to define a length range consistent with 2+ fish. This was defined using the sampling data available from the commercial catches taken in area IV in the third quarter, since there was more data available than from the IBTS, especially for younger fish (needed to distinguish between 1 and 2-year old fish). The index computation is described further in Section 4.3.

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[1] Considerations on the other models are available upon request.

Table 4.1. Number of age samples from Dutch commercial catches (Market) in the period 1995-2012 and from the IBTS survey (two ad hoc periods).

	N_{trips}	N_{fish}	*Min. age*	*Max. age*	*Mean age*
Market samples					
All quarters; area IVbc and VIId	563	14912	0	31	5.86
All quarters; area IVbc	216	5600	0	25	5.51
Q3; area IVbc and VIId	173	4524	0	24	4.70
Q3; area IVbc	139	3625	0	24	4.98
IBTS samples					
1991-1996; all quarters; area IVbc	n.a.	666	1	39	10.20
1991-1996; Q3; area IVbc	n.a.	298	1	39	8.91
2004-2009; Q3; area IVbc	n.a.	1162	0	32	4.74

The catch data show that the distribution of catches between area IV and area VIId is highly variable, but has in recent times shifted toward more catches being taken in area VIId (Figure 4.1 b). This may partly be due to a change in fishing behavior induced by the change in management areas and quota allocation in 2010 (see section 2.1.4 on the management of the fishery), which has also lead to a sharp decrease in total catches (Figure 4.1 a). In addition, the fluctuations in distribution of the fishery are enhanced by the (in appearance opportunistic) nature of the Norwegian fishery, which in recent years has occasionally taken substantial amounts of catches in area IVa in the first and second quarter of the years, which are assumed to be from North Sea stock origin.

Figure 4.1 d shows a bubble plot of the catch at age matrix (standardised to annual mean). Cohort structure is generally not clearly detectible in the data. This may partly be due to the shifts in distribution of the fishery. In addition, it may partly be due to age reading difficulties, which are a known to be encountered (e.g. Bolle *et al.* 2011). Most clearly detectable is the relatively large 2001 year class, although it is not clearly present in the catch in all years. There are indications that environmental circumstance may be an important factor (possibly stronger than stock size) contributing to spawning success in horse mackerel. This is for example illustrated by the largest year classes (1982 and 2001) observed in the Western stock which incidentally were produced at the lowest observed stock sizes. Since 2001 is considered to have been a relatively strong year class in the Western stock as well, it is plausible that circumstances in the North Sea were similar to those in Western areas and also allowed for relatively high spawning success in the North Sea.

Lastly, potential mixing of fish from the Western and North Sea stock in area VIId in winter may also confuse the cohort signals. For example, the large recruitment in the Western stock may have led to more of these fish being located in the North Sea stock area as age 1 fish in 2002. See further section 7.2.2. in the discussion for a further elaboration on the consequences of potential mixing of the stocks. Figure 4.2 shows log catch curves calculated from the catch at age matrix. These are noisy and at times indicate negative Z estimates. The catch curves generally indicate increasing mortality (Z) over time, however the poor quality of the cohort signals in the data likely make these Z estimates highly uncertain.

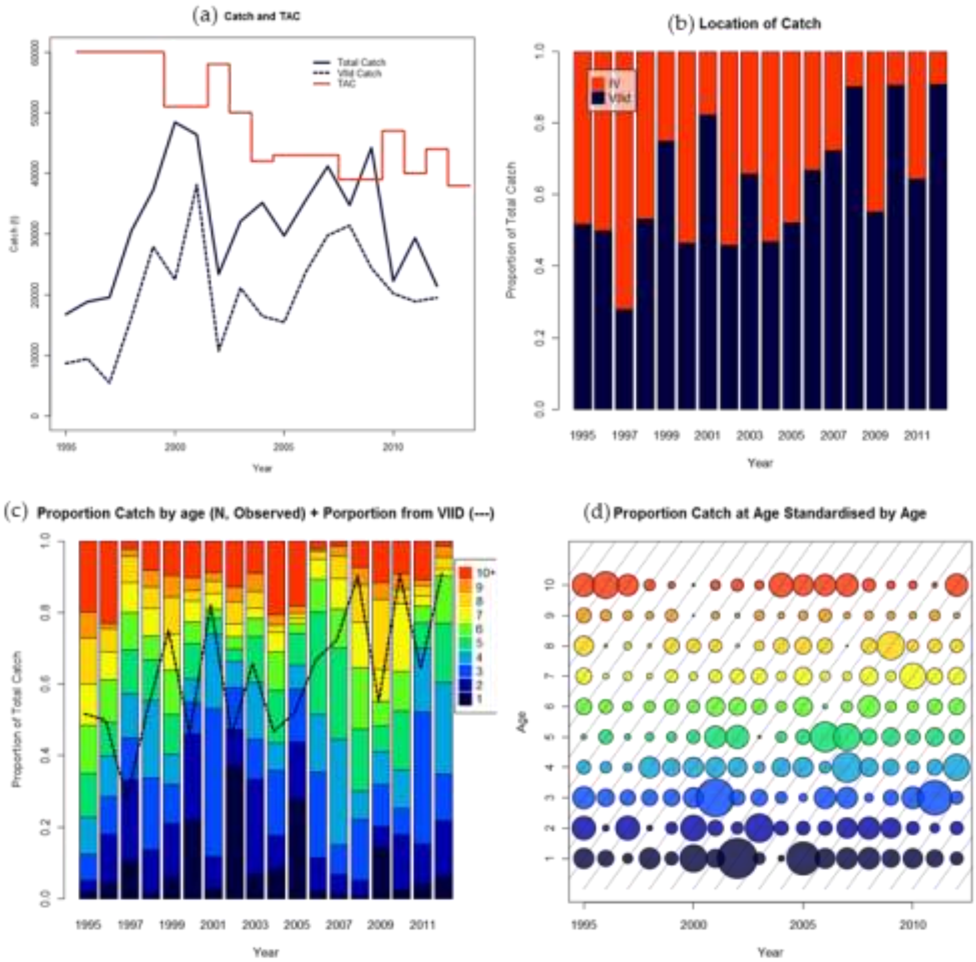

Figure 4.1. (a) Total Catch and TAC; (b) Location of Catch; (c) Age distribution of catch and proportion of catch taken in VIId; (d) standardized proportion at age (divided by year total, then mean proportion by age) Note that age-10 is a plus group.

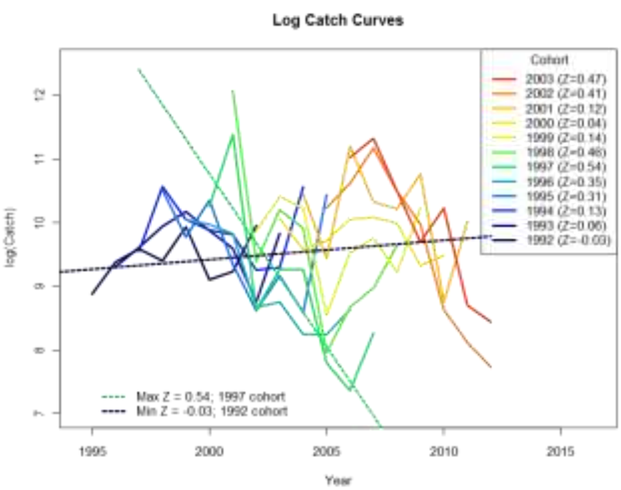

Figure 4.2. Log catch curves (by cohort) with Z values calculated as the negative slope over ages 3-9.

4.2 Biological data

Weight at age

Weight at age data were obtained from commercial catch samples. Figure 4.3 shows that the mean weight at age has remained stable for most ages in the stock, except for perhaps the oldest ages, which may have slightly increased. This may however also be due to relatively few samples and/or ageing error. There are a few year effects detectible, notably in 2001 when all fish age 5 and younger where found to be notably lighter.

Figure 4.3. North Sea horse mackerel mean weight at age (from the catch).

Maturity at age

Since there is no specific information available for the North Sea horse mackerel stock specifically, the maturity ogive used since 1998 in the assessment of the Western horse mackerel stock was used in the assessment and assumed constant over time (Table 4.2). Peak spawning in the North Sea falls in May and June (Macer, 1974), and spawning occurs in the coastal regions of the southern North Sea along the coasts of Belgium, the Netherlands, Germany, and Denmark.

Table 4.2. Constant maturity ogive used in the assessment.

Age:	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10+*
Proportion Mature	0.00	0.05	0.25	0.70	0.95	1.00	1.00	1.00	1.00	1.00

Natural mortality

There are no readily available estimates (or time series) of natural mortality for the North Sea horse mackerel stock. Two options (Table 4.3) were explored by inclusion in the assessment model. The first being the natural mortality assumptions used in the assessment for Western horse mackerel (WhmM). This stock is geographically closest to the North Sea stock and therefore possible better comparable than the Southern stock. It assumes a constant natural mortality rate of 0.15 for all ages and years, which is almost identical to estimates derived from simple maximum age methods to calculate M (results not shown here). The second option explored included the assumptions used in the assessment of the Southern horse mackerel stock (ShmM). This is an age-varying M, highest on the younger ages, decreasing to 0.15 for the older ages. Despite that this stock is geographically further away than the Western stock, predation on younger ages, especially in a more confined area as the North Sea, might be expected to be higher than in a situation like the Western stock where spawning occurs in more open waters, with possibly less threat of predation.

Table 4.3. Two alternative natural mortality at age vectors considered for use in the NS horse mackerel assessment.

Age:	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10+*
WhmM	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
ShmM	**0.6**	**0.4**	**0.3**	**0.2**	0.15	0.15	0.15	0.15	0.15	0.15

4.3 IBTS survey data

There are no surveys conducted specifically aimed at estimating trends in abundance of North Sea horse mackerel. The Western horse mackerel stock is surveyed by means of the egg-survey which captures spawning of the mackerel stock at the same time (since the spawning by these two species largely occur in the same area and season). An egg survey aimed at mackerel occurring in the North Sea is conducted in the North Sea as well, but in this case, the spawning seasons does not co-occur and therefore, this survey cannot be used for North Sea horse mackerel.

In the past, International Bottom Trawl Survey (IBTS) data has been explored on several occasions, and so it was decided to build further on those exercises. The International Bottom Trawl Survey (IBTS) was started in the 1960's as a survey that was directed at juvenile herring and was at that time called the International Young Herring Survey (IYHS). As it was gradually realised that the survey also yielded valuable information for other fish species, such as cod and haddock, and the objectives were broadened and the survey was renamed into the International Young Fish Survey (IYFS). Besides the IYFS, which was carried out in the first quarter, a number of national surveys developed in the 1970's and 1980's that were mainly carried out in the third quarter. In 1990 ICES decided to combine the international and the national surveys into the IBTS. The fishing method and gear (GOV trawl) were further standardized in subsequent years resulting in a fully standardised survey from 1998 onwards (see IBTS manual[2]).
In contemplating whether a bottom trawling survey can be used to survey horse mackerel, it was considered that many pelagic species are in fact frequently found close to the bottom during daytime (which is when the IBTS survey operates) and migrate upwards predominantly during the night they are susceptible to semi-pelagic fishing gear and to bottom trawls (Barange et al. 1998). Eaton et al (1983) argued that horse mackerel of 2 years and older are predominantly demersal in habit. This behaviour of seeking close proximity to the bottom may be more profound in the shallower waters of the North Sea than in deeper waters in the Western area. This vertical migration pattern was also confirmed when speaking to skippers experienced in the horse mackerel fishery during a dedicated workshop held with stakeholder in April 2013. The skippers explained that they conduct their fishery almost exclusively during nighttime, when the fish migrate vertically away from the bottom (and damage to pelagic nets is best avoided).

In 2011, it was decided to use IBTS data in the assessment of Southern horse mackerel (ICES 2012c). This assessment combines the Portuguese and Spanish components of the IBTS in the area although they are carried out with different vessels and slightly different bottom-trawl gears. Rückert et al (2002) argued that the behavior of horse mackerel is more similar to that of whiting than mackerel, both showing similar diurnal behavior and are of comparable sizes. Both the IBTS Q1 and Q3 indices are used in the assessment of whiting in the North Sea (ICES, 2013). Similarly, haddock are considered to be

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[2] Manual for the International Bottom Trawl Surveys (IBTS), Revision VII. International Bottom Trawl Survey Working Group, ICES; 2004. p. 51 pp. http://www.ices.dk/datacentre/datras/trawldetails.asp.

semi-demersal and IBTS Q3 survey is used in the assessment of that stock in the North Sea (ICES, 2013). Based on a comparison of IBTS data from 4 quarters in the period 1991-1996, Rückert et al (2002) showed that horse mackerel catches in the IBTS were most abundant in the third quarter of the year (Figure 4.4).

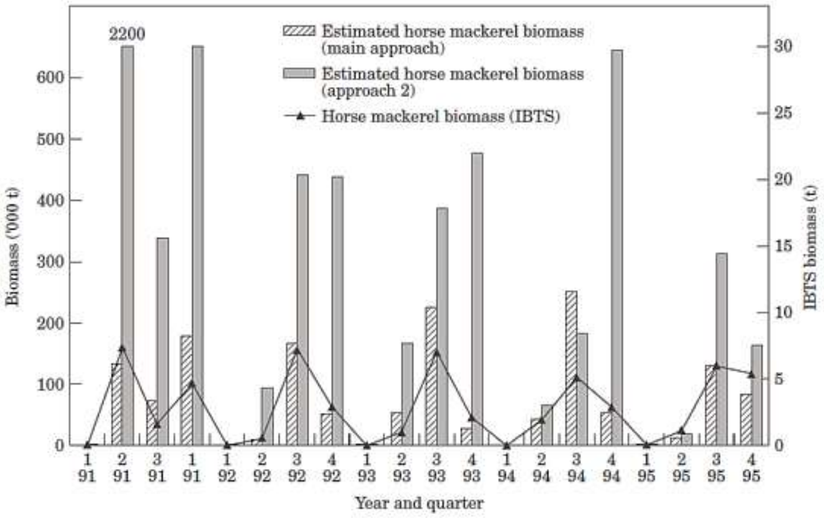


Figure 4.4. Intra-annual abundance estimates from 4 years of quarterly IBTS surveys (from Rückert et al, 2002).

The intra-annual pattern in abundance aligns with the current knowledge of horse mackerel migrations in the area. Horse mackerel spawn in the North Sea from March to August, primarily in the southeast along the coast. The youngest fish then move gradually Northeast along the coastal areas and reside in the North Sea, while the older fish subsequently move to over-wintering areas further South (Lockwood and Johnson, 1977).

It was therefore finally acknowledged that although patchiness in the distribution of horse mackerel and its characteristic forming of large shoals may mean that the abundance data by age and year do not follow a normal distribution, and could have a substantial proportion of zeros and some extreme values, with specific treatment of the data, information on stock trends can still be obtained.

Data exploration

Horse mackerel is abundantly caught in the third quarter IBTS survey. Survey data is available as numbers of fish (individuals) caught per hour (cpue) by length classes of 10 mm. Horse mackerel are not routinely aged in the survey. Age information from commercial catch data (see Section 4.2) indicates that individuals between 1-14 cm correspond to 0-year old fish, 15-19 cm individuals correspond approximately to 1-year old fish and the 20 cm and larger ones to 2-year old fish and older. Figure 4.5 shows the spatial distribution of horse mackerel catches in the survey for two grouped length classes roughly corresponding to the 0-year and 1-year old juveniles (left panel) and the 2-year old and older individuals, which are mostly mature (right panel). Examination of annual distribution maps (Appendix B) showed that juvenile fish are found in highest concentrations in the South Eastern part of the North Sea (in ICES areas IVb and IVc), along the Dutch, German and Danish coast. These fish are found often in more aggregated densities. 2-year and older fish are found somewhat more dispersed throughout the North Sea, while some concentrations are found around the Orkney Islands as well. Rückert et al (2002) described these North-West and South-East concentrations of abundance as two separate stock components in the North Sea. Results from the HOMSIR project also suggested that the North Western concentrations, are likely horse mackerel originating from the Western stock, migrating into area IVa (HOMSIR project, 2003) .

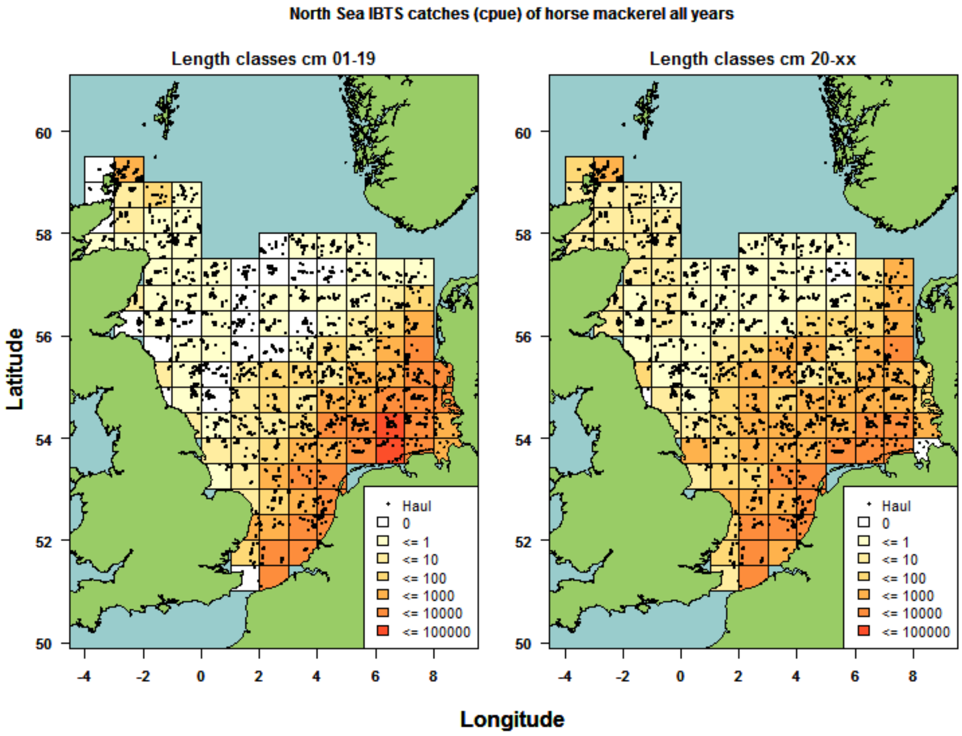


Figure 4.5. Horse mackerel catch rates (cpue) by rectangle in the third quarter IBTS survey (mean over 1991-2012) for two length groups.

Not all rectangles are covered in every survey year (e.g. due to weather conditions). Rectangles that were not covered more than once were therefore excluded from the index area. In 2007 – and in a number of subsequent years – explorations of IBTS index trends have been presented to WGWIDE (ICES 2007). These were based on the selection of an index area on condition that the rectangles were (a) never missed in the years 1991-2006 and (b) horse mackerel catches were reasonably abundant (Figure 4.6; right panel). In 2012, WGWIDE expressed concern that using such a 'narrow' index area did not sufficiently cover the distribution area of the stock, especially in years that the stock would be relatively more abundant and spread out more. Based on these considerations by WGWIDE, the information from Rückert et al (2002) and the HOMSIR project and examination of the annual distribution maps, 61 rectangles were identified to be included in the index area as shown in Figure 4.6 (left panel). This new index area was approved by WGIDE in 2013 (ICES 2013).

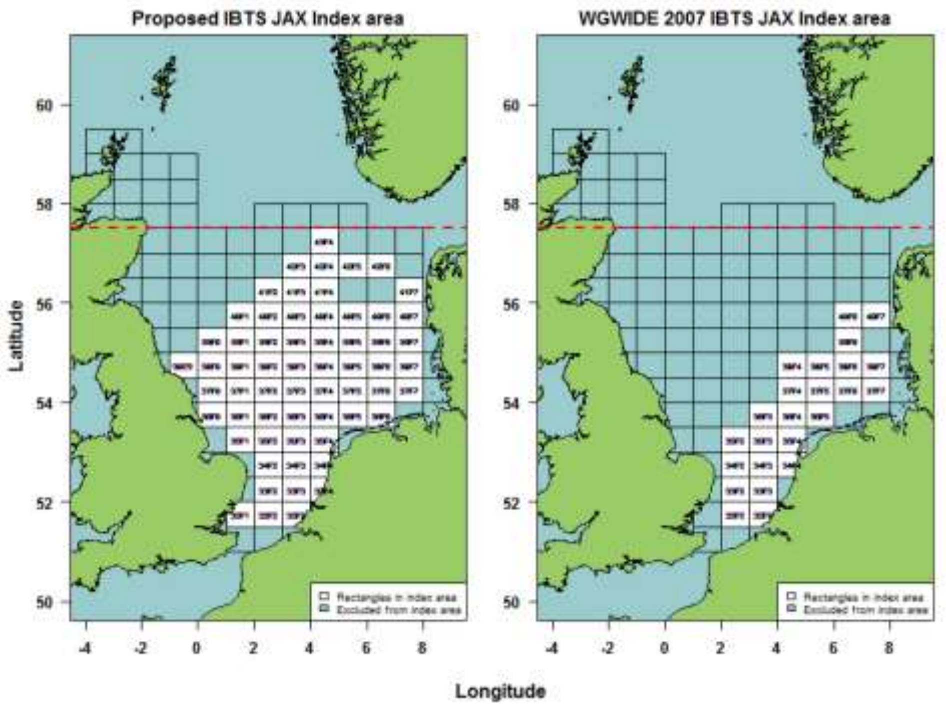


Figure 4.6. Index area including 61 rectangles (left) in comparison to previously used index area as presented to WGWIDE in 2007 (right).

Figure 4.7 shows the length distribution of the IBTS catches. 0-year old fish can be clearly distinguished by the first peak in the distribution. Age information from the Dutch sampling programme of commercial catches showed that no 0-year old fish were larger than 14 cm. Age information from the IBTS survey in the period 2004-2009 is consistent with this.

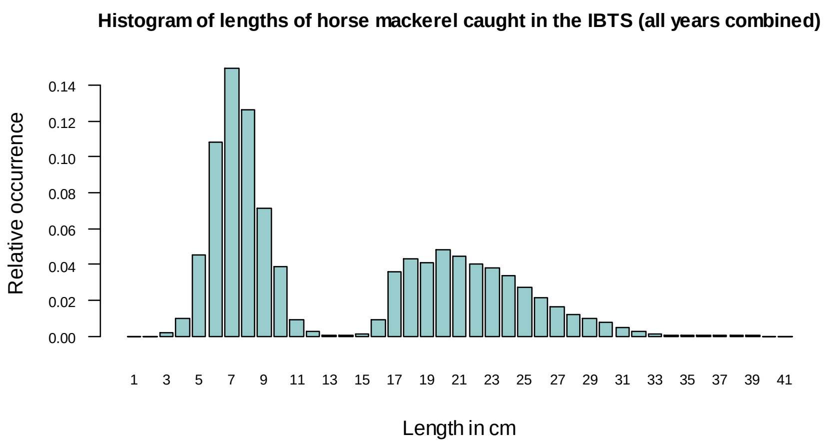


Figure 4.7. Length distribution of horse mackerel caught in the IBTS survey (mean over 1991-2012).

In contrast to previous years, when during WGWIDE meetings, three indices were prepared: (a) for fish <14 cm, (b) for fish >= 14 cm and <23 cm and (c) for fish >=23 cm, the WGWIDE in 2013 considered that using an 'exploitable biomass index' would be most appropriate for the purpose of interpreting trend in the stock. Commercial catch data show that 2-year old fish and older make up 96% of the catch. It was therefore decided to use a biomass index including fish of 2-year old and older. Attempts were made to establish indices for 0 and 1-year old fish, but this was abandoned because of the extremely high variance among different hauls, which suggested that these juvenile catches by the survey were rather incidental in nature.

Also for the 2-year old and older fish, the variation in numbers caught per haul is extensive. Zero catch hauls are also common. Figure 4.8 provides an impression of the distribution of the cpue values by rectangle (top) and the proportion of zero-hauls.

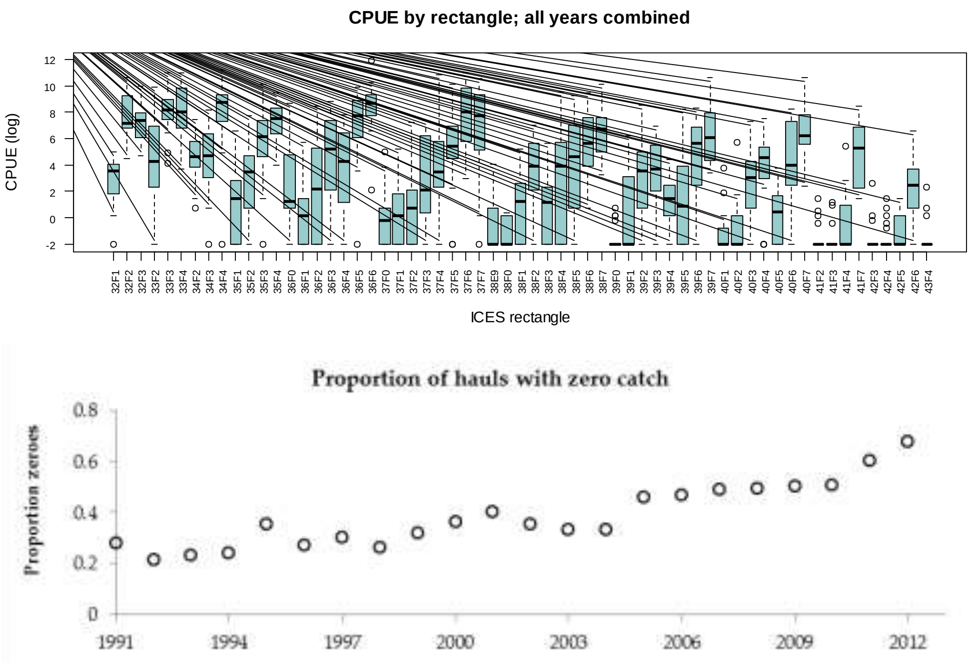


Figure 4.8. Cpue values by ICES statistical rectangle for the 61 selected rectangles included in the index area (top) and proportion of zero-hauls each year (bottom).

‘Jackpot hauls’ occur, where an aggregation of fish is caught and the numbers are orders of magnitudes higher than the mean, meaning that the data are not normally distributed and that the standard method used to derive abundance indices from the survey data (computing a mean cpue per ICES rectangle; and subsequently taking the mean of these values over the index area) is not appropriate. WGWIDE recommended in 2013 to explore transformations of the data to take better account of zeros and extraordinarily large data points in the data set. An alternative approach to establish an index was therefore opted for.

General Linear Modelling approach to index

Even though survey trawl hauls are supposed to be directly comparable, there still may exist differences in catchability of between vessels, especially with species for which the survey was not designed. If the proportion or the geographical distribution of the data collected by the different vessels varies among years, then the vessel effect needs to be accounted for in the computation of the abundance index.
A generalized linear model (GLM) approach accounts for the above mentioned issue in establishing the index. Catches from the survey can be modelled as a linear function of explanatory variables, which may be continuous (depth) or factors (year, vessel, gear type) and offer the possibility to specify a distribution different from the normal distribution. The abundance index (corrected for the other potential effects such as vessel effects) can then be obtained from the estimated year effects (Figure 4.9). Sensitivity tests suggested that the index is robust to the inclusion of new years of data.

In zero inflated GLMs, the zeros (absence of the species) are assumed to result of two different causes: i) the false zeros, corresponding to sampling errors (such as sampling in wrong areas, i.e. outside the distribution area of the species, or using an inadequate technique) and ii) the real zeros, corresponding to sampling in low abundance areas. The zero inflated GLM is then a combination of two models : a model for the probability of occurrence of a false zero multiplied by a model of the count data conditional to not having a false zero.

Where $E(Y_i)$ is the expected catch for the trawl haul *i,* and $var(Y_i)$ is the associated variance, π_i is the probability of having a false zero, μ_i is the expected catch, conditional to not having a false zero, and *k* is the dispersion parameter from the negative binomial distribution.
The probability of having a false zero is modelled by a logistic regression, where

$$logit(\pi_i) = I_{zero} + Depth\ Cathegory_{i,zero} + Vessel_{i,zero} + Year_{i,zero}$$

The expected number of fish, conditional to not having a false zero is modelled as negative binomial regression :

$$log(\mu_i) = I_{count} + Depth\ Cathegory_{i,count} + Vessel_{i,count} + Year_{i,count} + offset\ (\log(haul\ duration))$$

Using $\log(haul\ duration)$ as an offset is a common way of standardizing samples taken by trawl haul of different length and it comes down to modelling the CPUE of the horse mackerel in fish per hour.

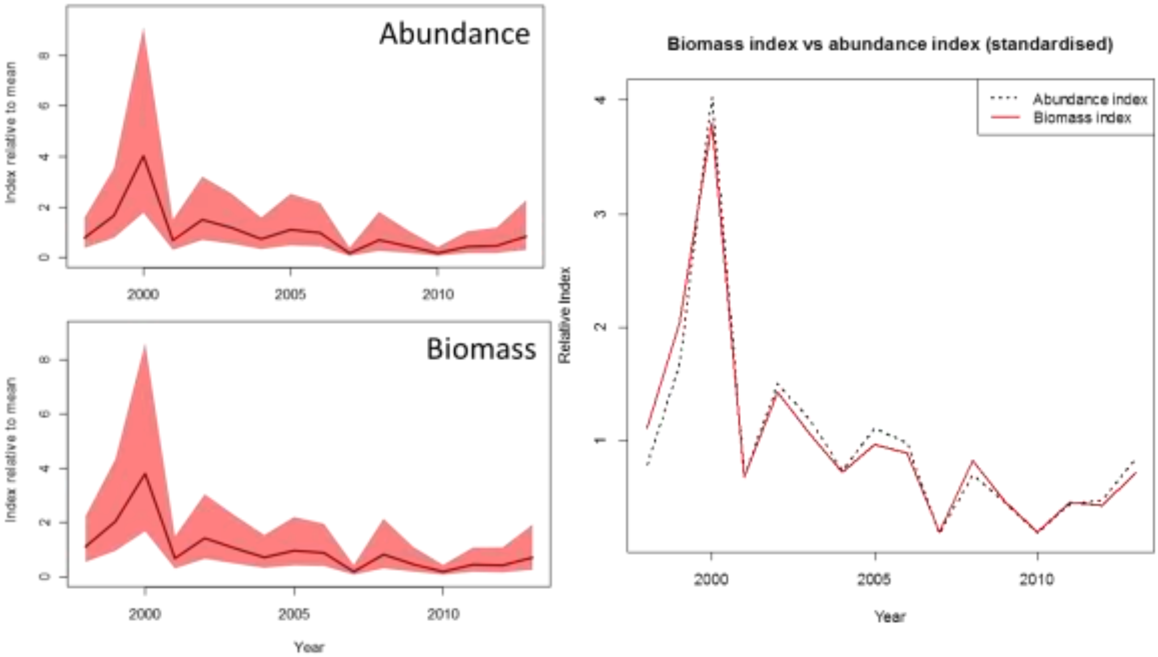


Figure 4.9. The GLM indices derived from the IBTS Q3 data (as calculated in 2014). The biomass index can be derived from the abundance index by using information on annual length distributions and weight at age estimates. In the graphs on the left, the shaded area represents 95% uncertainty bounds.

Delta Log-Normal computation of index

As an alternative approach to deal with the skewed nature of the data together with its relatively large number of zeros, the mean annual catch was computed assuming a lognormal distribution for the positive values, together with an additional probability mass at zero. This type of distribution is commonly referred to as the delta-lognormal distribution, and was first discussed by Aitchison (1957). It has been used in various applications since then, and is commonly used in fisheries research (e.g. Pennington, 1996; Fletcher 2008). The expected annual index values (Figure 4.10) were computed as:

$$\mu_Y = \pi \exp(\mu_X + \frac{\sigma_X^2}{2})$$

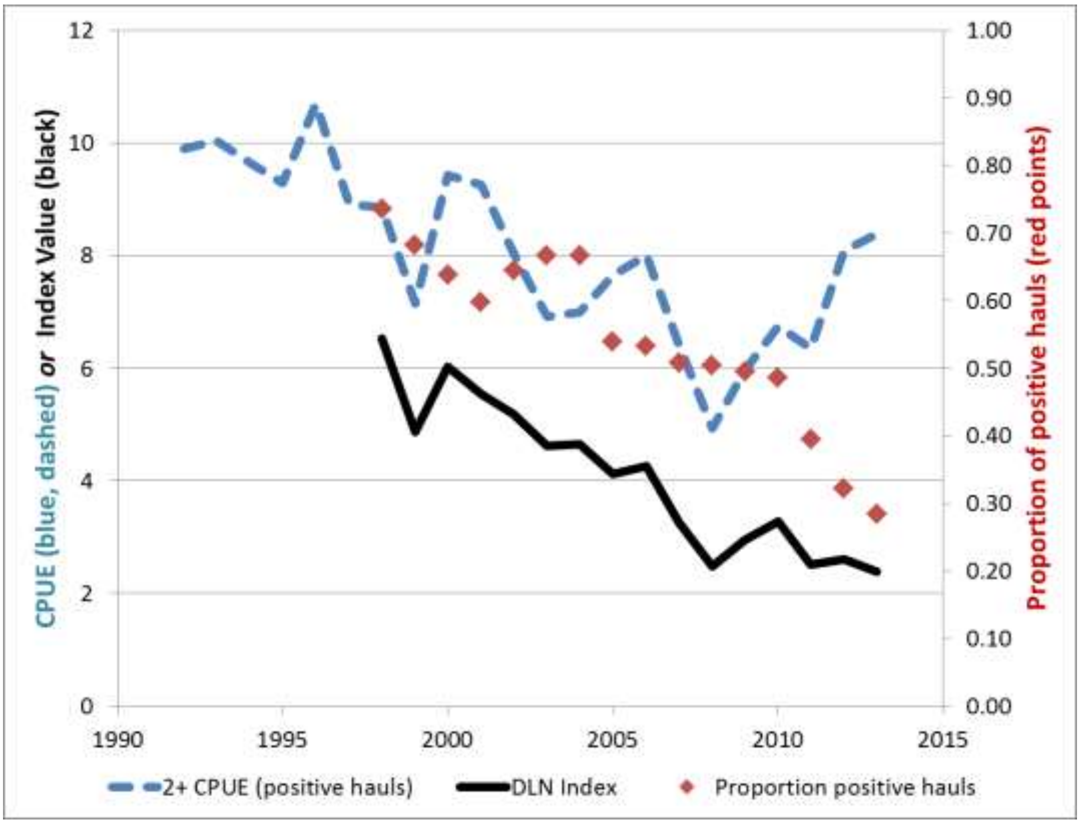


Figure 4.10. The DLN index (black, solid) and its components: the proportion of positive (non-zero) hauls (red diamonds) and the cpue in the positive hauls (blue, dashed).

The DLN index shows a more steady decline in biomass and is less noisy than the GLM index. However, the overall pattern of decline is seen in both variations (Figure 4.11).

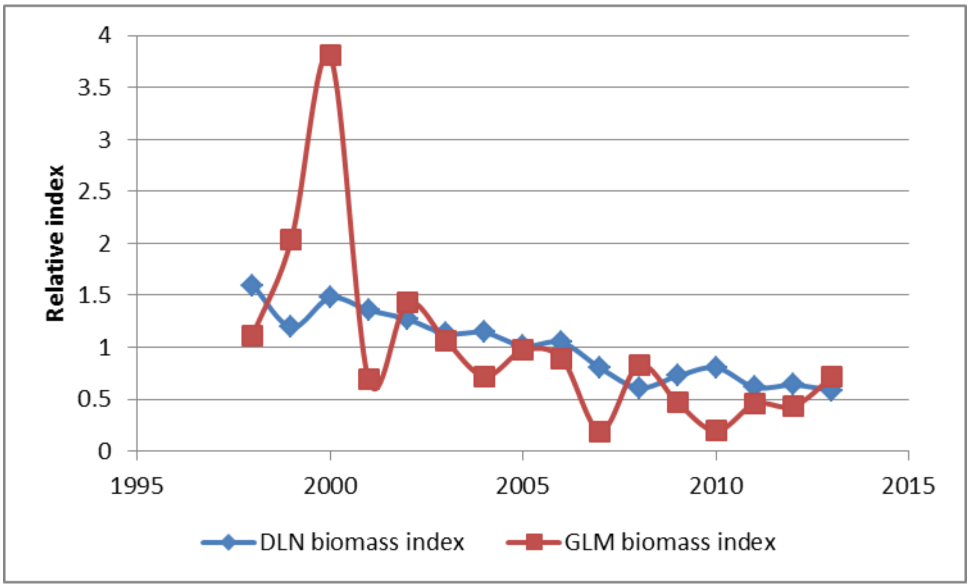


Figure 4.11. A comparison of the DLN and GLM biomass indices (values relative to the mean of the time series i.e. 1= average index value).

4.4 The JAXass assessment model

The JAXass (JAX assessment model) is a simple statistical catch at age model fitted to an age-aggregated index of (2+) biomass, total catch data and proportions at age from the catch. Difficulties in fitting an assessment model for this stock include:

- Unclear stock boundaries
- Difficulty aging horse mackerel
- lack of strong cohort signals in CAA data
- Scientific index derived from a survey not specifically designed for horse mackerel and not covering one of the main fishing grounds for the stock (VIId)
- Conflicting signals from data sources (especially from the mid-2000s)

Catches taken in area VIId are close to the management boundary between the (larger) western horse mackerel stock and the NS horse mackerel stock. It is quite possible that given changes in oceanographic condition, or changes in abundance of either of the two stocks, that some proportion of the catches taken in area VIId actually originated from the western horse mackerel stock. Sensitivity tests (not shown here) removing constant proportions of the VIId catch from the data simply results in alternative scaling of the assessment outcomes rather than any significant differences in trends. When VIId catch data are excluded, the fit to the IBTS survey data improves. Nevertheless, all assessment models used in the MSE assume that 100% of fish caught in area VIId belong to the North Sea horse mackerel stock. This is in agreement with stock and management definitions.

While all VIId catch is assumed to come from the North Sea stock, to account for the uncertainty associated with VIId catch, the catch data is inversely weighted according to the proportion of the total catch that was taken in area VIId when fitting the assessment models. In this way particularly large catches from area VIId, which may compromise a portion of western horse mackerel fish, are downweighted in the assessment model, while years where a large proportion was taken from area IV are upweighted. Overall, the effect of this weighting in limited, since catch is still an influential component of the objective function. However, there is a slight improvement in the fit to the IBTS index data and an increase in the estimated selectivity of the younger ages (which are mainly caught in area IV).

Table 4.4 shows the inputs and settings used in the JAXass model. In total the model estimates 58 parameters (for the period 1992-2012):

- Annual F multipliers (*N*=21, one for each year)
- Fishery selectivity parameters (*N*=2, selectivity is time invariant i.e. one selectivity curve)
- Initial population (*N*=9, ages 2-10+ in 1995)
- Annual recruitment (*N*=21, one for each year)
- Sigmas (variances) (*N*=5, one for total catch, one for index and three for CAA)

Table 4.4 statistical catch at age model inputs and settings.

Setting/Data	**Values/source**
Total Catch	Total Landings, 1992-2012. Discards considered negligible.
Catch at age	Landings at age, 1995-2012, ages 1- 10+
Tuning indices	IBTS Q3 (GLM year effect or delta lognormal index); 1998-2012; 20cm+
First Age	1
Plus group (last age)	10+
First tuning year	1992
Selectivity	Two parameter (α, β) logistic, constant over years

Annual F values in the model are bound between 0.01 and 1.5. Selectivity is modelled as a logistic curve. For *age* 1 to 10, the selectivity at age (Sel_{age}) is calculated as:

$$Sel_{age} = \frac{1}{1 + e^{\alpha + age \times \beta}}$$

The objective function is the weighted dnorm likelihoods for the total catch, catch at age and IBTS data:

$$objF = wt_C \times f_C + wt_{CAA} \times f_{CAA} + wt_I \times f_I$$

Where:

$$f_C = \sum_{y=1995}^{2012} 0.5 \times \left(\ln(2\pi\sigma_C^2) + \frac{\left(\ln C_y^{obs} - \ln C_y^{exp}\right)^2}{\sigma_C^2} \right)$$

$$f_{CAA} = \sum_{a=1}^{10+} \sum_{y=1995}^{2012} 0.5 \times \left(\ln(2\pi\sigma_{CAA,a}^2) + \frac{\left(\ln CAA_{a,y}^{obs} - \ln CAA_{a,y}^{est}\right)^2}{\sigma_{CAA,a}^2} \right)$$

$$f_I = \sum_{y=1998}^{2012} 0.5 \times \left(\ln(2\pi\sigma_I^2) + \frac{\left(\ln I_y^{obs} - \ln I_y^{exp}\right)^2}{\sigma_I^2} \right)$$

C^{obs} and C^{exp}	= The observed and expected total catch (*C*), over years (*y*)
CAA^{obs} and CAA^{exp}	= The observed and expected catch at age (*CAA*), over years (*y*)
I^{obs} and I^{exp}	= The observed and expected IBTS index (*I*), over ages (*a*) and years (*y*)
σ_C	= Estimated variance in the total catch time series
σ_I	= Estimated variance in the IBTS index time series
$\sigma_{CAA,a}$	= Estimated variance in the catch at age (*CAA*) time series for ages *a=1, a=2-9,* and *a=10*
wt_C / wt_{CAA} / wt_I	= Weightings applied to the total catch / catch at age / index

The index and total catch have single sigma (variance) values for the whole time series while the CAA has one for the youngest age (a=1, high variance), one for ages 2-9 (similar variance) and one for age 10 (high variance).

Stock recruitment relationships

All available data suggest that the North Sea horse mackerel stock is currently at a low biomass in relation to levels in the late 1990s. As a result all assessment models fit to these data estimate that current SSB is near the lowest observed. This makes projections of stock development sensitive to the choice of stock-recruit relationship (SRR). Figure 4.12 shows three SRRs fit to the GLM_Whm assessment model as an example (all assessments show similar fits):

1. Segmented regression ('*segreg*'), also known as 'hockey stick'. For all assessment models except the GLM_index weighted assessment, the stock-recruit pairs do not clearly indicate a clearly defined breakpoint and the resultant fit is a linear line from the origin through the cloud of points, with the breakpoint at the highest observed SSB. In the case of the GLM_index weighted model the breakpoint estimated at the lowest observed SSB and the plateau is at the geometric mean recruitment.
2. Declining limb ('*decLim*'), geometric mean recruitment with recruitment declining linearly from the lowest observed SSB to zero recruitment at 0t SSB.
3. Ricker stock recruit relationship, similar to the segmented regression fits without a breakpoint.

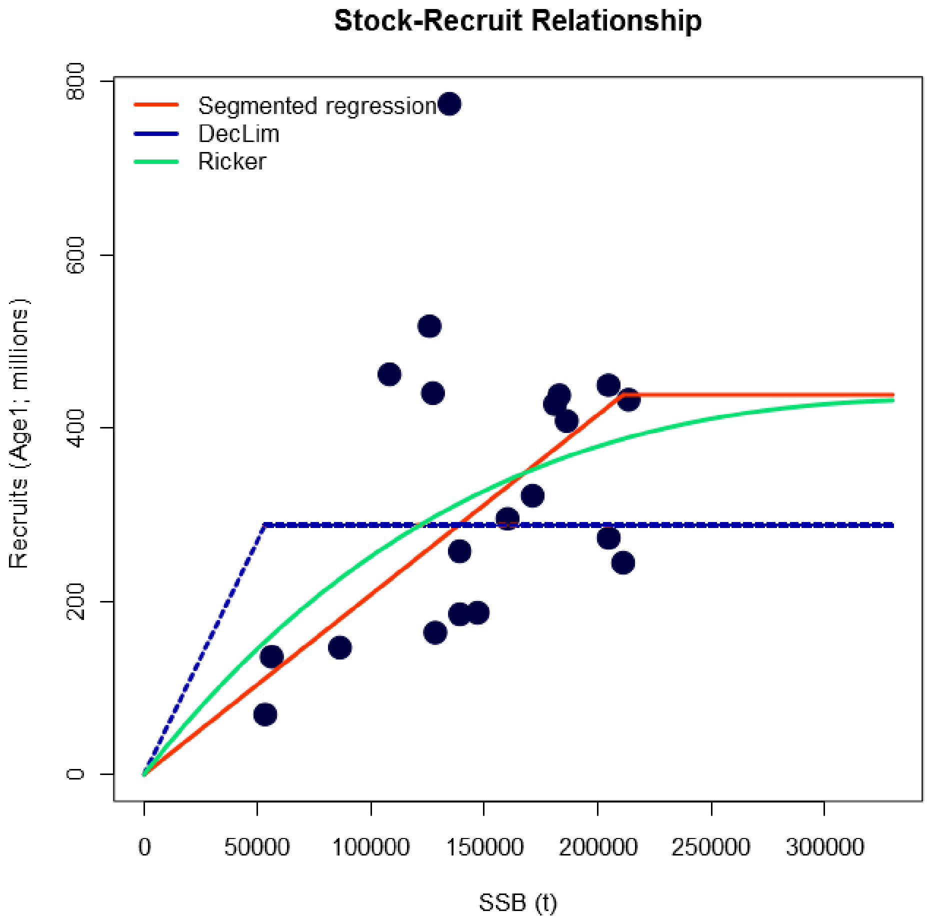


Figure 4.12. Alternative stock-recruitment fits to the GLM_Whm assessment model SSB and recruitment data.

The Ricker and most segmented regression SRRs (except the *GLM_index weighted*) have a low steepness, allowing for higher recruitments at high SSB, but below mean recruitment at low SSB. This means the recovery of the stock from low SSB is slow and very sensitive to the level of catch taken from the stock. Conversely, SRRs with a high steepness (i.e. '*decLim*', geometric mean with declining recruitment below the lowest observed SSB) have a lower average recruitment at higher SSBs but allow for higher recruitment at low SSB. These allow for the stock to recover at a quicker rate from the current low SSB and allow for higher catches to be taken from the stock in the short term.
Estimating stock recruit curves for data poor stocks is challenging. The short time series available for the North Sea horse mackerel stock shows an almost constantly declining SSB. The three most recent recruitment estimates are the lowest observed, forcing a very low steepness in any stock recruit relationship fit to the data. Removing the three most recent estimates would lead to a SRR fit with a steepness of the slope in between the scenarios described here, and so, they could be considered as 'best case' and 'worst case' scenarios. The assessment uses an age-aggregated index for the older ages and most information on age-structure comes from the catch at age matrix. The last three years have seen a high proportion of the catch come from area VIId, whilst it is thought that most age 0 and 1 fish are found in the North Sea area. This makes the most recent estimates of recruitment less reliable.
Especially for pelagic stocks, factors besides SSB may play an important role in determining the success of recruitment in any given year. The two highest observed year classes in the western horse mackerel stock have arisen from SSBs near the lowest observed SSB, suggesting that for horse mackerel environmental and ecological conditions play a more important role.

4.5 Reference points

Fishing mortality reference point values were calculated by running long term projections at varying levels of F. Since the stock is currently at a low SSB, the first 20 years of the simulations were run with F=0 to allow the stock to recover to a healthy state. This was done both deterministically (no uncertainty, recruitment according to the stock recruit relationship) and stochastically with 20 iterations per OM (variance in selectivity, weights at age, and lognormal error around the stock recruit relationship). Reference point values were obtained once the stock had stabilized at the end of 100 years for deterministic and 80 years for stochastic runs.

Three F reference points were calculated:

1. F_{MSY}: The fishing mortality providing the maximum yield at equilibrium.
2. F_{35}: The fishing mortality that leads to SSB at 35% of SSB_0 (virgin biomass) at equilibrium. F_{35} is thought to be robust proxy for Fmsy, commonly used by NOAA for fisheries advice in the USA (Gabriel and Mace, 1999). This F_{MSY} proxy is normally used in absence of a direct Fmsy estimate from yield per recruit (YPR) analyses with no SRR (= 35% SPR_0 i.e. spawner per recruit at 0 fishing). In the current analysis we have estimated SRRs, but we are combining (stochastically) different assessment model outputs (with different selectivities) and different SRRs, so these projections are a useful way of estimating this reference point from 'averaged' models and SRRs.
3. F_{crash}: Defined in this case as the fishing mortality that leads to the stock being below 1% of SSB_0 (virgin biomass) in equilibrium.

Since in MSE the 'true population' (reference set of operating models) is known, equilibrium projections are a direct estimate of the appropriate reference point values for this 'true population'. The performance of candidate HCRs can be directly compared with these values.

DecLim reference points

Figure 4.13 shows the results of the equilibrium projections for the *decLim* reference set (6 assessment models * one SRR, *decLim*). The resultant reference points (median values) are shown in Table 4.5. The uncertainty observed around the deterministic values comes from the difference between the assessment models used in the reference set. Adding stochasticity increases the uncertainty significantly.
In the deterministic equilibrium, F_{crash} occurs rapidly above F=0.3, due to the estimated breakpoints in the *decLim* SRR. F_{MSY} is very near to this F_{crash} level. The stochastic equilibrium yield curve is smoother with a higher F_{crash} since even at higher Fs the occasionaly large year class can sustain the population through a period of extended poor recruitment. The peak of the stochastic equilibrium yield curve is shifted to the left providing a lower estimate of F_{MSY} than in the deterministic analysis (0.24 vs 0.29). This is also further below F_{crash}. The estimate of F_{35} is more robust to stochasticity and is the same as in the deterministic analyses (F_{35}=0.14). Stochastic equilibrium yields are at a similar high level between Fs of 0.12 and 0.32, so despite being almost half the value of F_{MSY}, F_{35} has only slightly less long term yield (~2kt.yr^{-1}). F_{35} is considered to be a more precautionary alternative long term fishing mortality target to F_{MSY}. SSB_{MSY} is estimated to be approximately three times higher than the current stock size, with long term maximum yields of approximately 24kt, approximately equal to the average landings from 2010-2012.

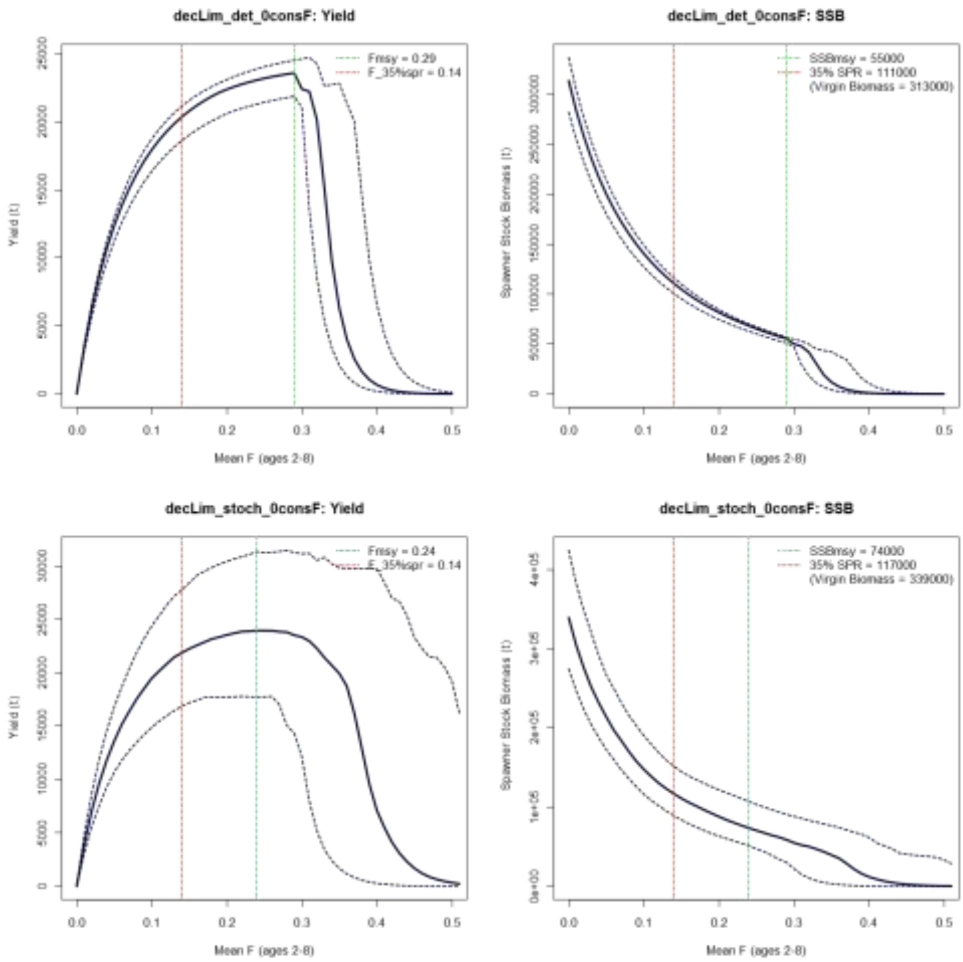


Figure 4.13. Deterministic (top) and stochastic (bottom) equilibrium yield (left) and spawner stock biomass (right) by fishing mortality for the *decLim* reference set of operating models. Median (solid lines) and 5 and 95 percentiles (dashed lines) are plotted.

Table 4.5. Reference points for the *decLim* reference set of operating models (median values).

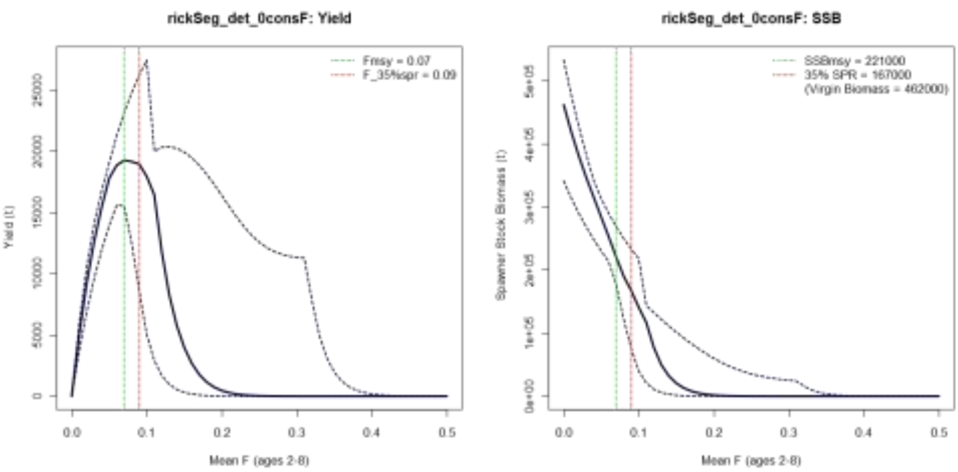
decLim_0consF	MSY			35% SPR				SSB < 0.01*SSB_0	
	F_{MSY}	Max. Yield	SSB_{MSY}	Virgin Biomass	F_{35SPR}	Y_{35SPR}	SSB_{35SPR}	F_{crash}	5% F_{crash}
Deterministic	0.29	23556	55298	313431	0.14	20331	110687	0.38	0.36
Stochastic	0.24	23945	73633	339303	0.14	21846	116841	0.45	0.35

Ricker-segmented regression reference points

Figure 4.14 shows the results of the equilibrium projections for the Ricker and segmented regression reference set (6 assessment models * two SRRs, Ricker and segmented regression). The resultant reference points (median values) are shown in Table 4.6. The uncertainty observed around the deterministic values comes from the difference between the assessment models used in the reference set.

Compared to the *decLim* curves, F_{crash} occurs less rapidly, due to use of the Ricker SRR which has no breakpoint. However, given the relative low steepness of the Ricker and segmented regression curves compared to the *decLim* SRR, F_{crash} occurs at a lower value (similar for both deterministic and stochastic analyses). The long term mean fishing mortality (1992-2012) of the reference set of operating models is 0.25, above the estimated Fcrash value (0.22). F_{crash} is also estimated below the *decLim* F_{MSY} and only very slightly above the *decLim* F_{35}.

The deterministic and stochastic equilibrium yield curves both have well defined peaks and result in similar F_{MSY} estimates (0.07 and 0.08, respectively). With these SRRs F_{35} (0.1) is estimated slightly higher than F_{MSY}, due to the density dependent effects in the Ricker SRR leading to lower recruitment and high SSB. F_{35} is still below the fishing mortality with a 5% probability of the stock crashing. SSB_{MSY} is estimated to be above the highest observed stock size, despite very low fishing mortality observed in the early 1990s. Long term maximum yields are slightly lower than those estimated in the *decLim* analyses (23kt vs 24kt), also approximately equal to the average landings from 2010-2012.



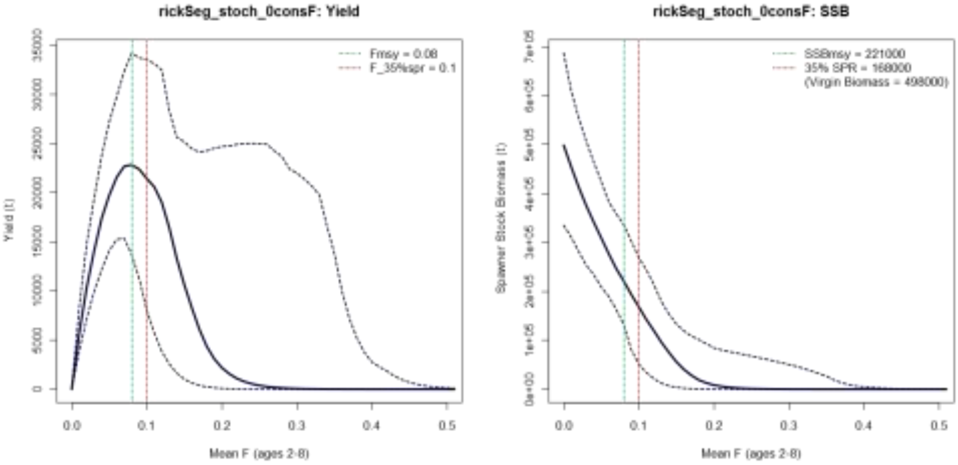


Figure 4.14. Deterministic (top) and stochastic (bottom) equilibrium yield (left) and spawner stock biomass (right) by fishing mortality for the Ricker and Segmented regression reference set of operating models. Median (solid lines) and 5 and 95 percentiles (dashed lines) are plotted.

Table 4.6. Reference points for the Ricker and Segmented regression reference set of operating models (median values).

rickSeg_ 0consF	MSY			35% SPR				SSB < 0.01*SSB0	
	F_{MSY}	Max. Yield	SSB_{MSY}	Virgin Biomass	F_{35SPR}	Y_{35SPR}	SSB_{35SPR}	F_{crash}	5% F_{crash}
Deterministic	0.07	19288	220587	462420	0.09	18979	167482	0.19	0.14
Stochastic	0.08	22852	221050	498437	0.1	21459	168451	0.22	0.15

The equilibrium analysis suggests that the rickSeg SRR is a bit unrealistic given the past history of the stock, leaning towards a ‘worse case’ scenario. Informal reports from both the scientific surveys and the demersal and pelagic fishing industry suggest that recent recruitment of the stock has been high. However, in the rickSeg reference set, the chances of a high recruitment in the short term are very limited due to the low SSB of the stock and the low steepness of the stock recruit curves. On the other hand, while the *decLim* SRR may overestimate the level of recruitment that could be produced by the stock at such low biomasses, it still generates recruitment values that are consistent with the level observed in the past and allows for strong year classes even at low SSB.

5 Management Strategy Evaluations

The evaluation of the multiannual plan is carried out using a numerical simulation model to study the interplay between the biological dynamics of the stocks and the dynamics of the fleet. Figure 5.1 provides a simple overview of how the model operates in terms of linking fish stocks to management decisions to fleet behaviour. The 'True populations' and 'Fishery' are simulated from the available information using simple population and fleet dynamics principles. In the model, the future fisheries management strictly follows the rules of the management measures to be evaluated (i.e. no implementation error). The 'Observation model' in the management system is modelled by assuming random noise for the survey, based on stock assessment model fits to the index. In this way, a 'Perceived biomass index' is created that is used is the HCR being tested to set for subsequent year's management decision (TAC).

The evaluation consists of a number HCRs applied on a reference set of operating models (OMs; combinations of assessment model used as the starting point and the choice of stock recruitment relationship used in the projections). Each HCR-OM combination (consisting of one HCR applied to one OM) was simulated for a number of iterations to capture stochastic variability. Each iteration runs from 2013 to 2026. For each operating models, 100 iterations were run per assessment model for each SRR. The results of the alternative operating models were combined with equal weighting.
The stock assessment models were fit in ADMB (Fournier et al 2012) and the projections were carried out in R (v3. 1; R Development Core Team 2014). All code, data and additional sources for checking, validating and evaluation are freely available upon request.

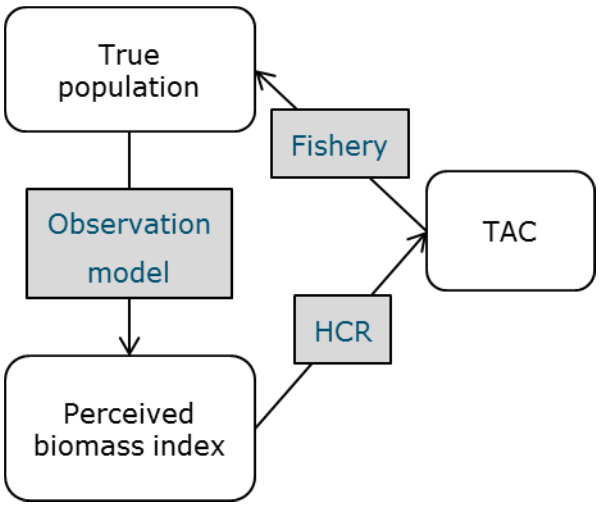


Figure 5.1. Schematic of the components of the management strategy evaluation.

5.1 Operating Models

Biological data

In the absence of time varying maturity and natural mortality estimates, in the projections these values are set to the same constant values used in the assessment. For the estimates of weight at age, future years were resampled (randomly with replacement) from previous years to account for the occasionally observed year effects in the weight at age data.

Starting points (assessment models)

The assessment models used in the final reference set differed in terms of the method used to calculate the biomass index, the weighting applied to each source of data in the model (catch vs index) and the choice of natural mortality (Table 5.1). Since both the catch data and the indices of stock biomass are uncertain (see Sections 4.1 and 4.3), alternative weightings of each data source were done in the assessment model to create alternative plausible fits to the data. Details of the natural mortality values and different indices can be found in Sections 4.2 and 4.3.

The reference set used consisted of 6 alternative assessment model fits to the data (Table 5.1). The model fits and some diagnostic plots are presented in Appendix E: Assessment model fits. MCMC analyses were run to account for uncertainty in model estimates and create alternative valid starting points (*n*=100) for each iteration from each assessment model.

Table 5.1. The six assessment models used in the final reference set.

Assessment model	Index Used	Weighting of catch data	Weighting of index data	Natural mortality
GLM_catch_weighted	GLM	5	1	Whm
GLM_Whm	GLM	2	1	Whm
GLM_Shm	GLM	2	1	Shm
GLM_index weighted	GLM	2	5	Whm
DLN_Whm	DLN	2	1	Whm
DLN_Shm	DLN	2	1	Shm

The different assessment models have different estimates of SSB, mean F and recruitment in 2012, both in absolute terms and in relative terms i.e. compared to the mean over the whole time series for each assessment model (Figure 5.2, Table 4.8). Using the GLM index instead of the DLN index leads to higher SSB and recruitment and lower mean F at the start of the projection period (i.e. a more optimistic view). The assessments fitting to the DLN estimate that SSB in 2012 is less than 20% of the mean of the time series, with mean F three times higher than the long term average (i.e. a more pessimistic view). Models fit to the DLN index have worse residual patterns in the total catch compared to models fits to the GLM index.

When extra weight is given to the GLM index both SSB and mean F in 2012 are reduced. This is because the assessment model estimates less total catch than observed in recent years. When more weight is given to the catch data, higher SSB is estimated since the stock needs to be large enough to allow for the full observed catch to the caught.

Rather than scaling SSB, alternative natural mortality values leads to higher estimated recruitment. This allows the model to account for the higher natural mortality on the younger ages. As a result the age structure in stock tends towards more young fish with Shm M.

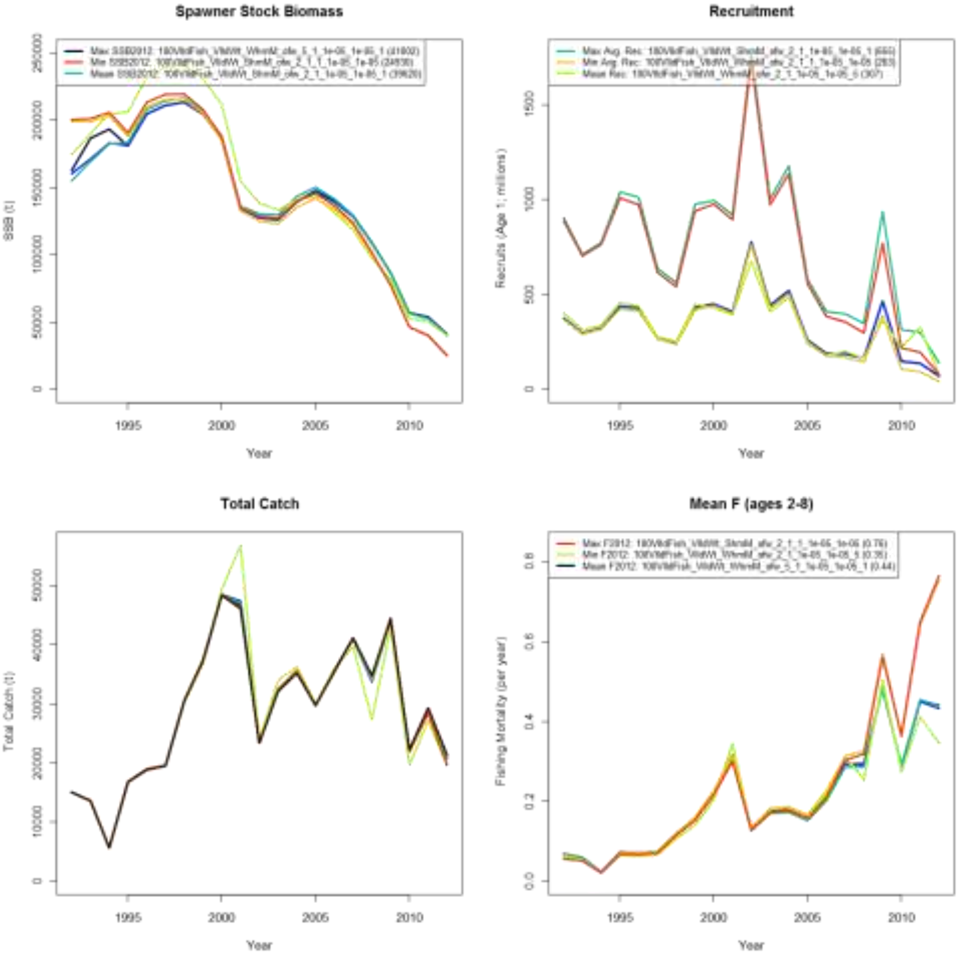


Figure 5.2. Spawner stock biomass (SSB, top left), Recruitment (top right), total catch (bottom left) and mean fishing mortality (ages 2-8, bottom right) for the six assessment models used in the reference set.

Table 5.2. Comparison of the recent values of spawner stock biomass (SSB), mean fishing mortality (ages 2-8) and recruitment from the six assessment models used in the reference set. Absolute values are given for 2012 (and average of 2010-2012 for recruitment) and values relative to the mean over the whole time series are shown (since different models show slightly different trends over time). Colours indicate how values compared within columns (red = lowest SSB/Recruitment, highest F; green = highest SSB/recruitment; lowest F).

	SSB (t)		Mean F (ages 2-8)		Recruitment (age 1, k)	
Assessment model	2012	Relative to mean	2012	Relative to mean	Avg. 2010-12	Relative to mean
GLM_catch_weighted	41002	0.28	0.44	2.17	209	0.6
GLM_Whm	40773	0.29	0.43	2.12	208	0.6
GLM_Shm	39620	0.27	0.44	2.19	463	0.59
GLM_index weighted	40033	0.26	0.35	1.76	294	0.84
DLN_Whm	25636	0.18	0.75	3.15	175	0.53
DLN_Shm	24930	0.17	0.76	3.26	383	0.51

Stock recruitment relationships

Hence results are presented separately for the *decLim* and rickSeg stock, the latter providing a more pessimistic view of the stock. Thus two sets of MSE results are presented to reflect the uncertainty of future stock development according to these assumptions:

1. *rickSeg*: The full reference set of operating models with both Ricker and segmented regression stock recruit relationships in equal proportions (6 assessment models * 2 SRRs * 100 iterations = a total of 1200 reference set iterations for each HCR).
2. *decLim*: The full reference set of operating models with geometric mean recruitment declining to 0 at 0kt SSB from the lowest observed SSB (6 assessment models * 1 SRRs * 100 iterations = a total of 600 reference set iterations for each HCR).

5.2 The Fleet operating model

A simple single fleet model is used in the projections.

Catch in 2013 and 2014

The catch at age data for North Sea horse mackerel will be compiled in advance of WGWIDE 2014 (August-September), and is therefore currently not available for use in the simulation model. In addition, the preliminary estimates of total catch available from ICES did not include all the fleets fishing this stock in time for inclusion in the MSE. For all projections, the total catch in 2013 is assumed to be equal to the average of the previous 3 years (22kt, 29kt and 21kt respectively) = 24kt.
A TAC has already been set for 2014 (28kt, EU only), but since the majority of the fishery takes place in the 3rd and 4th quarter, no estimates can be made of the likely catch in 2014. In the projections catch in 2014 follows from the applied HCR.

Catchability and selectivity

The fleet operating model affects the number at age of the 'true' stock via the fishing mortality rate (F) per year. Conversion from numbers to weights is done using the individual weights at age. The historic selectivity-at-age (Figure 5.3) were estimated in the stock assessments. The selectivity of the fleet is assumed to be constant over time (as is done in the assessment models) i.e. no technological creep. The selectivity curves estimated in the assessment models using SHM natural mortality have a lower selectivity on age 1-3 fish, since recruitment is estimated to be higher in these models. The selectivity curves for the remaining stock assessment models are very similar, nearing selectivity near the age at 50% maturity (~age 4).

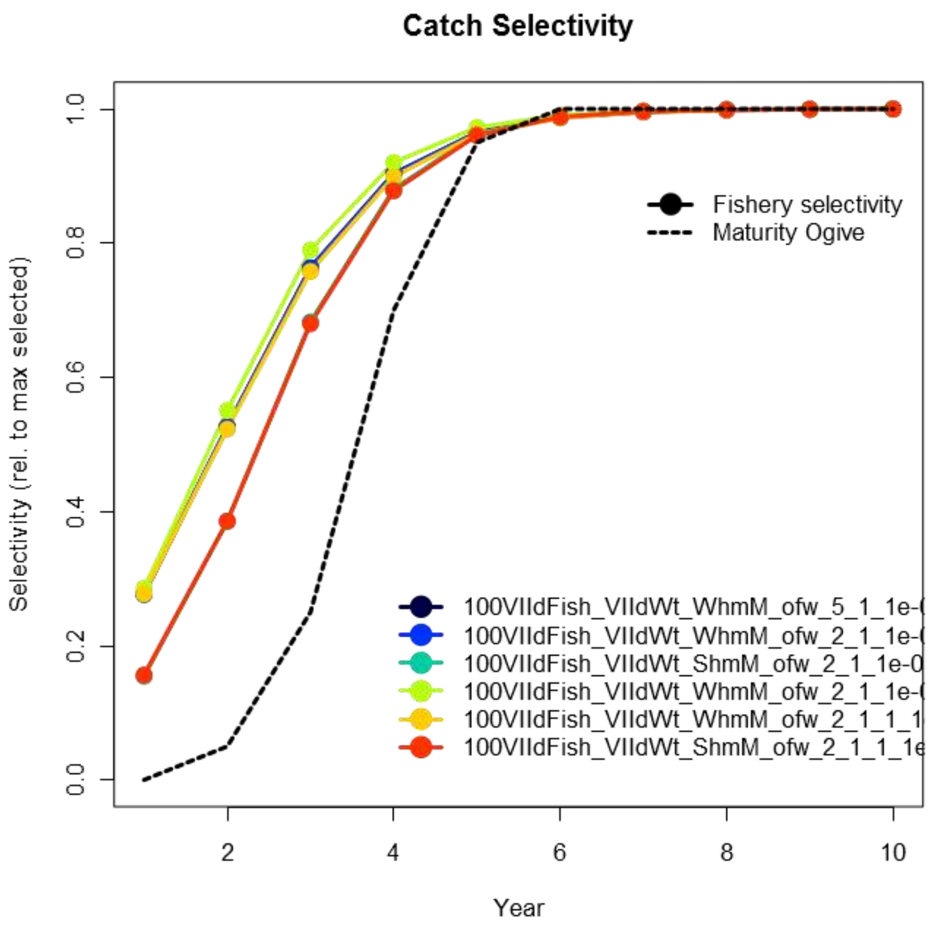


Figure 5.3. Estimated selectivity curves of the six assessment models used in the reference sets. Proportion mature at age is shown for comparison.

TAC utilisation considerations

There has been a consistent underutilisation of the EU quota in recent years (approximately 50% in 2010-2013; see Section 2.1.1). The MSE projections assume that the advised catches are fully utilised (100% landed). There are two possible problems when translating these projected *landings* into *TACs*:

1. If the landings values are used as absolute TACs, and the current rate of uptake of TAC continues (i.e. Denmark do not land their quota, Norway does not take significant landings), then the actual landings from the stock will be significantly lower than the HCR intends.
2. If the landings values are converted to absolute TACs by multiplying by some uptake proportion (constant or time varying), and TAC uptake rates change (i.e. Denmark starts to land its quota), then the actual landings from the stock will be higher than the HCR intends.

Both of these scenarios lead to HCR performance that is different from that observed in the simulations. If everything remains the same, then setting the TACs as described in (2) should lead to performance similar to that observed for the HCR (of course future recruitment will be the big driver for a recovering stock and we are not able to predict that with any degree of accuracy).
The stock as perceived using the data and models we have available cannot sustain any high catches in the short term. This makes the performance of any HCRs very sensitive to changes in uptake of TAC. The results presented here are indicative of the level of *catch* that the stock could potential yield, managers will need to be aware that there is currently a variable and uncertain link between the TAC and the landings taken for this stock.

5.3 Observation model

In order to set a management measure for year *y*, survey data will be available up to year *y*-2, with the assessment itself carried out in year *y*-1. A simple observation model is used to generate future annual index values. The catchability of the index used (*q*) in the HCR is estimated from the model fit to the data. Future residuals are sampled form a random lognormal distribution with mean and standard deviation estimated from the estimated model residuals.

5.4 Management options

The current poor state of the stock calls for recovery of the stock before consideration of the potential long term management goals and appropriate HCRs. It is standard practice to review management plans on a 3-5 year basis as new knowledge and data become available that may lead to a different perception of both the state of the stock and reference points used in the management of the fishery. For the North Sea horse mackerel stock it is proposed that a short term interim management plan should be applied that, given the uncertainties in the perception of the stock, would allow for recovery of the stock in the short term to more sustainable levels.
To this end, the following procedure was followed:
1. Scenarios of constant catch and constant F were examined to see what level of catch or F would allow for recovery of the stock in the short term.
2. On the basis of these runs, viable short term (3yr or 5yr) management options are proposed. These proposed landings are considered appropriate in the short term. A re-evaluation of potential HCRs looking at longer term management considerations should be undertaken in 3-5 years, unless anything changes in our understanding of the stock in the meantime that would require a re-evaluation of management options.
3. An initial examination of the potential HCR options is also presented, but to allow for a meaningful comparison of these some stock recovery is required first. In all cases the catch in the initial 3 years is set to 5kt, following which the HCRs are applied to the stock.

Constant F

Twelve different constant F scenarios were considered: current (three year average) F, zero fishing, F_{MSY} and F_{35} (from both the *decLim* and rickSeg analyses), and the F values that allow for the median SSB_{2020} to be above median SSB_{2012} ($F_{med2020>2012}$), 5^{th} percentile SSB_{2020} to be above the 5^{th} percentile SSB_{2012} ($F_{5\%2020>5\%2012}$) and the 5^{th} percentile SSB_{2020} to be above the median SSB_{2012} ($F_{5\%2020>2012}$).

Constant Catch

A range of constant catch values from 0 to 20kt were considered.

Harvest Control Rules

On the basis of these exploratory projections it became apparent that a significant reduction in catch is required in the short term to arrest any further decline in the stock SSB. Hence to compare the performance of proposed HCRs, subsequent runs initially lowered the starting TAC to 5kt, and maintained it at this level for three years before applying the candidate HCRs.
Candidate HCRs follow a simple trend based rule:

$$TAC_{y+1} = TAC_y \times \left(min\left(\frac{I_{rec}}{I_{trig}}, 1\right) + \lambda Slp \right)$$

Where:
TAC = Total Allowable Catch; *y* = assessment year
λ = slope multiplier
Slp = slope of the log-linear regression for the last *x* years of the survey index
I_{rec} = recent survey index = average of index values for the last *x* years up to year *y*-1
I_{trig} = survey index trigger value = I_{2012}

Negative *Slp* implies general trend over the last 3 or 5 yrs has been downward and TAC advice will be lower than TAC_y, regardless of the index values, and vice versa. The log linear slope does not really quantify the downward trend in an easily understandable way (i.e. it is not a percentage decline or a simple ratio that could be applied directly to a TAC value). So the λ (lambda) value should be tuned to find a reasonable value. A higher λ means a more reactive HCR. This can help declining stocks by reacting quicker (less catch, more recovery through stock growth) but comes at the cost of reducing TACs sharply (short term reductions, but could increase rapidly again depending on recruitment). Invariably a higher λ implies more interannual variability (possibly even with 20% rule). A lower lambda reduces the chances of over-reacting to a noisy survey.
The min(I_{rec}/I_{tirg}, 1) components means that at or above the index trigger value the HCR follows the λSlp component completely, below the trigger the advised TAC is reduce depending on how far below the recent index values are (following a linear line to the origin). This component should theoretically help maintain stocks above a certain SSB level, rather than maintaining SSB size at the current level (something that has been a criticism of the ICES DLS category 3.2 approach in the past). However, if $I_{rec}/I_{tar} < 1$, using an average of recent years, then poor index years will have a sustained influence on average and the value could change sharply as these years drop out of the recent period (3 or 5 years later). Also, in the case of a recovering stock, the index would probably have to be above the trigger level for at least 2 years before the average became greater than the trigger level again. Using only the last year for I_{rec} would risk reacting too much to noise in the index leading to high inter annual variability (in the absence of a stabiliser), because it could lead to more drastic changes (larger than using an average would allow). This problem could be helped by using TAC change limits (though the limit could be hit often), or by changing the slope below I_{tar} and introducing an I_{stop}.

The TAC is to be revised annually from 2017 to 2026 based on the GLM index from the North Sea IBTS Q3 survey. For comparison purposes, the ICES DLS category 3.2 rule (the '2 vs 3' rule) was also applied. In some cases a +/-20% annual TAC change limit was applied (Table 5.3). A zero fishing scenario is included to indicate maximum recovery potential of the stock.

Table 5.3. The HCR formulations examined for North Sea horse mackerel.

HCR	TAC 2014-2016 (kt)	*Slp*	λ (slope multiplier)	TAC change limits
LL5_lam1_5k	5	5yr	1	-
LL3_lam05_5k	5	3yr	0.5	-
LL3_lam1_chngLim_5k	5	3yr	1	+/-20%
DLS_5k	5	Last 2yrs : Previous 3yrs	-	+/-20%
Zero_fishing	0	-	-	-

5.5 Performance Statistics

Given the current poor perceived state of the stock, short term considerations outweigh potential long term performance. Hence performance statistics are tailored to short term considerations to give an idea of the short term prospects for the fishery and the short term recovery of the stock (by 2020). A recovery of the stock above SSB_{2012} (lowest observed, candidate for B_{lim}) is considered the first priority. This recovery is unlikely by 2015, but should be expected at least by 2020 (European Union 2013). Expecting the lower 5th percentile of SSB in 2020 to be above the median SSB of 2012 is a very strict criterion because there is a more uncertainty in the forecasts than in the model fits. So three potential measures of recovery are examined:

- 1. $P(SSB_{\mathbf{50\%},2020}>SSB_{\mathbf{50\%},2012})$: Median SSB in 2020 should be above median SSB in 2012.
- 2. $P(SSB_{\mathbf{5\%},2020}>SSB_{\mathbf{5\%},2012})$: The 5th percentile of SSB in 2020 should be above the 5th percentile of SSB in 2012.
- 3. $P(SSB_{\mathbf{5\%},2020}>SSB_{\mathbf{50\%},2012})$: The 5th percentile of SSB in 2020 should be above the median SSB in 2012.

A number of standard biological and fishery indicators were retained from the simulations to analyse the outcomes. These are divided into fishery and stock metrics. For all metrics, medians are presented and for SSB the lower 5th percentiles. The metrics are evaluated at the following specific years and time horizons.

Landings:
- Annual values from 2014-2018
- Average values in the short term (2014-2018) and a ten year medium-term period following the initial three year constant TAC (2017-2026)

Spawner stock biomass:
- SSB in 2015 (initial target year for F_{MSY})
- SSB 2020 (secondary target year for F_{MSY})
- Median SSB_{2020}/SSB_{201} (values greater than one indicating recovery).
- Probability of recovery of the stock biomass above SSB_{2012} in 2020

Fishing mortality
- F in 2015 (initial target year for F_{MSY})
- F 2020 (secondary target year for F_{MSY})
- F/F_{MSY}, F/F_{35} (candidate Fmsy values) and F/F_{mean} (the mean F over the time series)

For each reference set (*decLim* and *rickSeg*) six assessment models are used. The results combined to produce single performance statistics for each reference set rather than presenting each operating model individually. Final results are summary statistics from of equal numbers of iterations for each assessment model – stock recruit relationship pairing.

6 Results

6.1 Constant catch

The runs of constant catch (CC) over the entire simulation period were done in order to obtain a general idea about the average level of catch that the stock may be expected to sustain in the short term whilst still allowing recovery of the stock. A range between zero catch and 20 kt was explored. Tables 6.1 summarises the results of these simulations. Figures 6.1 and 6.2 show the results in terms of projected landings, associated fishing mortalities and median and lower 5th percentile SSB, under the *declim* and *rickSeg* scenarios respectively.
Under the *decLim* scenario, catch up to 3kt would bring the SSB to above 2012 in 2020 with 95% probability and the median SSB trajectories of the runs including catch up to 11 kt increase to above the 2012 level (see table 6.2). Recruitment under this stock recruit relationship increases somewhat quicker throughout the projection period than in the *rickSeg* scenario, because of the steeper slope in the recruitment relationship, which allows quicker recovery of the stock.
Not even with zero catch throughout the time period is a 95% probability of recovering the stock to above the 2012 level expected (see table 6.3). Of the median SSB trajectories, the runs including up to 4 kt of constant catch increase to above the 2012 level. Recruitment under this reference set remains very low throughout the projection period, because of the very gradual slope in the recruitment relationship. This leads to only a very slow recovery of the stock.

Table 6.1. The probability of SSB in 2020 being above the median and 5th percentile of SSB in 2012 for the constant catch values examined. Values are rounded to the lowest 5% e.g. at 97% probability is given as 0.95. Bold values indicate a greater than 95% probability (i.e. the lower 5th percentile of the SSB_{2020} is greater than the median/5th percentile in 2012).

Constant Catch	decLim		rickSeg	
Catch level	Prob(SSB2020 > median SSB2012)	Prob(SSB2020 > 5th %ile SSB2012)	Prob(SSB2020 > median SSB2012)	Prob(SSB2020 > 5th %ile SSB2012)
20kt	0.1	0.15	<0.01	<0.01
15kt	0.3	0.4	0.05	0.05
12kt	0.45	0.6	0.1	0.15
11kt	0.5	0.65	0.1	0.15
10kt	0.6	0.7	0.15	0.2
9kt	0.65	0.75	0.2	0.3
8kt	0.7	0.8	0.2	0.35
7kt	0.75	0.85	0.3	0.4
6kt	0.8	0.9	0.35	0.5
5kt	0.85	0.95	0.45	0.55
4kt	0.9	0.95	0.5	0.65
3kt	0.95	0.95	0.55	0.75
0kt	0.95	0.95	0.85	0.95

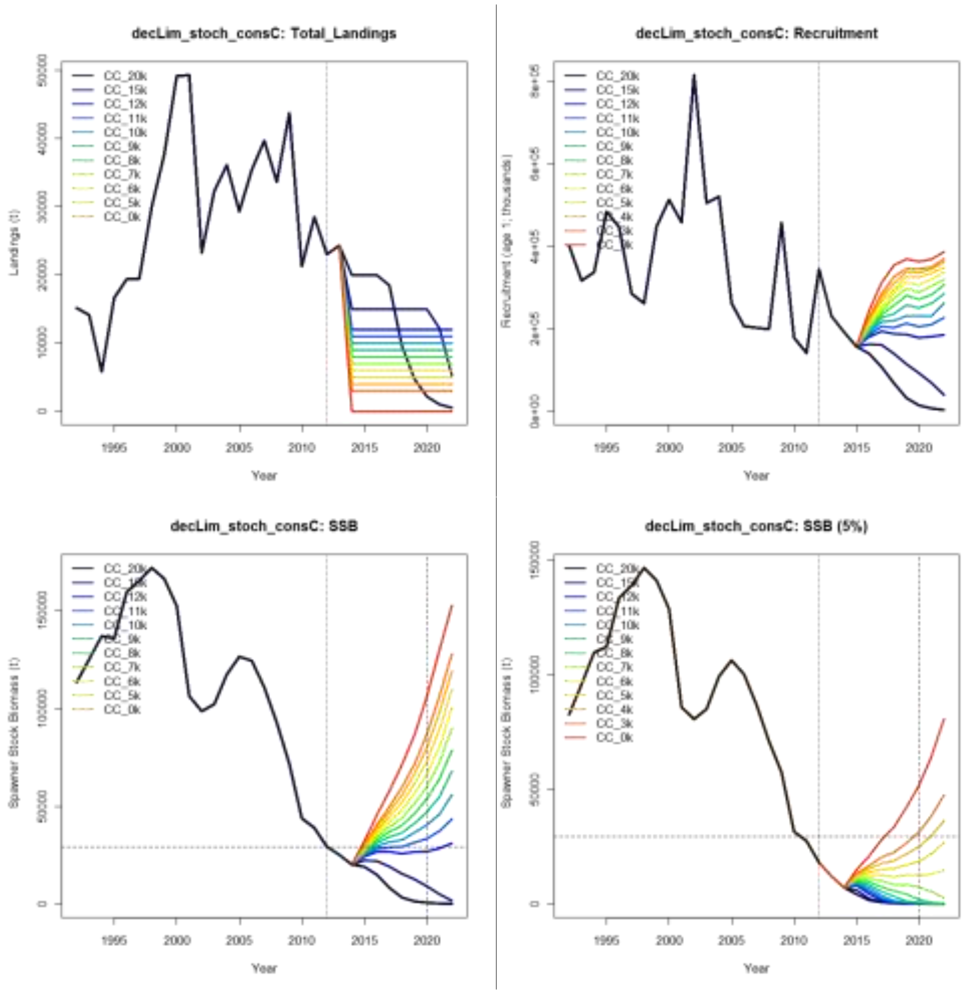


Figure 6.1. Median results of stochastic constant catch projections in the *decLim* reference set of operating models. Landings (top right), recruitment (top left), median SSB (bottom left) and the 5th percentile of SSB (bottom right). Vertical lines indicate 2012 (reference biomass point, dotted) and 2020 (target year for recovery, dashed). In the SSB plot the horizontal line indicates the median SSB in 2012.

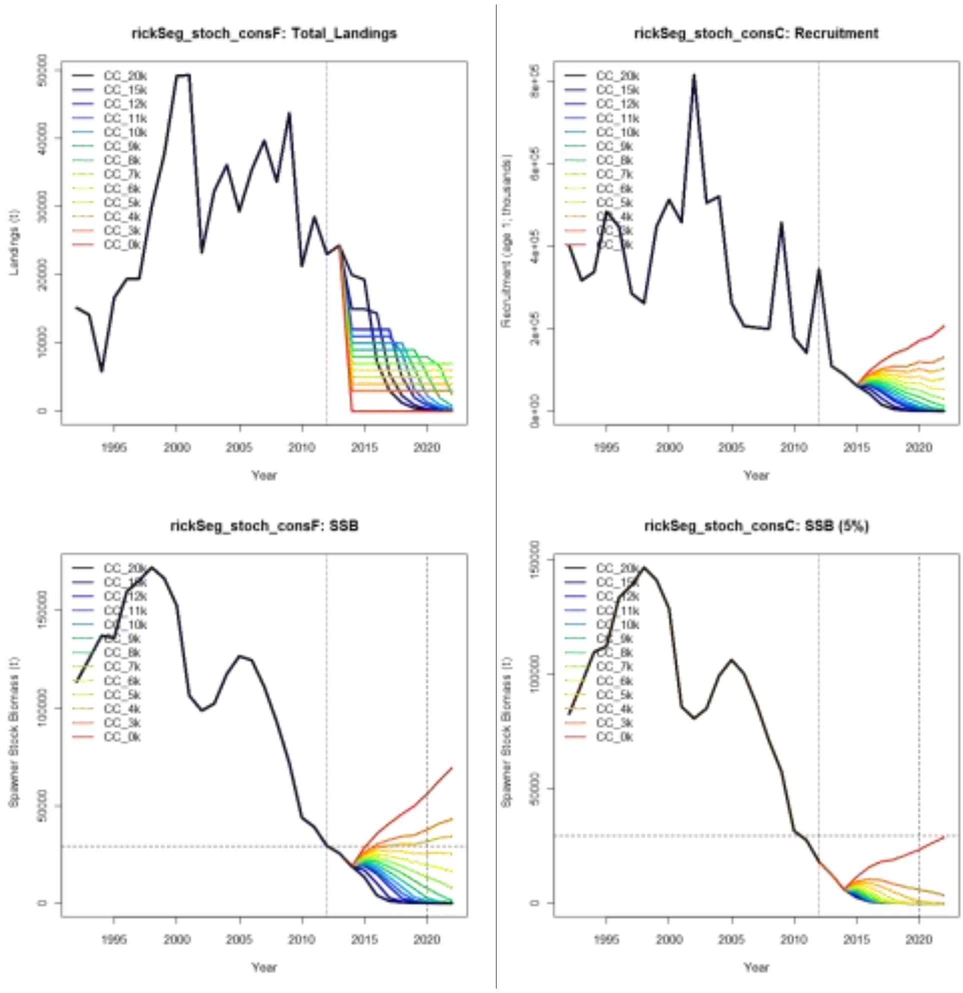


Figure 6.2. Median results of stochastic constant catch projections in the rickSeg reference set of operating models. Landings (top right), recruitment (top left), median SSB (bottom left) and the 5ht percentile of SSB (bottom left). Vertical lines indicate 2012 (reference biomass point, dotted) and 2020 (target year for recovery, dashed). In the SSB plot the horizontal line indicates the median SSB in 2012.

Table 6.2. Results of stochastic constant catch projections in the *decLim* reference set of operating models.

Constant Catch	Landings							SSB			Mean F (age 2-8)				
Catch level	2014	2015	2016	2017	2018	5yr Avg.	2017-2022 (MT avg.)	SSB 2015	SSB 2020	SSB2020 / SSB2012	F2015	F2020	F2020 / FMSY	F2020 / F35	F2020 / Fmean1992-2012
20kt	20000	20000	20000	18492	9642	17627	6111	19127	770	0.03	0.77	1.92	8	13.71	3.76
15kt	15000	15000	15000	15000	15000	15000	12909	22389	9178	0.31	0.46	1.24	5.19	8.89	2.44
12kt	12000	12000	12000	12000	12000	12000	12000	24284	26941	0.92	0.33	0.29	1.21	2.07	0.57
11kt	11000	11000	11000	11000	11000	11000	11000	24911	33494	1.14	0.29	0.21	0.89	1.53	0.42
10kt	10000	10000	10000	10000	10000	10000	10000	25557	40557	1.38	0.26	0.16	0.67	1.14	0.31
9kt	9000	9000	9000	9000	9000	9000	9000	26234	47060	1.6	0.22	0.12	0.51	0.87	0.24
8kt	8000	8000	8000	8000	8000	8000	8000	26914	53868	1.83	0.19	0.09	0.4	0.68	0.19
7kt	7000	7000	7000	7000	7000	7000	7000	27489	60043	2.04	0.16	0.07	0.31	0.53	0.14
6kt	6000	6000	6000	6000	6000	6000	6000	28186	66466	2.26	0.13	0.06	0.24	0.41	0.11
5kt	5000	5000	5000	5000	5000	5000	5000	28846	73003	2.48	0.11	0.04	0.18	0.31	0.09
4kt	4000	4000	4000	4000	4000	4000	4000	29481	79902	2.72	0.08	0.03	0.13	0.23	0.06
3kt	3000	3000	3000	3000	3000	3000	3000	30119	86885	2.96	0.06	0.02	0.09	0.16	0.04
0kt	0	0	0	0	0	0	0	32488	108041	3.68	0	0	0	0	0

Table 6.3. Results of stochastic constant catch projections in the *rickSeg* reference set of operating models.

Constant Catch	Landings							SSB			Mean F (age 2-8)				
Catch level	2014	2015	2016	2017	2018	5yr Avg.	2017-2022 (MT avg.)	SSB 2015	SSB 2020	SSB2020 / SSB2012	F2015	F2020	F2020 / FMSY	F2020 / F35	F2020 / Fmean1992-2012
20kt	20000	19313	7254	3017	1235	10164	832	13430	84	0	1.47	2.03	25.37	20.3	3.98
15kt	15000	15000	14376	5494	2300	10434	1540	16956	161	0.01	0.85	1.98	24.79	19.83	3.89
12kt	12000	12000	12000	11999	5051	10610	3391	19170	367	0.01	0.54	1.87	23.31	18.65	3.66
11kt	11000	11000	11000	11000	8569	10514	4125	19846	562	0.02	0.47	1.77	22.12	17.69	3.47
10kt	10000	10000	10000	10000	10000	10000	4978	20583	1017	0.03	0.4	1.63	20.39	16.31	3.2
9kt	9000	9000	9000	9000	9000	9000	5870	21334	2776	0.09	0.34	1.41	17.61	14.09	2.76
8kt	8000	8000	8000	8000	8000	8000	6860	22075	7742	0.26	0.29	0.97	12.1	9.68	1.9
7kt	7000	7000	7000	7000	7000	7000	7000	22861	13467	0.46	0.24	0.43	5.31	4.25	0.83
6kt	6000	6000	6000	6000	6000	6000	6000	23589	19570	0.67	0.2	0.24	2.99	2.4	0.47
5kt	5000	5000	5000	5000	5000	5000	5000	24348	25566	0.87	0.16	0.15	1.85	1.48	0.29
4kt	4000	4000	4000	4000	4000	4000	4000	25084	31617	1.08	0.12	0.09	1.16	0.93	0.18
3kt	3000	3000	3000	3000	3000	3000	3000	25933	37661	1.28	0.09	0.06	0.72	0.58	0.11
0kt	0	0	0	0	0	0	0	28207	56327	1.92	0	0	0	0	0

6.2 Constant F simulations

The results of the stochastic constant F projections for the *decLim* reference set are shown in Figure 6.3 and Table 6.5, and the results for the *rickSeg* reference set are shown in Figure 6.4 and Table 6.6. The overall results are summarized in Tables 6.4.

Fishing at the three year (2010-2012) average fishing mortality would lead to a reduction in SSB of 50% by 2020 compared to 2012 under *decLim* recruitment and a greater than fivefold reduction under *rickSeg* recruitment, and is clearly unsustainable in the short or medium term. Zero fishing allows for a more than threefold increase in SSB by 2020.

In the *decLim* reference set a constant F=0.31 (greater than F_{MSY}) allows for the median SSB to recover above median SSB_{2012} by 2020 with an average catch in the first five years of 9.6kt. At F=0.21 (less than F_{MSY} but greater than F_{35}) the 5th percentile of SSB_{2020} is greater than the 5th percentile of SSB_{2012} and the short term average catch is 8.6kt. To recover the 5th percentile of SSB above median SSB_{2012} by 2020 requires a large reduction in fishing mortality to F=0.10, with average short term catches of 5.1kt.

In the *decLim* reference set, all runs except for zero fishing and the current F, landings are strongly reduced in the first year and then gradually increase over time as the stock recovers. In these scenarios, the medium term landings (2017-2026) are all forecast to be higher than the short term (2014-2018) landings and median SSB is forecast to increase above the 2012 level by 2020 in these cases. Only the $F_{med2020>2012}$ and current F runs have fishing mortality in 2015 and 2020 that is greater than the estimated F_{MSY} for this reference set.

Much lower catches are required to ensure recover of the stock in the *rickSeg* reference set compared to the *decLim* reference set. Only F values at 0.12 or lower, corresponding to average catches of approximately 3.9kt over the first 5 years allow for the median SSB_{2020} to be greater than the median SSB_{2012}. This implies that a five-fold reduction in catch is required compared to current levels to achieve any likelihood of recovery.

In the *rickSeg* reference set, fishing at F_{MSY} (F=0.08) allows for the median SSB to recover above median SSB_{2012} by 2020 but with an average catch of only 2.8kt in the first five years. At F=0. 1 (F_{35}, an alternative to F_{MSY}) the median SSB_{2020} still recovers the median biomass above SSB_{2012} with slightly higher average catch (3.4kt).

Table 6.4. The probability of SSB in 2020 being above the median and 5^{th} percentile of SSB in 2012 for the constant F values examined. Values are to the lowest 5% e.g. at 97% probability is given as 0.95. Bold values indicate a greater than 95% probability (i.e. the lower 5^{th} percentile of the SSB_{2020} is greater than the median/5^{th} percentile in 2012).

Constant F	decLim		rickSeg	
F level	Prob(SSB2020 > median SSB2012)	Prob(SSB2020 > 5th %ile SSB2012)	Pr Prob(SSB2020 > median SSB2012)	Prob(SSB2020 > 5th %ile SSB2012)
Current (3yr avg.)	<0.01	0.2	0.01	<0.01
FMSY	0.7	0.9	0.6	0.8
F35	0.85	0.95	0.55	0.75
Fmed2020>2012	0.5	0.75	0.5	0.7
F5%2020>5%2012	0.75	0.95	*	*
F5%2020>2012	0.95	0.95	*	*
0	0.95	0.99	0.8	0.9

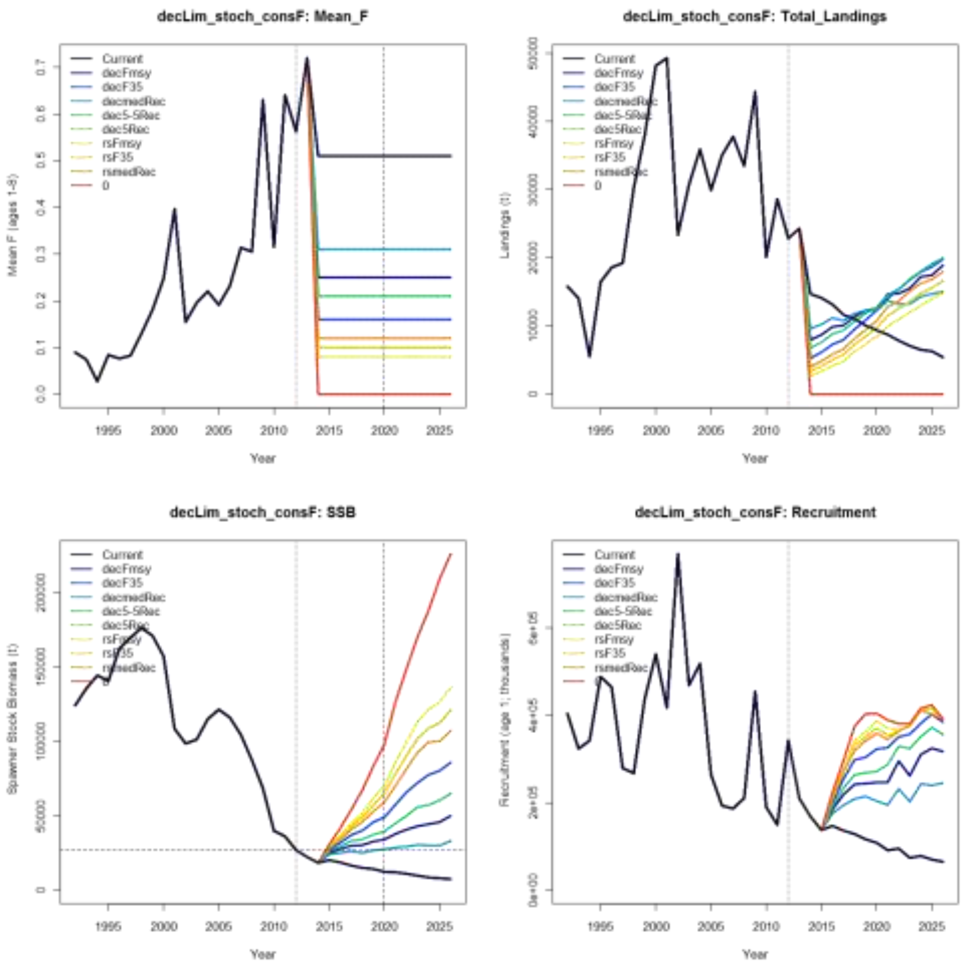


Figure 6.3. Median results of stochastic constant F projections in the *decLim* reference set of operating models. Fishing mortality (mean ages 2-8, top left), associated landings (top right), SSB (bottom left) and recruitment (bottom left). Vertical lines indicate 2012 (reference biomass point, dotted) and 2020 (target year for recovery, dashed). In the SSB plot the horizontal line indicates the median SSB in 2012.

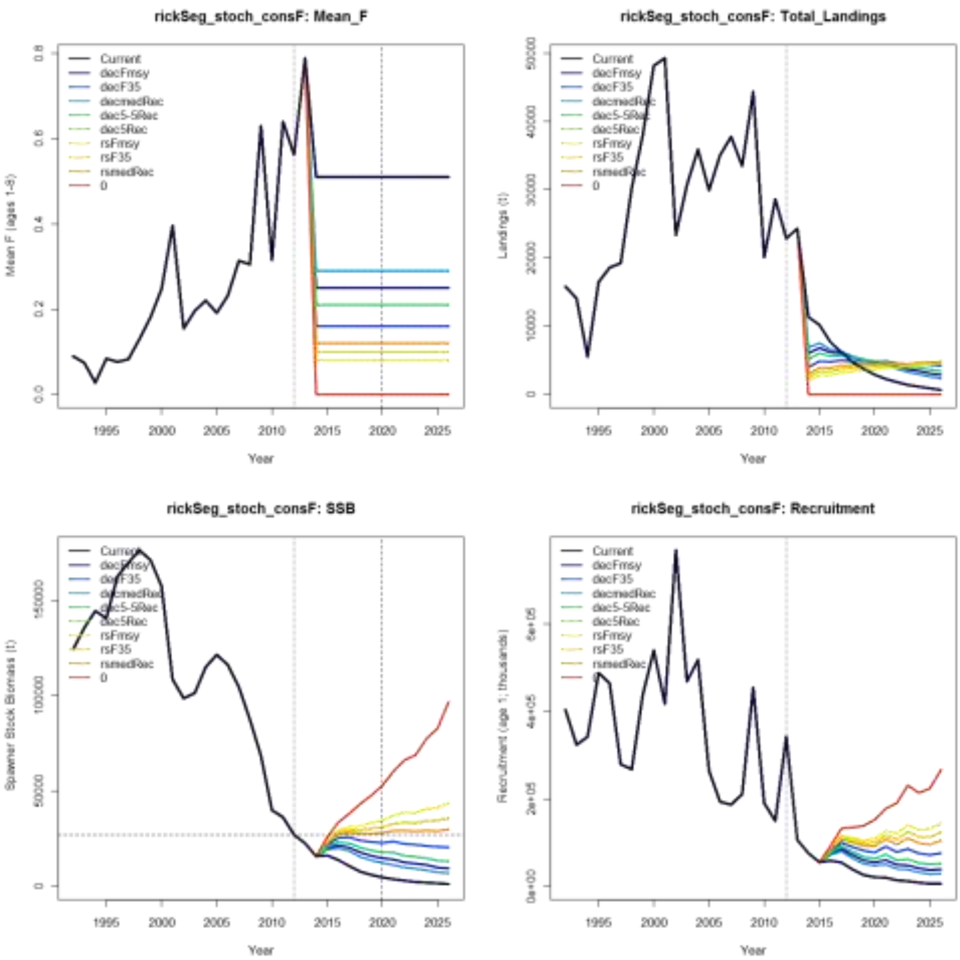


Figure 6.4. Median results of stochastic constant F projections in the *rickSeg* reference set of operating models. Fishing mortality (mean ages 2-8, top left), landings (top right), SSB (bottom left) and recruitment (bottom left). Vertical lines indicate 2012 (reference biomass point, dotted) and 2020 (target year for recovery, dashed). In the SSB plot the horizontal line indicates the median SSB in 2012.

Table 6.5. Results of stochastic constant F projections in the *decLim* reference set of operating models.

Constant F	Landings							SSB			Mean F (age 2-8)				
F level	2014	2015	2016	2017	2018	2014-2018 (5yr avg.)	2017-2026 (MT avg.)	SSB 2015	SSB 2020	SSB2020 / SSB2012	F2015	F2020	F2020 / FMSY	F2020 / F35	F2020 / Fmean1992-2012
Current (3yr avg.)	14719	14137	13174	11658	11057	12949	8421	20244	12423	0.46	0.51	0.51	2.04	3.64	2.04
FMSY	7962	8728	9893	10118	11364	9613	14507	25238	34113	1.26	0.25	0.25	1	1.79	1
F35	5280	6174	7315	7991	9538	7260	14339	27163	49095	1.82	0.16	0.16	0.64	1.14	0.64
Fmed2020>2012	9645	10252	11204	10820	11852	10755	13160	24063	27457	1.02	0.31	0.31	1.24	2.21	1.24
F5%2020>5%2012	6794	7615	8848	9400	10671	8666	14882	26075	39579	1.47	0.21	0.21	0.84	1.5	0.84
F5%2020>2012	3380	4127	5054	5831	7262	5131	11613	28475	64954	2.41	0.1	0.1	0.4	0.71	0.4
0	0	0	0	0	0	0	0	32488	108041	3.68	0	0	0	0	0

Table 6.6. Results of stochastic constant F projections in the *rickSeg* reference set of operating models.

Constant F	Landings							SSB			Mean F (age 2-8)				
F level	2014	2015	2016	2017	2018	2014-2018 (5yr avg.)	2017-2026 (MT avg.)	SSB 2015	SSB 2020	SSB2020 / SSB2012	F2015	F2020	F2020 / FMSY	F2020 / F35	F2020 / Fmean1992-2012
Current (3yr avg.)	11351	10202	7657	6191	4748	8030	2578	16232	4672	0.17	0.51	0.51	7.29	5.67	2.04
FMSY	2075	2704	2851	3168	3344	2828	3894	23500	34603	1.28	0.08	0.08	1.14	0.89	0.32
F35	2572	3292	3413	3715	3854	3369	4262	22994	30959	1.15	0.1	0.1	1.43	1.11	0.4
Fmed2020>2012	3061	3855	3920	4212	4275	3865	4517	22499	28021	1.04	0.12	0.12	1.71	1.33	0.48
F5%2020>5%2012	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
F5%2020>2012	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
0	0	0	0	0	0	0	0	28207	56327	1.92	0	0	0	0	0

*Even 0 fishing does not recover SSB, no F value.

6.3 Harvest Control Rule examination

For examination of the performance of several HCRs, runs were conducted assuming an arbitrary low level of landings in the first three years of 5 kt (which is the highest possible catch with a 95% probability of bringing SSB above the 5th percentile of the SSB_{2012} estimate under both SRR scenarios), in order to investigate the performance of the HCRs in the medium term and make their performance slightly less sensitive to the starting conditions. The results are summarized in Table 6.7. Starting with a constant catch of 5k for three years increases the chances of the stock having a >50% probability of SSB2020>SSB2012 (i.e. stop decline of the stock).

In all cases landings drop below 5kt following the end of the constant catch period. Landings remain low in the short and medium term. This highlights the need for a more drastic reduction in catch in the short term.

Though median recovery is strong in the *decLim* reference set, none of the HCRs allow for the 5th percentile of SSB in 2020 to be greater than median SSB in 2012. See table 6.8 Figure 6.5. In the *rickSeg* reference set (see Table 6.9 and Figure 6.6), median recovery is barely achieved by all HCRs, though the two HCRs with interannual TAC change constraints show low probabilities of SSB_{2020} $>SSB_{2012}$. The lower 5th percentiles of SSB in the *rickSeg* reference set remain far below SSB_{2012}. The 3 year slope HCR with lambda=1 and 20% catch constraint limits surprisingly has lower interannual variability than the supposedly more stable 5 year slope HCR with the same lambda and no catch constraints. This is most likely because, at the time when the declining trend in the SSB starts to reverse and in fact is level for a few years, the 3-year slope HCR keeps the TAC also stable, while the 5-year HCR continues longer with declines, after which quickly changes to increases again. The 3 year slope would also lead to a sooner increase in TAC in a recovering stock for the same reason.

The landings in the HCRs without catch constraints fall less than the other HCRs after the constant catch period since the maximum 20% reduction comes into effect. This leads to larger catches at the cost of slower recovery in the short term.

Table 6.7. The probability of SSB in 2020 being above the median and 5th percentile of SSB in 2012 for the harvest control rules examined. Values are rounded to the lowest 5% e.g. at 97% probability is given as 0.95. Bold values indicate a greater than 95% probability (i.e. the lower 5th percentile of the SSB_{2020} is greater than the median/5th percentile in 2012).

HCRs	decLim		rickSeg	
HCR	Prob(SSB2020 > median SSB2012)	Prob(SSB2020 > 5th %ile SSB2012)	Prob(SSB2020 > median SSB2012)	Prob(SSB2020 > 5th %ile SSB2012)
LL_5yr_lam1	0.9	0.95	0.55	0.75
LL_3yr_lam0.5	0.9	0.95	0.55	0.75
LL_3yr_lam1 (20% TAC change limits)	0.85	0.95	0.45	0.65
DLS (20% TAC change limits)	0.9	0.95	0.45	0.65
0kt	0.95	>0.99	0.85	0.95

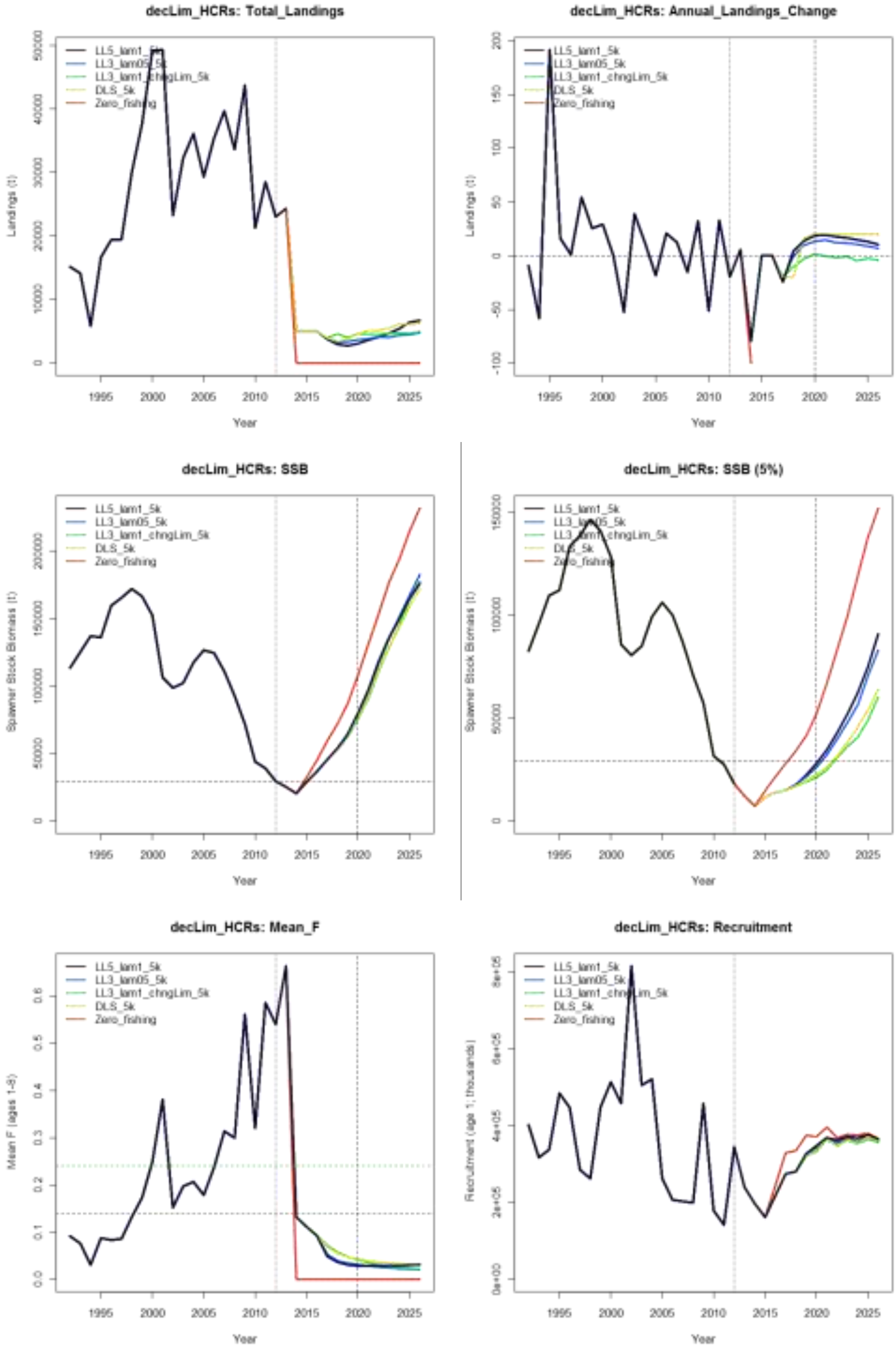


Figure 6.5. Median results of the harvest control rule projections in the *decLim* reference set of operating models. Total landings (top left), annual change in landings (top right), median SSB (middle left) and 5th percentile SSB (middle right), fishing mortality (mean ages 2-8, bottom left), and recruitment (bottom right). Vertical lines indicate 2012 (reference biomass point, dotted) and 2020 (target year for recovery, dashed). In the SSB plot the horizontal line indicates the median SSB in 2012.

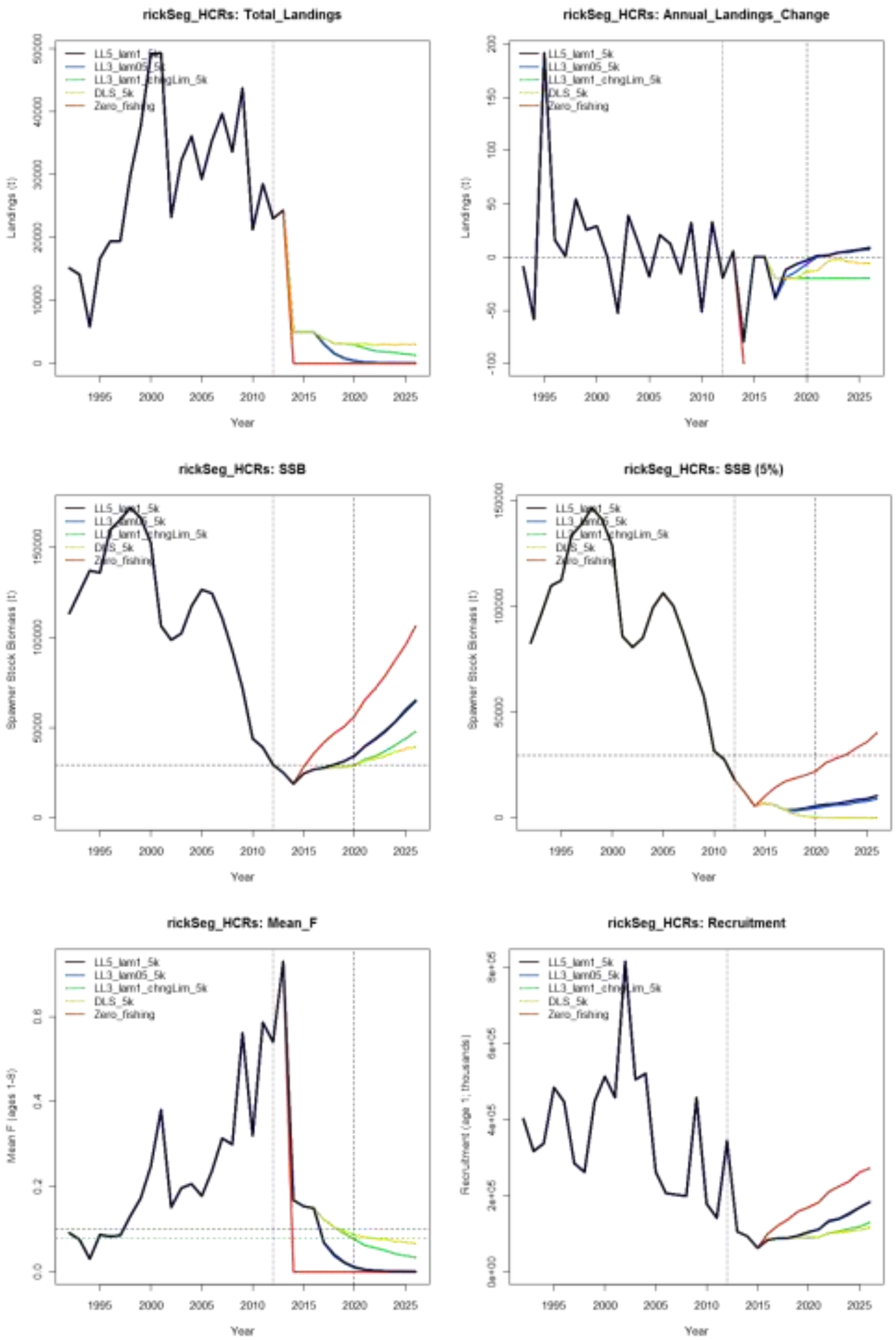


Figure 6.6. Median results of the harvest control rule projections in the rickSeg reference set of operating models. Total landings (top left), annual change in landings (top right), median SSB (middle left) and 5th percentile SSB (middle right), fishing mortality (mean ages 2-8, bottom left), and recruitment (bottom right). Vertical lines indicate 2012 (reference biomass point, dotted) and 2020 (target year for recovery, dashed). In the SSB plot the horizontal line indicates the median SSB in 2012.

Table 6.8. Results of harvest control rule projections in the *decLim* reference set of operating models.

HCR	Landings							IAV	SSB			Mean F (age 2-8)				
HCR	2014	2015	2016	2017	2018	5yr Avg.	2017-2026 (MT avg.)	Avg. Landings abs(change) 2017-2026	SSB 2015	SSB 2020	SSB2020 / SSB2012	F2015	F2020	F2020 / FMSY	F2020 / F35	F2020 / Fmean1992-2012
LL_5yr_lam1	5000	5000	5000	3772	2945	4343	4351	15	28872	79838	2.72	0.11	0.03	0.12	0.2	0.06
LL_3yr_lam0.5	5000	5000	5000	3907	3273	4436	3985	11	28872	79165	2.69	0.11	0.03	0.13	0.22	0.06
LL_3yr_lam1 (20% TAC change limits)	5000	5000	5000	4001	4580	4716	4533	5	28872	75706	2.58	0.11	0.04	0.17	0.29	0.08
DLS (20% TAC change limits)	5000	5000	5000	4000	3434	4487	5014	20	28872	76767	2.61	0.11	0.04	0.18	0.31	0.08
0kt	0	0	0	0	0	0	0	0	32488	108041	3.68	0	0	0	0	0

Table 6.9. Results of harvest control rule projections in the *rickSeg* reference set of operating models.

HCR	Landings							IAV	SSB			Mean F (age 2-8)				
HCR	2014	2015	2016	2017	2018	5yr Avg.	2017-2026 (MT avg.)	Avg. Landings abs(change) 2017-2026	SSB 2015	SSB 2020	SSB2020 / SSB2012	F2015	F2020	F2020 / FMSY	F2020 / F35	F2020 / Fmean1992-2012
LL_5yr_lam1	5000	5000	5000	3082	1639	3944	665	9	24446	34250	1.17	0.15	0.01	0.14	0.11	0.02
LL_3yr_lam0.5	5000	5000	5000	3024	1566	3918	644	10	24446	34422	1.17	0.15	0.01	0.12	0.1	0.02
LL_3yr_lam1 (20% TAC change limits)	5000	5000	5000	4000	3200	4440	2419	20	24446	29243	0.99	0.15	0.08	0.96	0.77	0.15
DLS (20% TAC change limits)	5000	5000	5000	4000	3200	4440	3166	11	24446	28970	0.99	0.15	0.09	1.09	0.87	0.17
0kt	0	0	0	0	0	0	0	0	28207	56327	1.92	0	0	0	0	0

7 Discussion

7.1 General interpretation of results

The available data suggest that the North Sea horse mackerel stock is currently at a low biomass in relation to levels in the late 1990s. Recent IBTS surveys have had a high proportion of 0 hauls and low CPUEs. Alternative methods of calculating the index from the raw data (e.g. delta-lognormal method, GLM analysis or simple mean CPUE of all hauls) indicate that the stock is near the lowest level observed. As a result, all exploratory assessment models fit to these data estimate that current SSB is near the lowest observed. Fishing mortality has been above fishing mortality levels suggested for Fmsy (proxies), especially in the recent past and a reduction in catches in the short term is therefore required to allow for recovery of the stock.

In terms of providing an estimation of what level of catch the stock could take in the short term, the MSE results are highly sensitive to the choice of stock-recruit relationship (SRR), especially in the short term. SRRs with a low steepness (e.g. Ricker and most segmented regressions) allow for high recruitments at high SSB, but lead to forecasted very low recruitment in the short term since SSB currently is estimated to be very low. Conversely, SRRs with a higher steepness (e.g. geometric mean with declining recruitment to the origin from the lowest observed SSB) have a lower average recruitment at higher SSBs but allow for higher recruitment at a low SSB. These allow for the stock to recover at a quicker rate from the current low SSB and allow for higher catches to be taken from the stock in the short to medium term.

7.2 Limitations to this study

Survey data

North Sea horse mackerel is a data limited stock with large uncertainties in stock boundaries, the origin of caught fish and the applicability of available survey data. During the course of the project, the IBTS survey data was explored. Alternative indices were prepared treating the data in different ways (GLM and DLN). This much improved the way that the noisy survey data is treated in comparison to previous WGWIDE attempts. One other source of information was crudely explored, namely landings per unit effort (lpue) from the Dutch beam trawl fleet, for an impression of trends in catch rates of a fishery that does not target this species, so may be considered as an independent source of information. Figure 7.1 shows an overall decreasing trend in lpue of this fleet, which is in accordance with the overall trend observed in the index. These data were not used in the assessment however, because since the demersal fleet does not target this species discards may occur and the catch per unit effort (cpue) might look differently. There is not enough data on discards of horse mackerel of this fleet available however to establish a reasonably credible index to be used.

It is unfortunate that the survey data on zero and one year old fish could not be used because the quality was considered too poor, which possibly has to do with the fact that the survey does not quite go close enough inshore where these youngest fish reside. For future purposes, it may still be useful to explore the potential of inshore survey data, such as from the Sole Net Survey (SNS) or the Demersal Fish Survey (DFS) for establishing an appropriate recruitment index, from which the assessment model would greatly benefit. Both surveys take place near shore along the Dutch coast in autumn where juveniles may be expected to reside at that time.

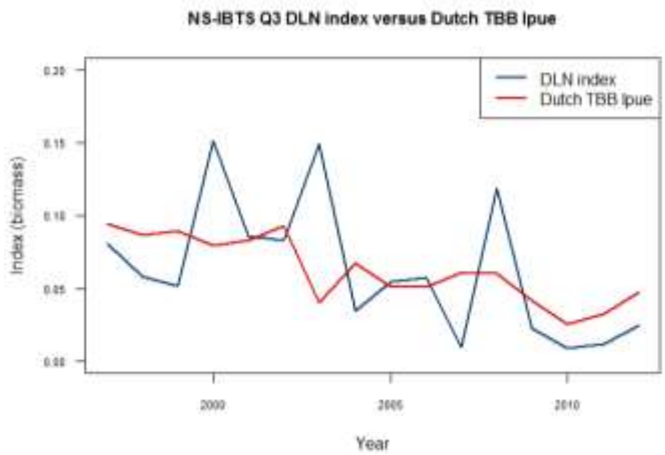


Figure 7.1. Comparison of a biomass index computed from IBTS data (using a Delta Log-Normal model (DLN)) and an lpue index computed from landings and effort in the Dutch demersal fleet, where horse mackerel is caught as a bycatch species.

Catch data

In this case however, the age composition of the catches appear to vary almost annually in accordance with the area where most catches are taken. This is to be expected considering that the youngest fish reside in the North Sea, while the older fish move to over-wintering areas further South (Lockwood and Johnson, 1977). In the absence of a recruitment index to be included in the model, catch data forms the only source of information on the relative strength of incoming year classes. When the proportion of catch from area IV is relatively high, more young fish (age-1 and age-2) are present in the catches. So the location of fishing clouds the signal on incoming year classes in the catch data. One possible solution to this would be to compile separate catch-at-age matrices for the two different areas, which would allow for separate estimation of selectivity for two fleets in the different areas. This was not available at the time of the current project being conducted, but would also be problematic to compile from the data available given the occurrence of misreporting in the past (see Section 3.2).

In addition, it is likely that an inter-annually varying proportion of the commercial catches in VIId come from the western horse mackerel stock, so the actual removals from the North Sea stock are less than those estimated. The assessment models assume zero mixing, and the stock dynamics are thus defined 'taking this into account'. In other words, it can be considered that advice on landings ignore the possible mixing and its consequent uncertainties in consistence with the way that the assessment model ignore it. It may however be expected that with the low level of SSB at present, the *proportion* of Western horse mackerel in the catches in area VIId has increased, which may be cause for a bias in the assumption, rather than uncertainty and could lead to an underestimate of the catch that could be sustained in the stock management area.

Generally speaking, any long-term management plan is most effective when its measures apply to all fisheries exploiting the stock and when catches can be identified as originating from that stock with some certainty. Considering the potential of mixing between Western and North Sea horse mackerel occurring in area VIId, better insight in the origin of landings from that area will be a major benefit, if not crucial (see e.g. Hintzen et al 2014), for improvement of the quality of future scientific advice and thus management of the North Sea horse mackerel stock.

Visually, individuals from the two stocks cannot be distinguished, which makes it difficult to discriminate between them after they are landed. In comparable situations, with mixing of herring stocks which are caught together (in ICES area IIIa for instance), allocation of those landings against the two stocks is done by determining the mixing ratio in the catch based on investigation of otolith shape. This technique, however, cannot be applied for horse mackerel because otolith characteristics are not distinctly different enough between the two stocks.

Another way to possibly distinguish between individuals of the two stocks is with the GCxGC-MS (Gas chromatography x Gas chromatography–mass spectrometry). This technique uses a 'fingerprint', showing the chemicals in the fish muscle tissue, which have accumulated there through feeding and respiration. Because individuals of the two stocks typically reside in different feeding areas (for at least a good part of the year), they may have absorbed different chemicals, resulting in distinguishable fingerprints. Other studies by IMARES (mostly in freshwater systems) have shown to be very effective in distinguishing between individual fish that forage in different locations. A pilot project aimed at determining whether this technique could be used for distinguishing between Western and North Sea horse mackerel is currently underway.

7.3 Outlook for 2015-2017

In short, the results from the exploratory assessment model runs and the evaluation of expected future performance of the stock are rather pessimistic. Depending on the SSR scenario (*segRick* or *decLim*), the suggested level of catch in the next few years which could allow for a reversal in the declining trend in SSB and bring SSB to above the SSB_{2012} level vary.

Determining what levels of TACs will lead to this level of catch is problematic, because of the consistent underutilisation in the TAC observed in recent years due to the absence of the Danish fishery (see Section 3.2). In order to reduce the fishing opportunities for those fleets who do utilise their quota not more drastically than necessary, this underutilisation could be taken into account when establishing the level of the TAC. In addition, a reduction in TAC would naturally only be effective if the TAC would be restrictive to the collective of all countries exploiting the stock, i.e. including Norway, which has caught highly variable but occasionally substantial quantities.

Expectations on recovery rate of the stock are here based on traditional SRRs, where it is assumed that recruitment is reduced at low stock sizes (such as presently observed). Western horse mackerel is known however for its unpredictable recruitment success, illustrated by the two largest year classes in 1982 and 2001, which were produced at the two lowest observed levels of SSB. There is some anecdotal evidence suggesting that one or more relatively strong year classes may have been produced in recent years in the North Sea. Firstly, in March 2013, one of the pelagic fishing companies reported that they had encountered substantial quantities of juvenile horse mackerel in the Southern North Sea during their fishery, of which they brought samples to IMARES. Secondly, a near shore survey conducted in the 'Voordelta' area by IMARES which took place for the 4th consecutive year, caught a large number of juvenile horse mackerels in summer – fairly consistently during all hauls – in contrast to hardly any individuals in the years before. These two incidents might signal a relatively stronger year class in 2013. In addition, the bycatch quota provided to the Dutch demersal fleet was exhausted approximately mid-year in 2013, which was considered very early in comparison to other years when the bycatch quota had been sufficient for the entire year of the fishing operation. This may have been the result of a change in behaviour in the demersal fishery, e.g. in response to a change in market conditions, or it could be a sign of increased abundance of the fish. Although naturally it is not possible to incorporate these observations into the evaluation, if they are a true reflection of actual events, then this may lead to a more rapid recovery of the stock than the results of the current study suggest. This should then be measurable in the IBTS survey data in upcoming years, in which case management measures can be revised accordingly.

Lastly, considering that the chances for successful recovery of this stock in the upcoming years partly depends on the strength of the incoming year classes, as well as giving these year classes the chance to reach maturity and contribute to future year classes, fisheries targeting juveniles should be limited to increase the probability of a successful recovery of the stock..

Juvenile horse mackerel from the Southern North sea, provided to IMARES by the Dutch industry in March 2013.

8 Conclusions

Given the current poor state of the stock, short term considerations outweigh potential long term performance. With the limited data used in the assessment and the uncertainty associated with the resulting stock dynamics (stock recruitment relationship in particular), longer term implications are likely to be highly dependent on the assumptions made in the assessment model and forecast model. The immediate concern is to decrease fishing mortality and prevent the further decline of the stock. The stochastic 100 year projections including a wide range of constant F levels provide estimates for candidate Fmsy reference points (or proxies). Table 8.1 summarises the results. Potential candidate values defining a range could be between 0.10 – 0.14 on the basis of the F associated to producing 35% of the virgin biomass. These values lay some distance away from the F_{crash} and are thus more precautionary than the direct Fmsy estimates. At the same time, the flat-topped nature of the equilibrium yield curves suggests that little potential of extra yield in the long term is lost.

Table 8.1. Summary of results from stochastic equilibrium yield analyses (100 year projections)

	MSY			35% SPR				SSB<0.01*SSB0	
	FMSY	Max. Yield (kt)	SSBMSY	Virgin Biomass	F35SPR	Y35SPR	SSB35SPR	Fcrash	5% Fcrash
decLim	0.24	23.9	73.6	339.3	0.14	21.8	116.8	0.45	0.35
rickSeg	0.08	22.9	221.1	498.4	0.1	21.5	168.4	0.22	0.15

The evaluation results provide numerous options for consideration, with all differing expectations on short, medium and long term yield and probability of recovery of SSB. Table 8.2 summarises the implications of three options for the two SSR scenarios. The two scenarios provide differing outlooks, and as 'best case' and 'worst case' scenarios, they describe the range of options considered suitable for further consideration by managers.

Table 8.2. Candidate management options for the short term.

		FMSY	F35	$F_{med2020}$>F_{2012}
decLim	Prob. (SSB2020 > median SSB2012)	0.7	0.85	0.5
	Prob. (SSB2020 > 5th %ile SSB2012)	0.9	0.95	0.75
	Mean landings first 3 years	8861	6256	10367
	Expected mean landings 2017-2026	14507	14339	13160
rickSeg	Prob. (SSB2020>median SSB2012)	0.6	0.55	0.5
	Prob. (SSB2020>5th %ile SSB2012)	0.8	0.75	0.7
	Mean landings first 3 years	2543	3092	3612
	Expected mean landings 2017-2026	3894	4262	4517

The special request sent to ICES asked "to assess whether the proposal as presented in Appendix A is precautionary and if it will deliver Fmsy by 2015 or 2020 at the latest". It was decided at the WKHOMMP meeting that with simulations including a constant catch or a constant F, the focus of the evaluations should rather be on what level the catch could be in the short term in order to reverse the declining trend in the stock than on the performance of the HCRs.

Investigation of how the HCRs performed in comparison to each other in the long term, was investigated as a hypothetical exercise however. The current evaluation results, suggest that the HCR based on a log-linear regression interpretation of the slope with a lambda value of 0.5 performs relatively well. It showed a lower interannual variability than when a 5 year slope was used but still responded most quickly to changes (markedly a reverse) in the trend of the index. This is most likely because, at the time when the declining trend in the SSB starts to reverse and in fact is level for a few years, the 3-year slope HCR keeps the TAC also stable, while the 5-year HCR continues longer with declines, after which quickly changes to increases again. At the same time it indicated more recovery in SSB than the DLS rule or the HCR including a 20% constraint in TAC change.

It is however recommended that the situation is re-evaluated in 3 years' time, to assess whether the stock has shown some signs of recovery and conduct new simulations. In case that recent stronger year classes as speculated upon indeed have occurred, the starting point for simulations may be different at that time which may affect the choice of preferred HCR.

9 North Sea horse mackerel research priorities

There are a number of challenges fitting an assessment model for the North Sea horse mackerel stock: the stock boundaries are unclear, few reliable stock size indicators are available, aging of horse mackerel is difficult and there is consequently a lack of strong cohort signals in the catch at age data. While an assessment model is not necessarily essential for management of the stock, some measures of the changes in stock size over time in response to the fishery are required before reliable quantitative advice can be provided for this stock.

Stock boundaries and mixing

For effective fish stock management it is necessary to have management measures which apply to all fisheries exploiting a stock and thus to be able to identify catches as originating from that stock. Considering the potential of mixing between Western and North Sea horse mackerel occurring in Division VIId/VIIe, better insight into the origin of catches from that area will be a major benefit for improvement of the quality of future scientific advice and thus management of the North Sea and Western horse mackerel stocks. This could be achieved by:

- Actively engaging the industry in data collection Application of GCxGC-MS (Gas chromatography x Gas chromatography–mass spectrometry). A pilot project aimed at determining whether this technique could be used for distinguishing between Western and North Sea horse mackerel was planned at IMARES but due to funding restrictions this is unlikely to proceed further.
- Methods for distinguishing between fish of North Sea or Western origin in the catches in this region (e.g. genetics, otolith shape analyses) should be explored. Some of these methods have been attempted in the past (e.g. HOMSIR project), but improvements in technology and reductions in the costs involved in such work may in future allow for more thorough applications with clearer results.

Reliable stock size indicators

The IBTS survey used to develop indices for this stock is a bottom trawl survey targeting primarily ground fish (gadoids), but also catching pelagic species (e.g. horse mackerel). Although it covers the area of the North Sea where the population is thought to be in Quarter 3, it does not cover Division VIId where the majority of the fishery occurs (in Quarter 1 and 4). With an apparently record low level of the stock size, one might question if the presence of fish in area IV is still representative of the total stock. Perhaps, with the stock being relatively small, migration patterns change and for instance a relatively larger component of the population stays in the Channel, also in summer. The age structure of the population may also impact on the relative abundance of horse mackerel in the North Sea in Q3. Alternative reliable stock size indicators would be very beneficial in developing an assessment model for this stock, as they could confirm or complement the information retrieved from the IBTS survey. Possible data sources to be explored are:

- The French CGFS survey in VIId may provide information on horse mackerel abundance in the main fisheries area for the stock
- CPR larvae data from the Continuous Plankton Recording (CPR) programme could be analysed on the occurrence of horse mackerel larvae
- Ongoing projects at IMARES on utilizing commercial acoustics data for mackerel and blue whiting could be extended to horse mackerel

Aging

Improving the quality of age data for this species would help resolved some of the lack of clear cohort signals in the catch data. Additionally, aging of horse mackerel caught in the IBTS survey (currently only length measures are taken) would improve the indices derived from this data source.

- Maintain regular age-reading workshops to ensure accuracy and consistency of age reading of this species (through ICES).
  Recommend to ICES to undertake age reading of horse mackerel caught in the IBTS survey

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11 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

Justification

Rapport C097/14
Project Number: 4301502401

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Niels Hintzen
Fisheries scientist

Signature:

Date: 30 June 2014

Approved: Nathalie Steins
Department head of department fisheries

Signature:

Date: 30 June 2014

Appendix A. Proposal for the Pelagic RAC

Proposal for a multi-annual plan for horse mackerel in the North Sea
Prepared by David Miller and Aukje Coers (IMARES) for discussion in the Pelagic Regional Advisory Council. This proposal can be used for submission to ICES for an evaluation.
30-01-2014, Ijmuiden, Netherlands

Background

Scientific knowledge of the state of the horse mackerel stock in the North Sea has been rather limited. In contrast to other stocks, there has not been a scientific survey established for the specific purpose of monitoring stock abundance trends. As a consequence, ICES advice on catch limits was for over a decade consistently along the line that catches should not be more than the 1982-1997 average in order to avoid an expansion of the fishery until there would be more information available (ICES, 2007). Due to a number of circumstantial changes, improving the scientific basis for management has recently become more pertinent.

Alignment of management areas

One such circumstantial change was a European Council decision on new management area boundaries between the three (Western, Southern and North Sea) horse mackerel stocks, which came into effect on the 1st of January 2010. The management area boundaries previously did not match the biological stock boundaries that ICES utilised for its advice. In addition, the results of a research project (HOMSIR) suggested that a change in the management area boundaries would be appropriate (HOMSIR project, 2003). This particular decision by the European Council, which included a redistribution of quota among EU Member States, had a substantial impact on the operating conditions for fisheries targeting horse mackerel.

Data Limited Stocks advice by ICES

Another recent development that impacts the industry's fishing opportunities was the introduction by ICES of a new approach for the underpinning of Total Allowable Catch (TAC) advice for data limited stocks (DLS) (ICES 2012a and ICES 2012b). The main objective for this new DLS approach was to apply a more precautionary approach for exploitation of stocks where it is unknown whether their current catch levels are sustainable. In other words, rather than *rolling over* a particular TAC level in the absence of reasons for action otherwise, as was previously customary for TAC-setting for a substantial number of data limited stocks, it should become customary to take precautionary action by *reducing* the TAC if no information is available for action to be taken otherwise. This should both promote more sustainable exploitation levels in stocks for which little information is available as well as stimulate EU Member States to take action in improving the knowledge base for all commercially exploited fish stocks that their fishing industries have stakes in.

Development of a multi-annual plan

North Sea horse mackerel has been classified as a DLS in category 5 with only landings data available. This led to the advice for 2013 being a TAC which represented a reduction of 20% of recent landings as a precautionary measure. In response, the main stakeholder in the fishery - the Dutch Pelagic Freezer-trawler Association (PFA) - sought collaboration with IMARES to develop a multi-annual plan for this stock. The plan should specify a rationale for establishing TACs through a Harvest Control Rule (HCR) and it should stipulate how the stock could be ‘moved up the ladder’ of the DLS categories; ultimately aiming to progress it to become a data rich (category 1) stock. The current document presents a proposal for a HCR, which can be evaluated by ICES. Implementation of the plan should enable recovery of the stock in the short term. In addition – in line with the objectives of the reformed Common Fisheries Policy (European Union, 2013) – it should ensure achieving a Maximum Sustainable Yield (MSY) exploitation rate by 2015 if possible or at the latest by 2020.

The plan

The objective of this multi-annual plan is to provide a TAC setting basis that promotes recovery of the stock in the short term and ensures achieving a Maximum Sustainable Yield (MSY) exploitation rate at the latest by 2020. In addition, it should also stabilise inter-annual variation in catches. It further outlines a prioritized list of data issues that, when resolved, will benefit the knowledge basis for the management of this stock in the future.

Total Allowable Catch

- The TAC shall be revised annually based on the North Sea IBTS Q3 survey trend information

- In a TAC setting year, the TAC shall be set as follows:

$$TAC_{y+1} = TAC_y \times \left(min\left(\frac{I_{rec}}{I_{trig}}, 1\right) + \lambda Slp \right)$$

  TAC = Total Allowable Catch; *y* = assessment year
  λ = slope multiplier
  Slp = slope of the log-linear regression for the last *x* years of the survey index
  I_{rec} = recent survey index = average of index values for the last *x* years
  I_{trig} = survey index trigger value

- **[Optional]** The resulting TAC for year *y* +1 shall not deviate more that 20% from TAC in year *y*

Strengthening the knowledge base

- Age information should be collected from horse mackerel caught in the third quarter International Bottom Trawl Survey (IBTS) in the North Sea

- Information should be obtained on potential mixing of catches of Western and North Sea horse mackerel in ICES area VIId

- The potential to utilise acoustic data from commercial vessels as a supplementary data source should be explored

Re-evaluation of the plan

- Considering the observed decrease in stock abundance, the primary aim of this plan is to reverse this trend. A re-evaluation of this plan to ensure long term high and stable yield should be conducted when:
  - The survey index value *I* has been above I_{tar} (to de determined) for three consecutive years, or;
  - New data becomes available, which will enable improvement of the assessment, or;
  - The exploitation pattern of the fleet changes substantially;
  - TAC uptake differs substantially from the scenario assumed in the MSE;
  - Latest in 2019.

Supporting information

<u>The fishery</u>

Catches by the Danish industrial fleet for reduction into fishmeal and fish oil formed the majority of North Sea horse mackerel catches throughout the 1970s and 1980s. Catches were taken in the fourth quarter mainly in Divisions IVb and VIId. The 1990s saw a drop in the value of industrial resources, limited fishing opportunities and steep increases in fuel costs. In 2001, an individual quota scheme was introduced in Denmark, which resulted in a rapid restructuring of the fleet. Since then the fleet size has been radically reduced and now numbers less than 20% that in the 1980s and Danish North Sea horse mackerel catches have diminished. Since the 1990's, a larger portion of catches has been taken in a directed horse mackerel fishery for human consumption by the Dutch freezer-trawler fleet.

Denmark has traded parts of its quota with the Netherlands for fishing opportunities for other species, however due to the structure of the Danish quota management set-up only a limited amount of quota can be made available for swaps with other countries. These practical implications of the management scheme largely explain the consistent underutilisation of the TAC (approximately 50% in 2010-2012) in recent years (Figure 1).

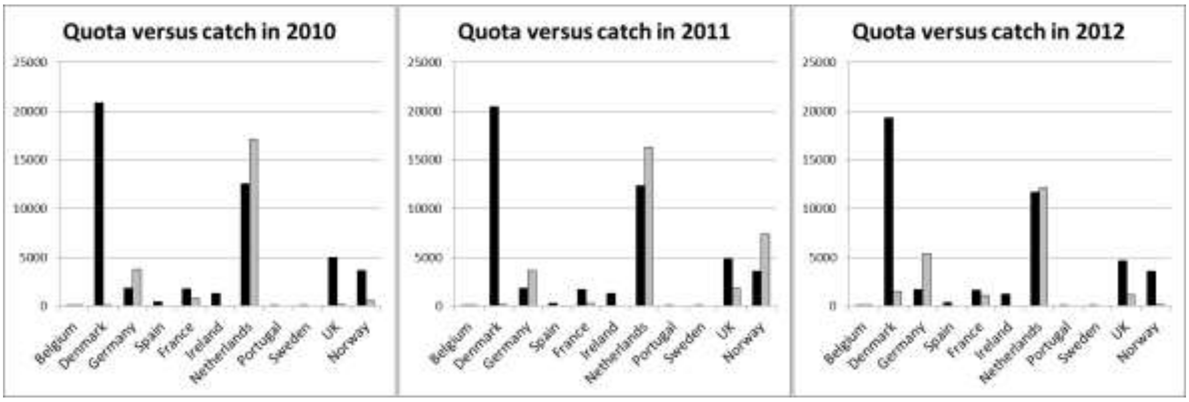

Figure 1. Quota and landings by country in recent years, showing the substantial differences in utilisation of available quota by different countries. The black bars are quota (before international swaps) and the light grey bars are reported landings.

<u>IBTS survey data</u>

The International Bottom Trawl Survey (IBTS) started in the 1960's directed at juvenile herring (as the International Young Herring Survey (IYHS)). In 1990 ICES decided to combine international and national surveys into the IBTS, which was fully standardised across countries in subsequent years. The fishing method and gear (GOV trawl) are described in the IBTS manual (Anon, 2004).

Horse mackerel is abundantly caught in the North Sea IBTS survey. Survey data are available as numbers of fish (individuals) caught per hour (cpue) by length classes of 10 mm. Fish between 1-14 cm correspond to 0-year old fish and 15-19 cm correspond approximately to 1-year old fish and 20 cm and larger to 2-year old fish and older. Figure 2 shows the spatial distribution of horse mackerel catches in the survey for two grouped length classes roughly corresponding to 0-year and 1-year old juveniles (left panel) and 2-year old and older individuals, which are mostly mature (middle panel). Examination of annual distribution maps showed that juvenile fish are found in highest concentrations in the South Eastern part of the North Sea (in area IVb and IVc), along the Dutch, German and Danish coast. These fish are found often in more aggregated densities. 2-year and older fish are found somewhat more dispersed throughout the North Sea, while some concentrations are found around the Orkney Islands as well.

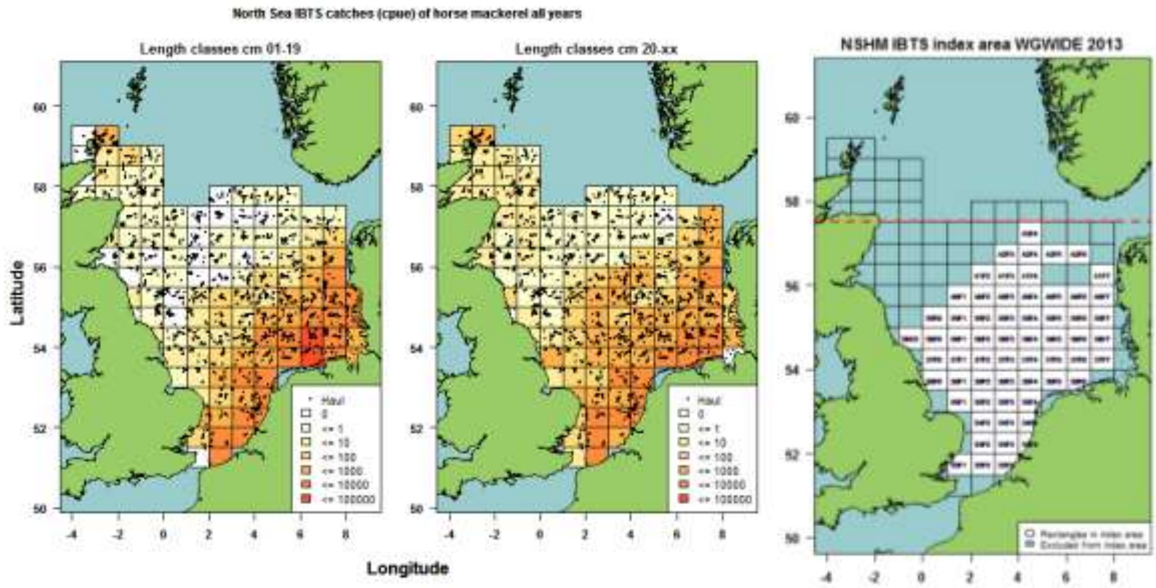

Figure 2. Horse mackerel caught in the third quarter North Sea IBTS survey. 0- and 1-year old juveniles (left panel); 2-year old fish and older (middle panel) and agreed index area (right panel).

Rückert et al (2002) described these North-West and South-East concentrations of abundance as two separate stock components in the North Sea. Results from the HOMSIR project suggested that the North Western concentrations are likely horse mackerel originating from the Western stock, migrating into area IVa (HOMSIR project, 2003). The statistical rectangles that should be included in the index area for the survey index for the stock was agreed by WGWIDE in 2013 (ICES, 2013). It excludes the rectangles in the North-Western corner of the North Sea and some rectangles that have not been consistently covered by the survey over the years (Figure 2, right panel).

The survey index

The IBTS is an bottom trawl survey targeting primarily ground fish (gadoids), but also catching pelagic species (e.g. herring, sprat, mackerel and horse mackerel). The standard method used to derive abundance indices consists in computing a mean CPUE per ICES rectangle, and take the mean of these values over the area representative of the stock of interest (ICES DATRAS technical description including indices calculation[3]).

This approach is designed for dispersing ground fish and is probably not appropriate for dealing with a species that displays schooling behaviour for two reasons. First, by taking the mean of the CPUEs, it assumes that the data is normally distributed. With species that display schooling behaviour, such as horse mackerel, the proportion of zeros (absence in the trawl haul) may be high, in which case an assumption of normal distribution is not appropriate.

The second problem is that even though survey trawl hauls are supposed to be directly comparable, there still may exist differences in catchability of this species between vessels. If the proportion or the geographical distribution of the data collected by the different vessels varies among years, then it is necessary to check for a vessel effect, and account for it in the computation of the abundance index.

Using a generalized linear model (GLM) approach accounts for the above mentioned issues in establishing an appropriate survey index. Catches from the survey can be modelled as a linear function of explanatory variables, which may be continuous (e.g. depth) or factors (e.g. year, vessel, gear type) and offer the possibility to specify a distribution different from the normal distribution. The abundance index (corrected for the other potential effects such as vessel effects) can then be obtained from the estimated year effects. Figure 3 shows the estimated abundance index for North Sea horse mackerel based on the application of a GLM on the IBTS survey data. Sensitivity tests suggested that the index is robust to the inclusion of new years of data.

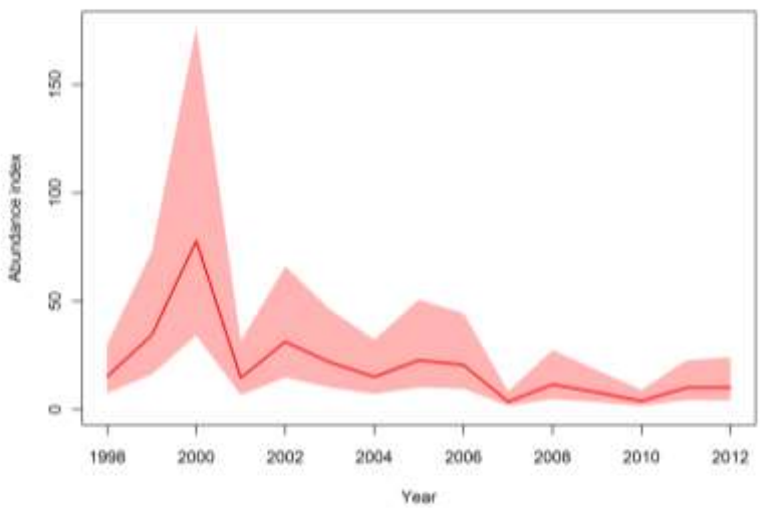

Figure 3. North Sea horse mackerel abundance index. The shaded area indicates the 95% confidence intervals for the estimated index values.

Basic assessment model

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3 http://www.ices.dk/marine-data/Documents/DATRAS/Indices_Calculation_Steps_IBTS.pdf

The GLM abundance index can be used to fit a simple age based model. The assessment model used follows the approach first presented to the WGMHSA (ICES, 2007). It is an age-based model that is fit by comparing trends in age 2+ abundance with the GLM-derived IBTS index, since the index approximates 20cm+ fish (primarily age 2 or older). Catch at age data are available for a large part of the fleet and total catch estimates for the stock are obtained from the ICES database. It is a separable model that assumes constant selectivity of the fleet over time and does not assume that catch is known exactly. Alternate assumptions, e.g. on natural mortality and the validity of input data, can be used to test sensitivity of the model's results to uncertainties.

Management Strategy Evaluation (MSE)

This assessment model, or variants thereof, provides a basis for conditioning a set of operating models to simulate the future performance or alternate HCRs. This allows for the selection of satisfactory parameters in the HCR (e.g. number of years to calculate the index slope and λ) and allows for the comparison of the performance of alternate HCRs in terms of trade-offs between stock development, catch and inter-annual variation in catch.

The MSE works by projecting the stock forward and calculating observed index values based on stock size and historic uncertainty in survey estimates. These observed index values are then used in an HCR to determine future TACs. The simulations then project the stock forward again, removing the catch associated with the advised TAC and adding recruitment calculated from a stock-recruit relationship (including variability). Figure 4. This framework can also be used to determine a candidate value for F_{msy} through long term simulations applying various fixed fishing mortality rates.

The performance of candidate HCRs can be compared over the short and medium term. Given the limited data used in the assessment and the uncertainty associated with the resulting stock dynamics (stock recruitment relationship in particular), longer term implications are likely to be highly dependent on the assumptions made in the assessment model. Also, given the apparent poor condition of the stock, the immediate goal of any HCR should be to halt decline in the short term. A new HCR should be proposed once more data informing on the status of the stock become available or the stock displays reasonable recovery from the current condition.

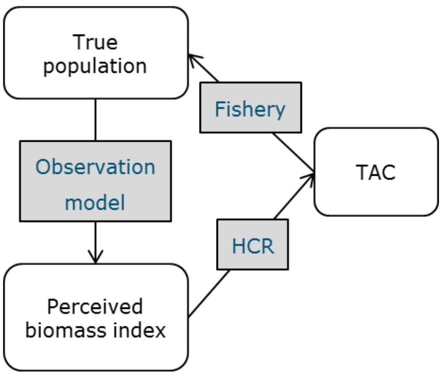

Figure 4. A Schematic of the basic procedure modelled in the MSE simulations.

Preliminary exploration

A preliminary exploration using the MSE framework provides some insight in the stock's performance. It should be noted that this is a preliminary result and no conclusions about the robustness of the HCR can be drawn until a full evaluation has taken place. Figure 5 shows an example of an assessment result and an example of the projected catch for one candidate HCR. The HCR could be considered to provide reasonable performance (in terms of the median):

- Landings are maintained at similar levels or slightly decreased
- The declining trend in SSB is halted (it stabilises around the estimated level of SSB in 2013)
- Landings are not very variable from year to year

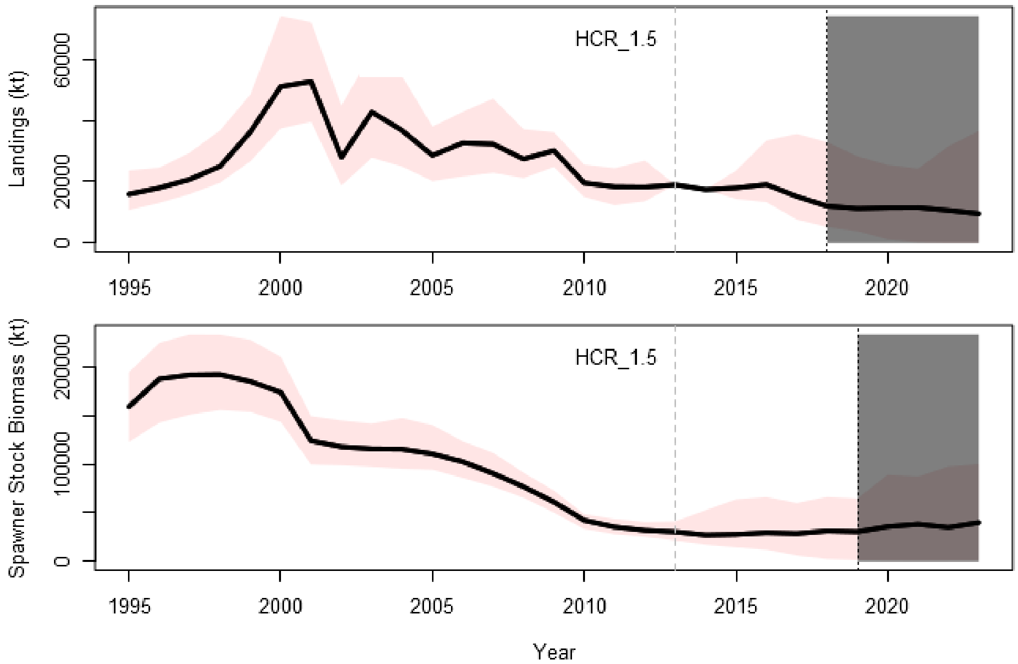

Figure 5. Projections of landings (top) and SSB (bottom) for an example HCR based on the basic assessment. The red shaded areas represent 5% and 95% confidence intervals. Projections start in 2013. The results in the grey shaded area should be regarded with extra caution due to high uncertainty in the population dynamics.

Issues for consideration in the full evaluation

Evaluation should make it possible to choose the optimal HCR parameters by exploring:

- A range of years (*x)* over which the trend in the survey (*Slp*) is determined **[candidate values: 3, 5]**
- A range of values for λ (slope multiplier) **[candidate values: 0.75, 1, 1.25]**
- I_{trig} = survey index trigger value **[candidate value: I_{2012}]**
- Stabiliser on inter-annual variation of the TAC **[candidate values: no stabiliser, 20%]**
- Starting TAC

Robustness of the candidate HCR should be tested using a reference set of biological and fleet operating models. Sensitivity of the assessment results to model assumptions and validity of input data should be tested:

- Stock-Recruitment function
- Natural mortality
- Selectivity of the fleet
- Percentage of utilisation of the TAC
- Uncertainty on origin of catches from area VIId

Evaluation criteria that should be included (no exhaustive list):

- SSB
- Fishing mortality (F) in 2015 and in 2020
- Landings
- Inter-annual variation in the TAC
- Length/age distribution in the population (optional)

References

European Union 2013. Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC

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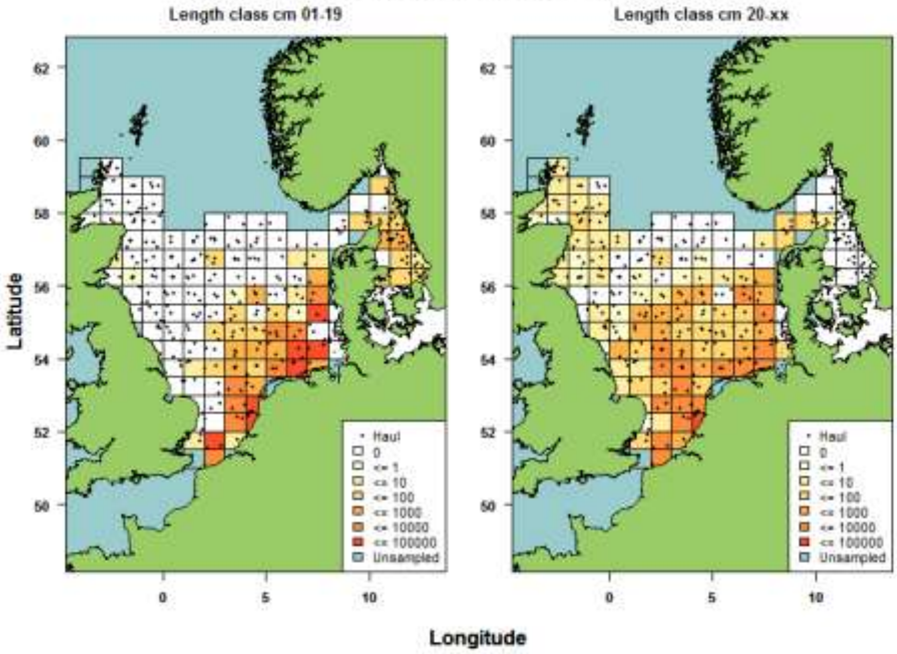
ICES 2013. Report of the Working Group on Widely Distributed Stocks (WGWIDE), 27 August–02 September 2013, ICES Headquarters, Copenhagen, Denmark. ICES CM 2013/ACOM:15.

Appendix B. WKHOMMP meeting 2014

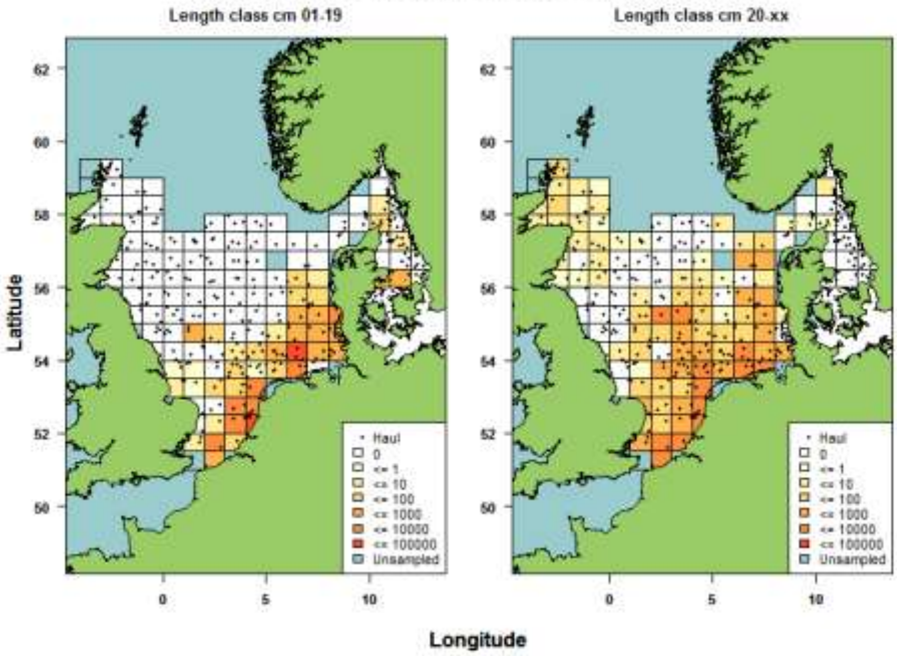
Date:	17-18 June
Place:	IJmuiden, Netherlands
Reviewers:	Ernesto Jardim
	Hoskuldur Bjornsson
Chair Ad-Hoc Group:	Aukje Coers/David Miller
Secretariat:	Mette Bertelsen

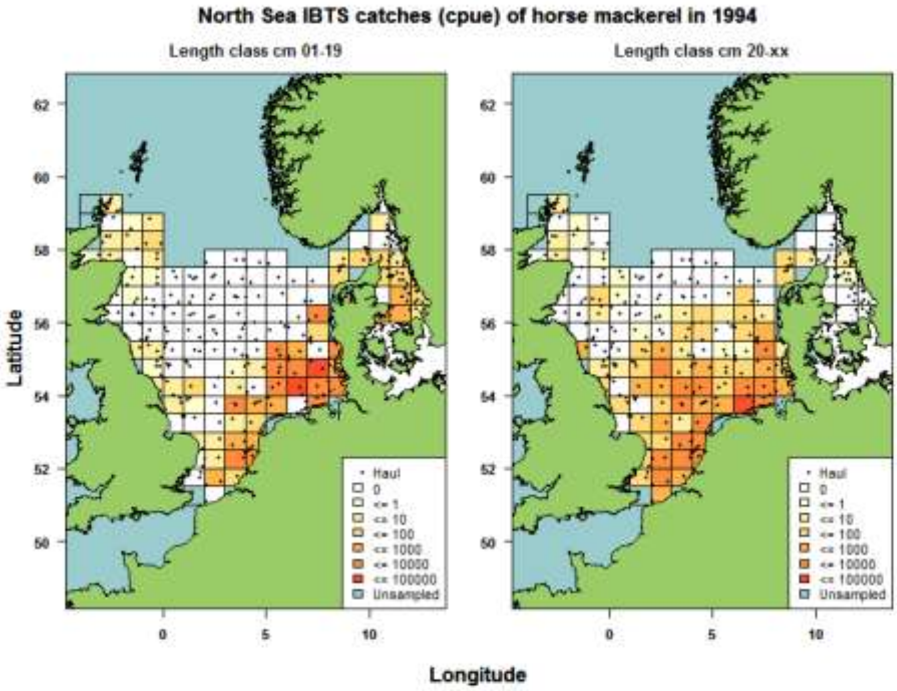
Appendix C. Annual distribution maps of IBTS catches

North Sea IBTS catches (cpue) of horse mackerel in 1992



North Sea IBTS catches (cpue) of horse mackerel in 1993




North Sea IBTS catches (cpue) of horse mackerel in 1994
Length class cm 01-19
Length class cm 20-xx
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0
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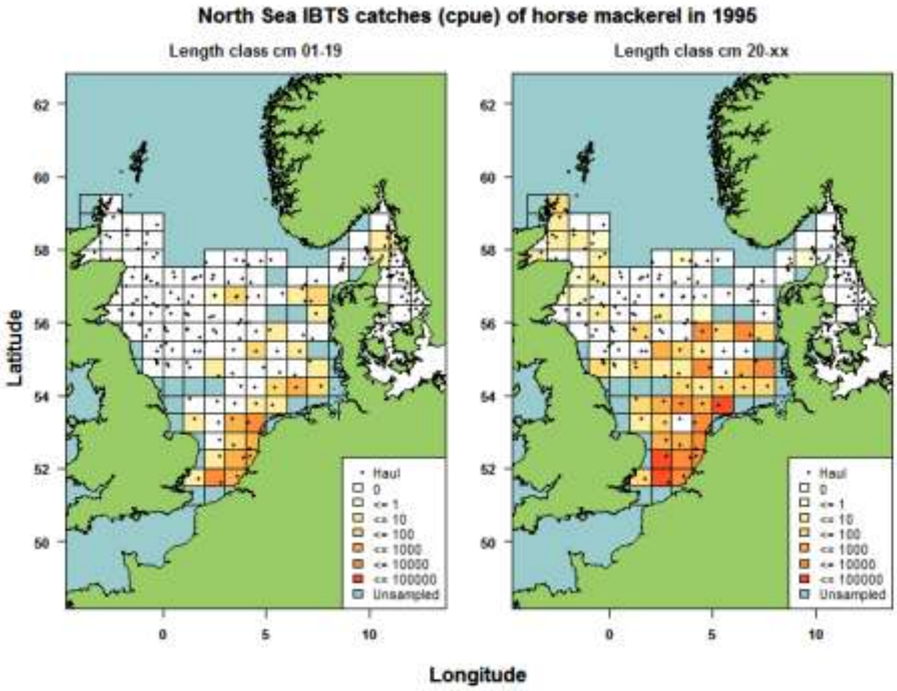
<= 100000
Unsampled


North Sea IBTS catches (cpue) of horse mackerel in 1995
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
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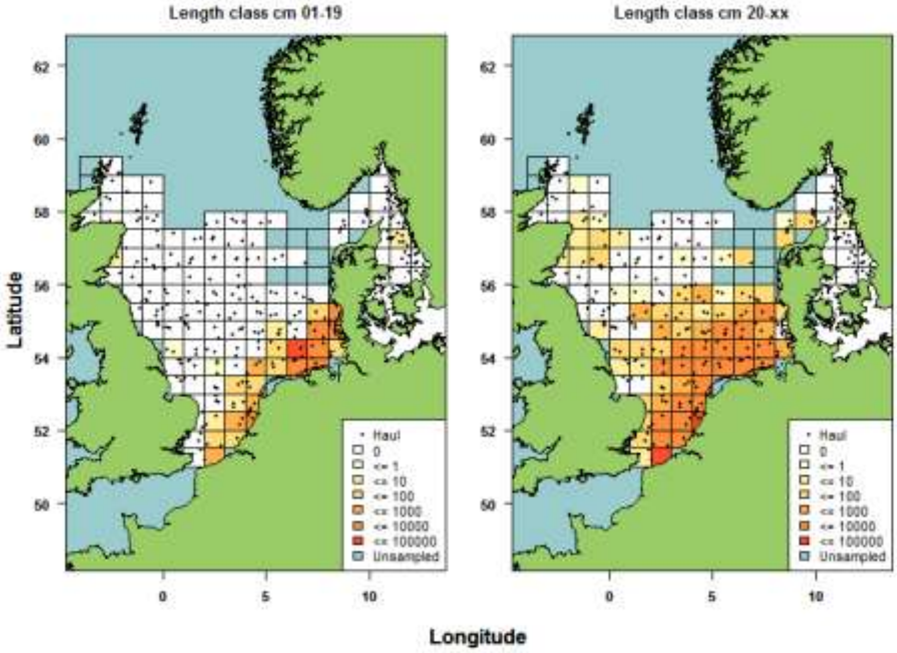
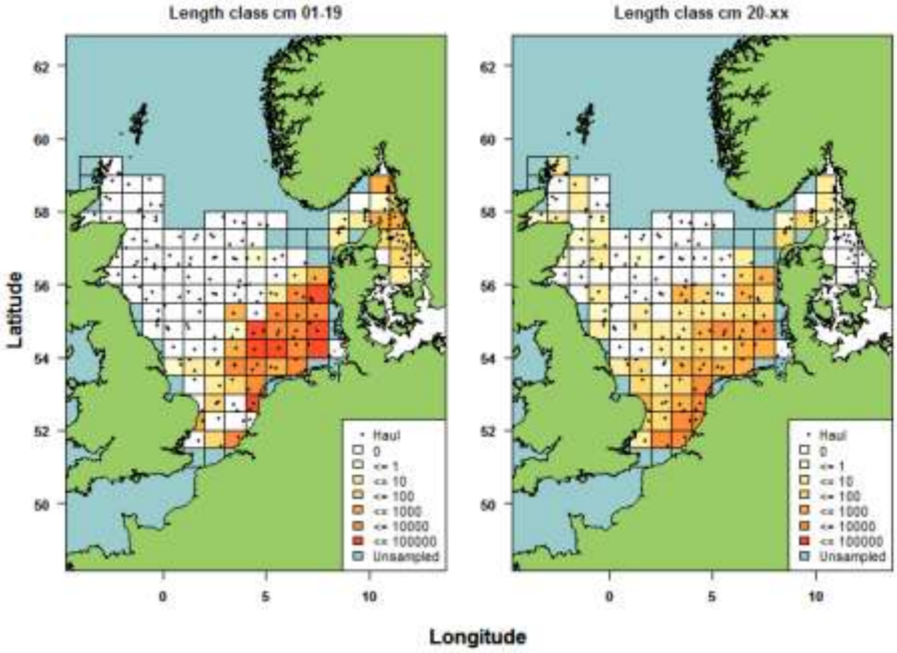
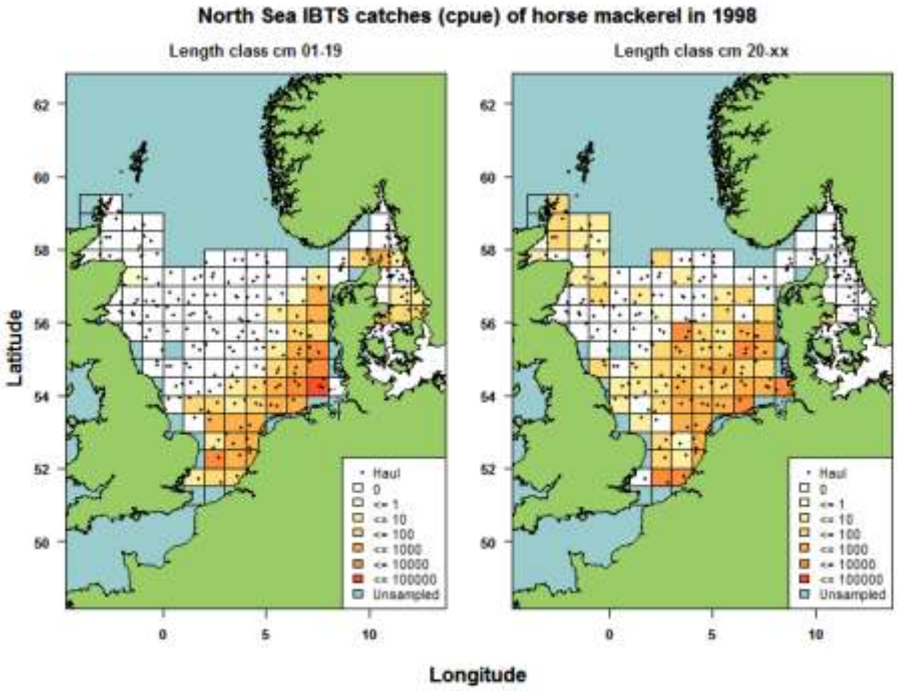
<= 1000
<= 10000
<= 100000
Unsampled

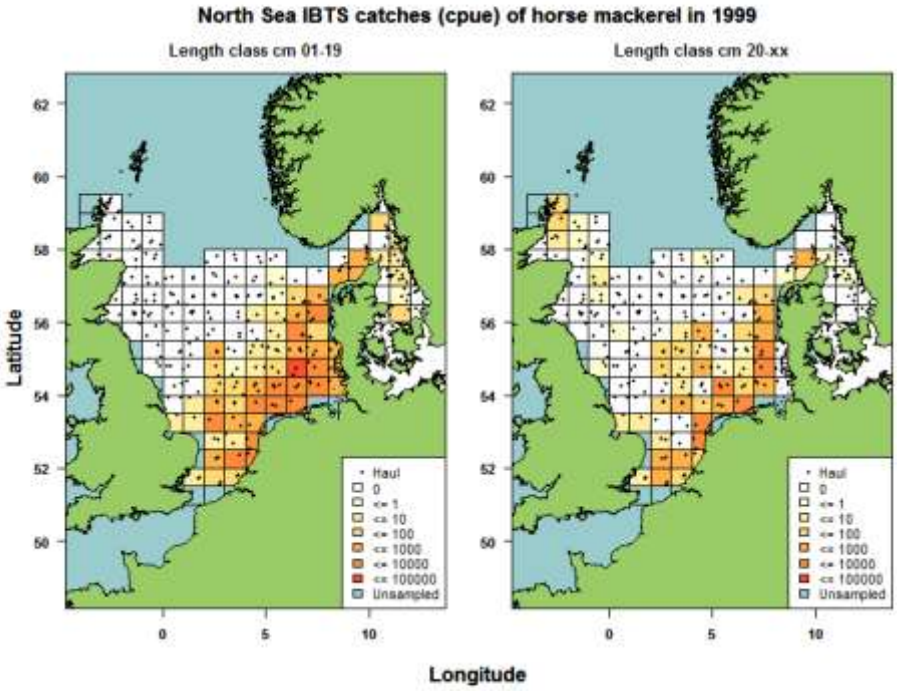
North Sea IBTS catches (cpue) of horse mackerel in 1996

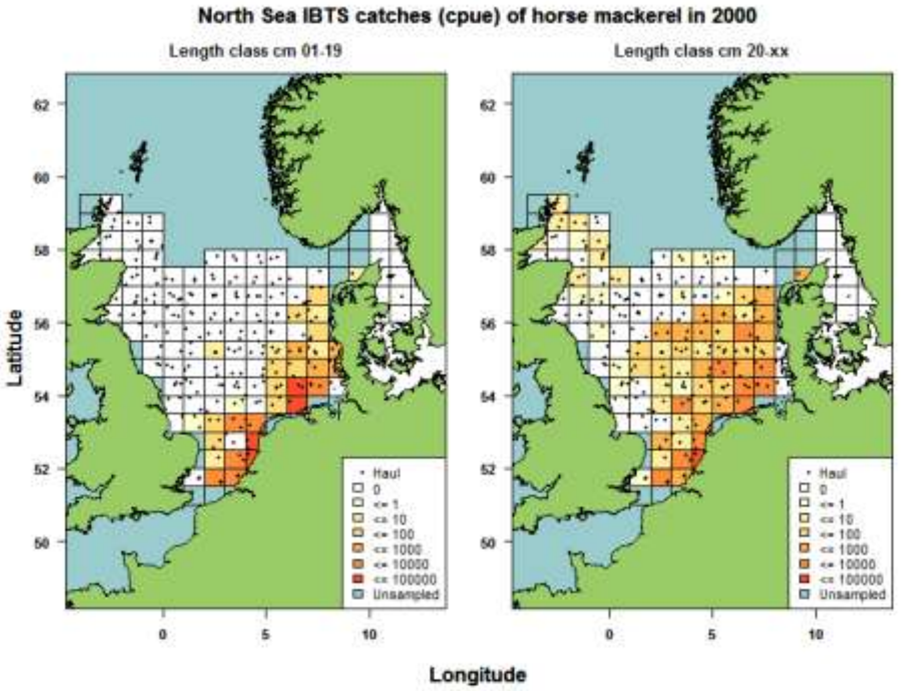


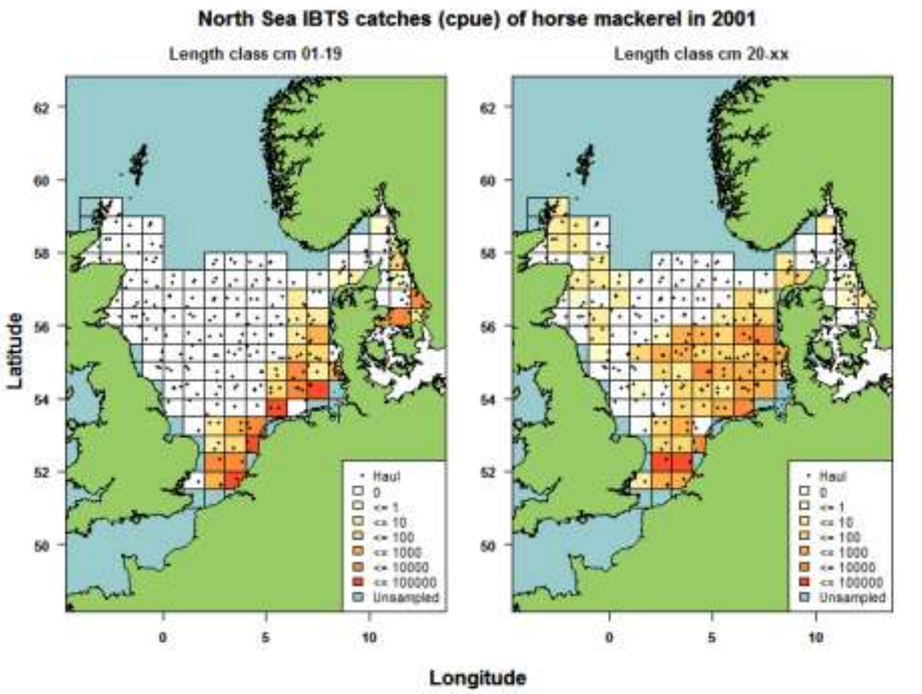
North Sea IBTS catches (cpue) of horse mackerel in 1997




North Sea IBTS catches (cpue) of horse mackerel in 1998
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
62
60
58
56
54
52
50
0
5
10
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled


North Sea IBTS catches (cpue) of horse mackerel in 1999
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
62
60
58
56
54
52
50
0
5
10
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled


North Sea IBTS catches (cpue) of horse mackerel in 2000
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled


North Sea IBTS catches (cpue) of horse mackerel in 2001
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
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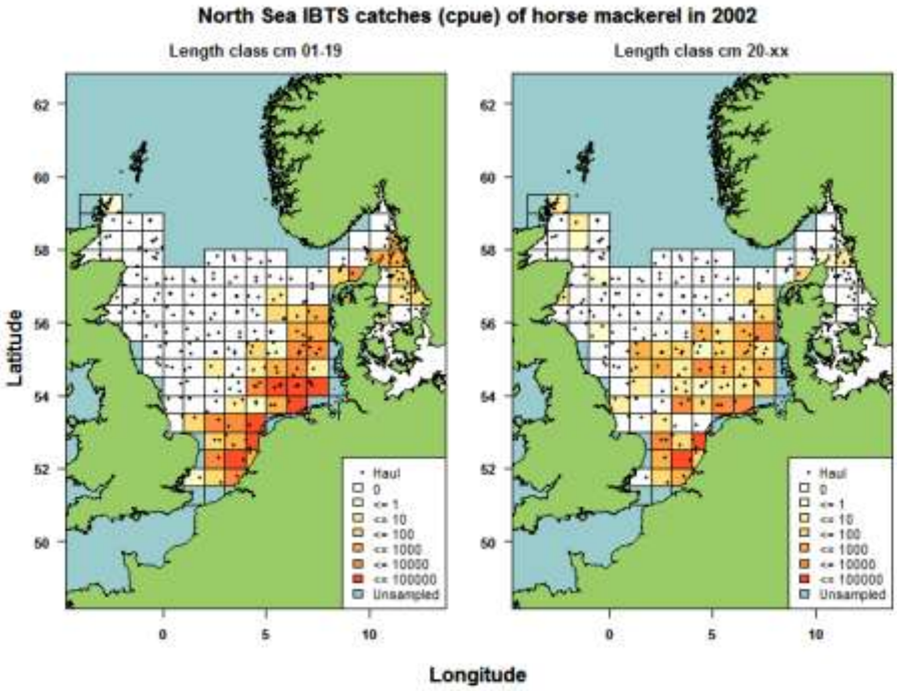
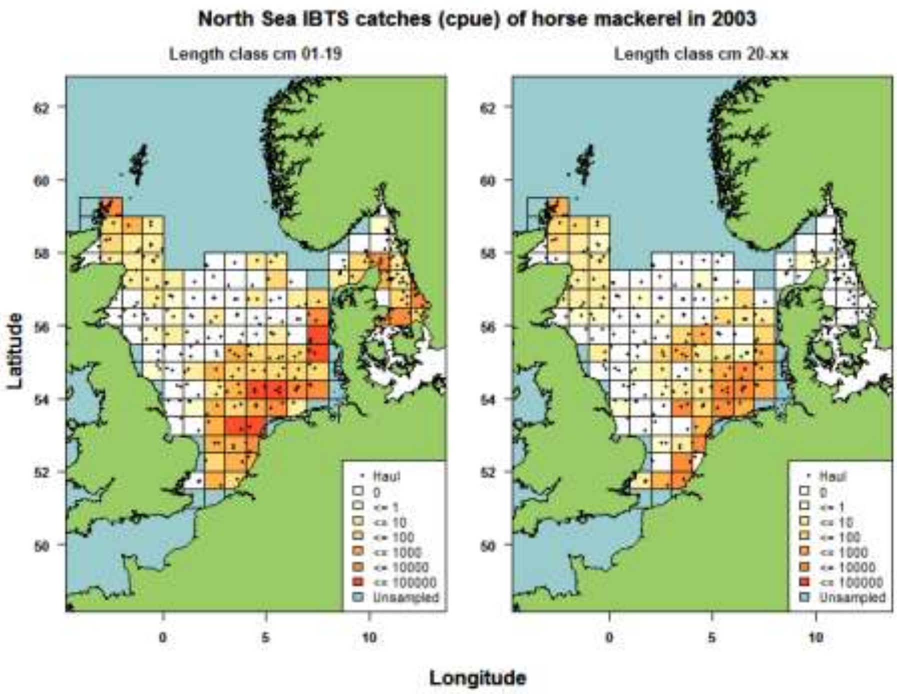
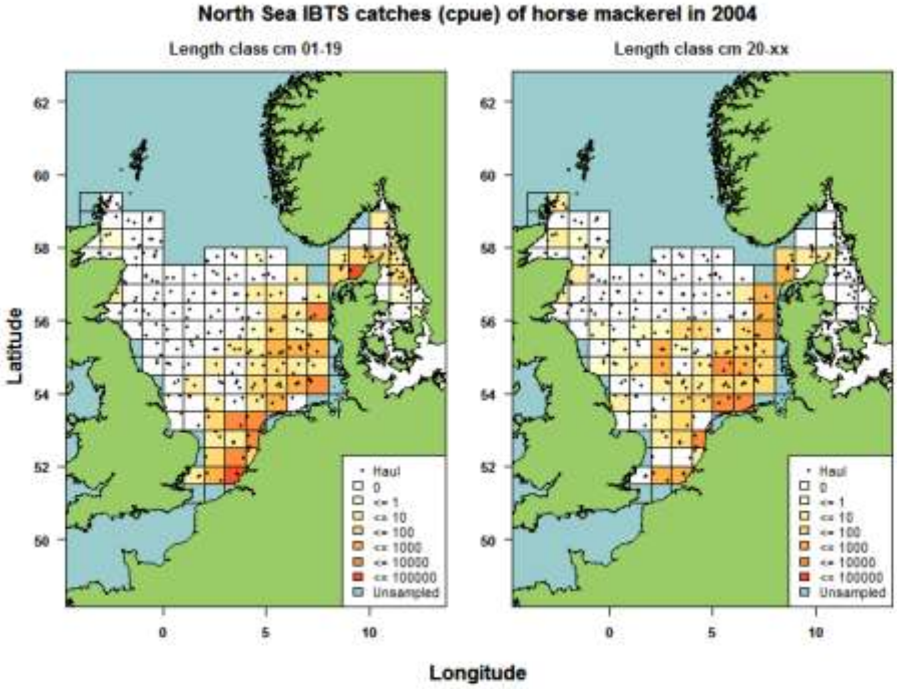
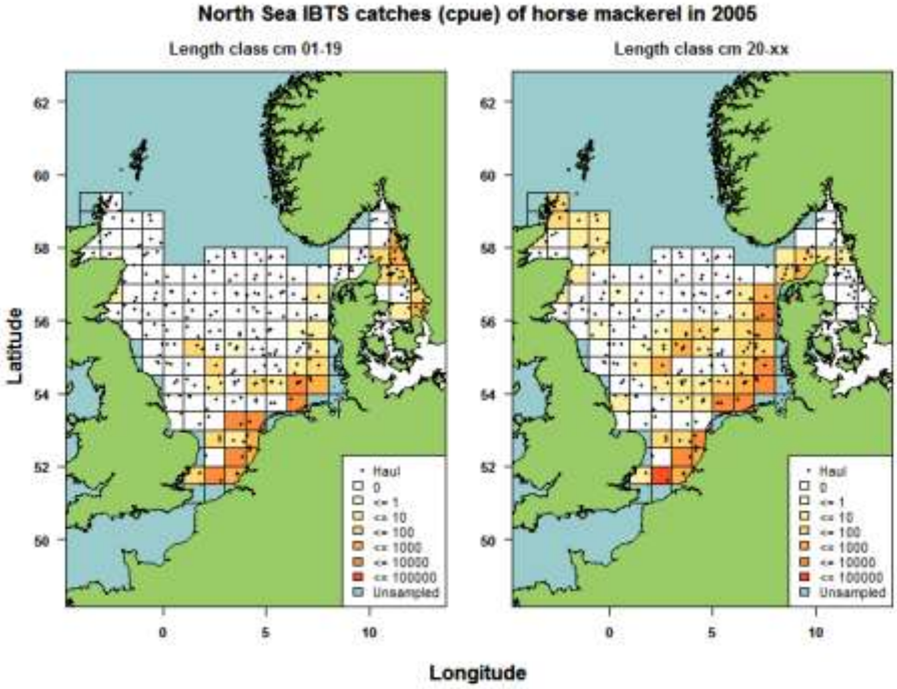
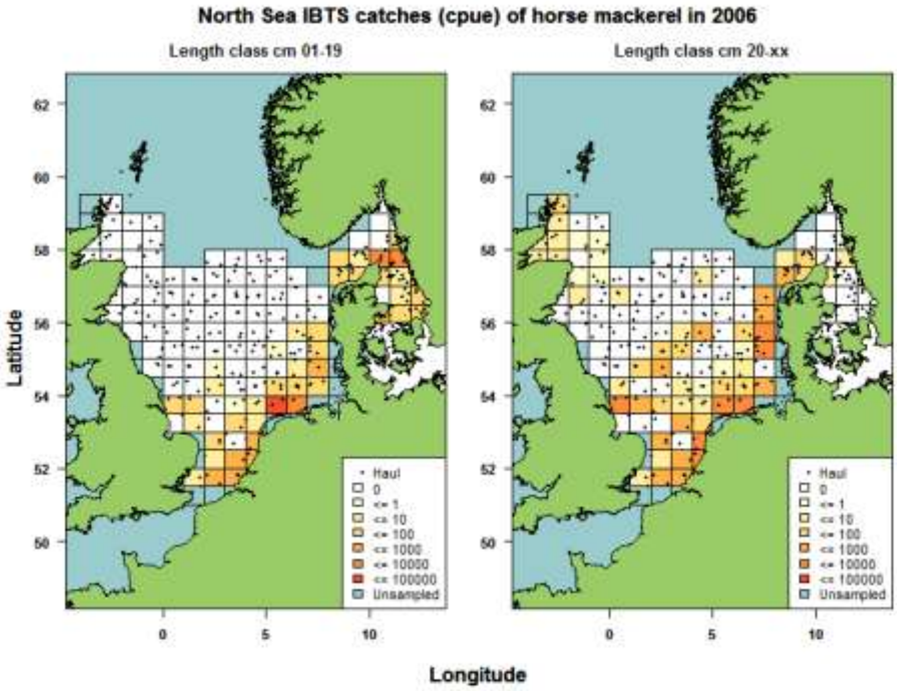
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled

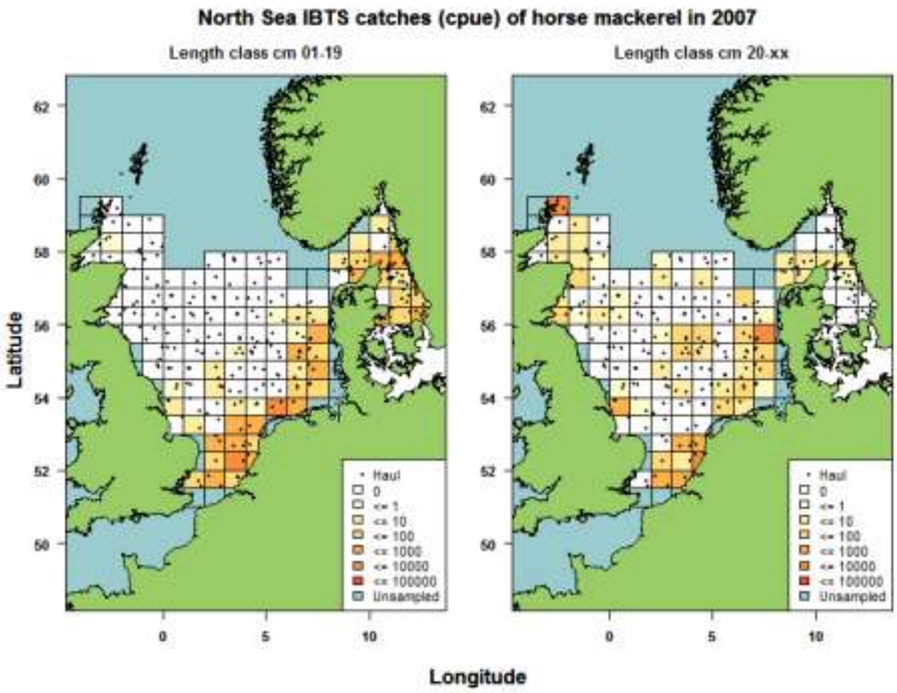

North Sea IBTS catches (cpue) of horse mackerel in 2002
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled

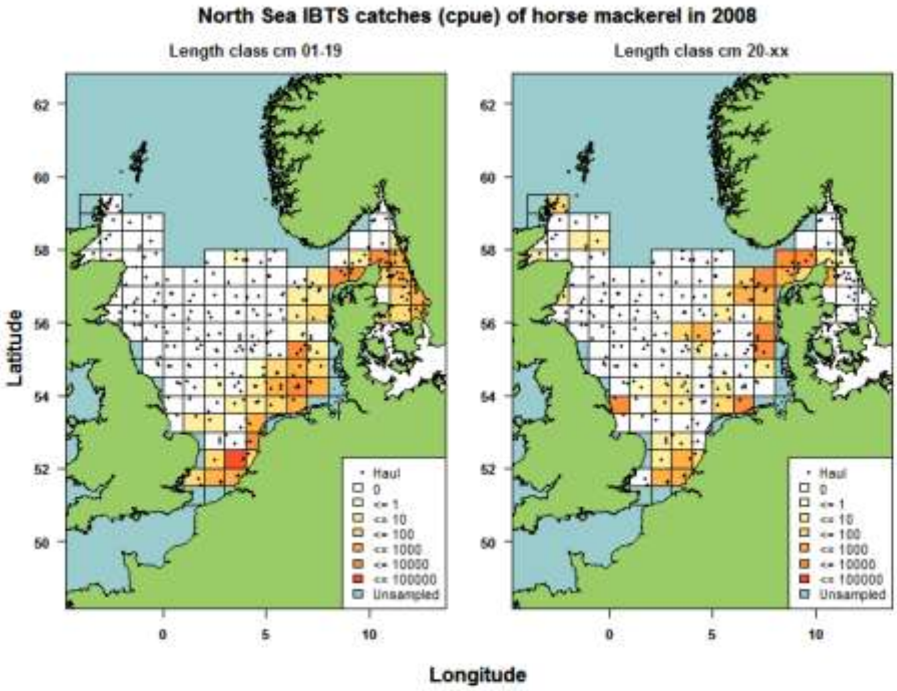

North Sea IBTS catches (cpue) of horse mackerel in 2003
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled

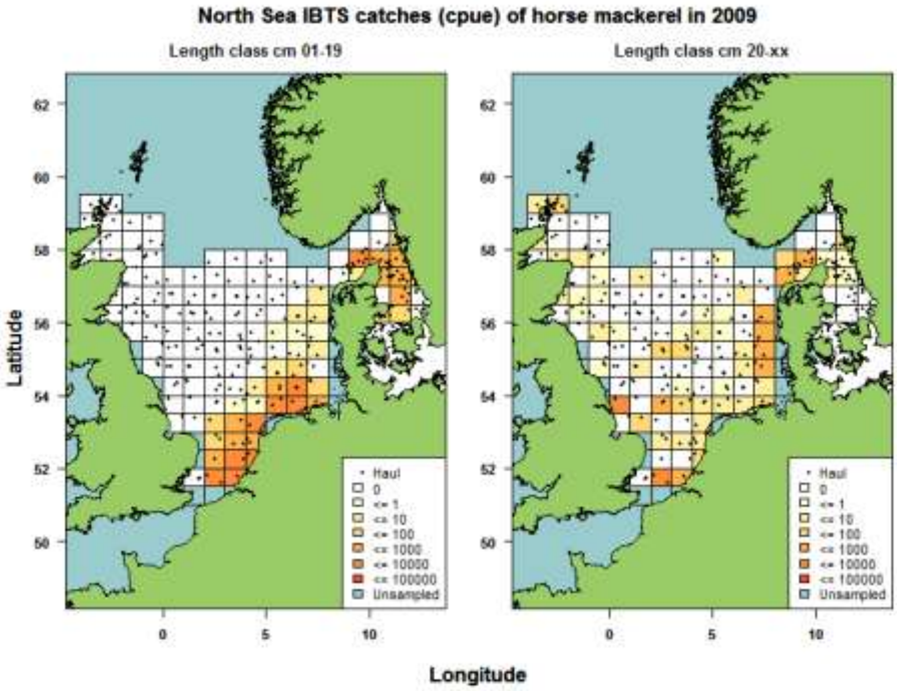

North Sea IBTS catches (cpue) of horse mackerel in 2004
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled

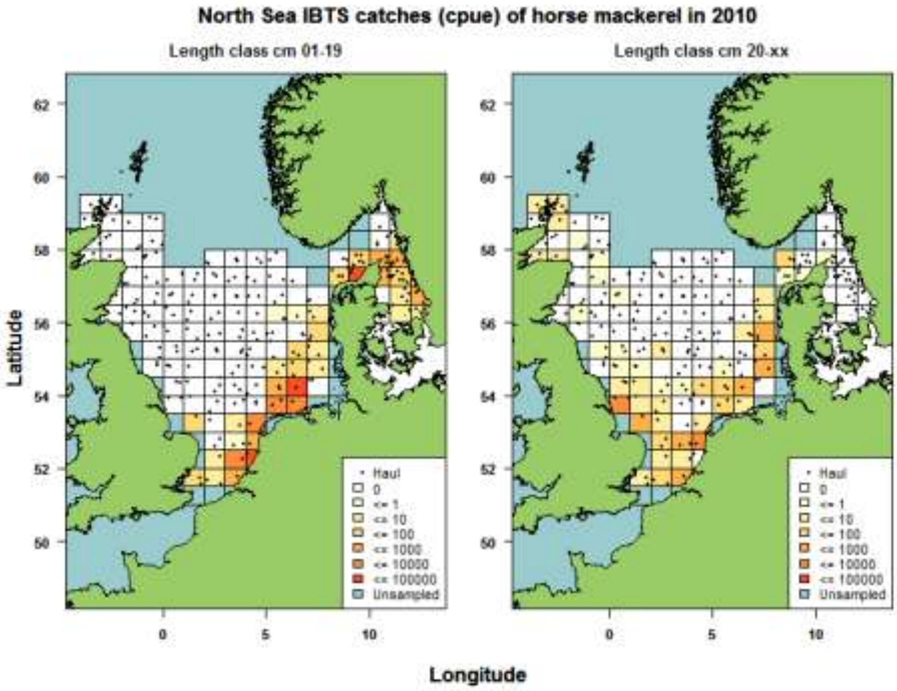

North Sea IBTS catches (cpue) of horse mackerel in 2005
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled

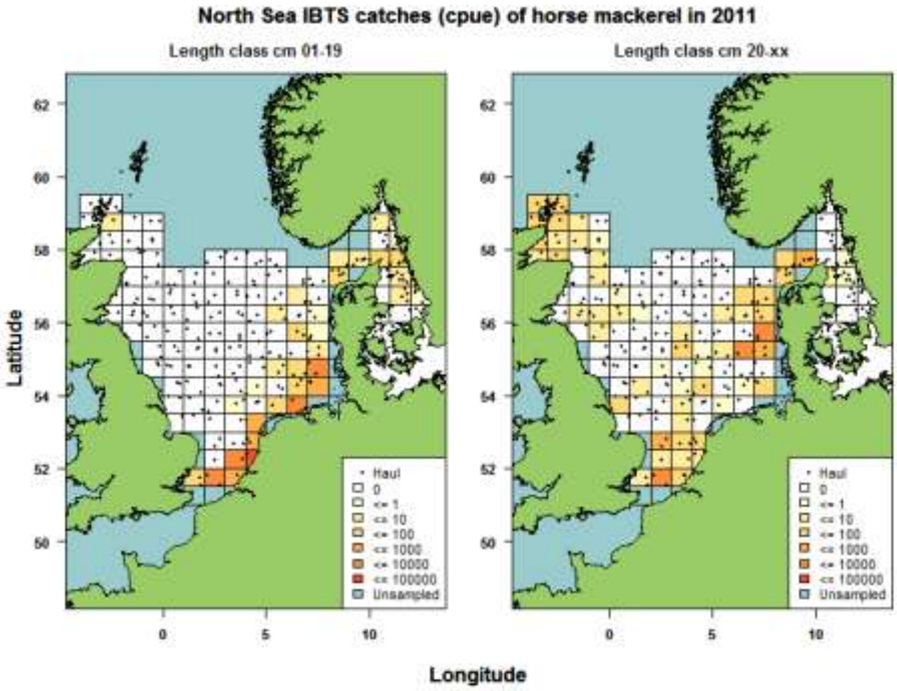

North Sea IBTS catches (cpue) of horse mackerel in 2006
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled

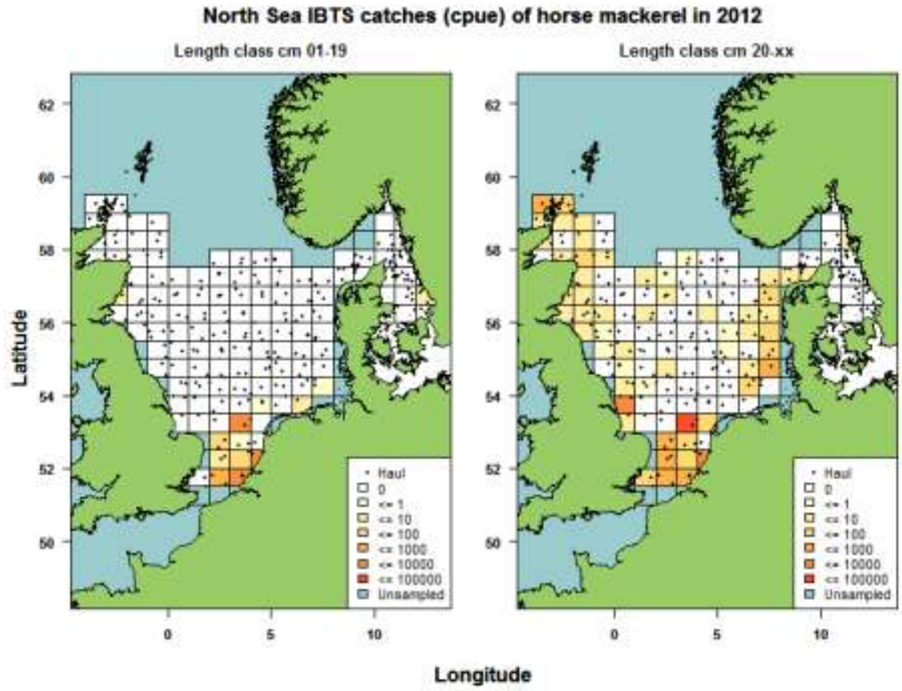

North Sea IBTS catches (cpue) of horse mackerel in 2007
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled


North Sea IBTS catches (cpue) of horse mackerel in 2008
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
62
60
58
56
54
52
50
0
5
10
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled


North Sea IBTS catches (cpue) of horse mackerel in 2009
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
62
60
58
56
54
52
50
0
5
10
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled


North Sea IBTS catches (cpue) of horse mackerel in 2010
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled


North Sea IBTS catches (cpue) of horse mackerel in 2011
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled


North Sea IBTS catches (cpue) of horse mackerel in 2012
Length class cm 01-19
Length class cm 20-xx
Latitude
Longitude
Haul
0
<= 1
<= 10
<= 100
<= 1000
<= 10000
<= 100000
Unsampled

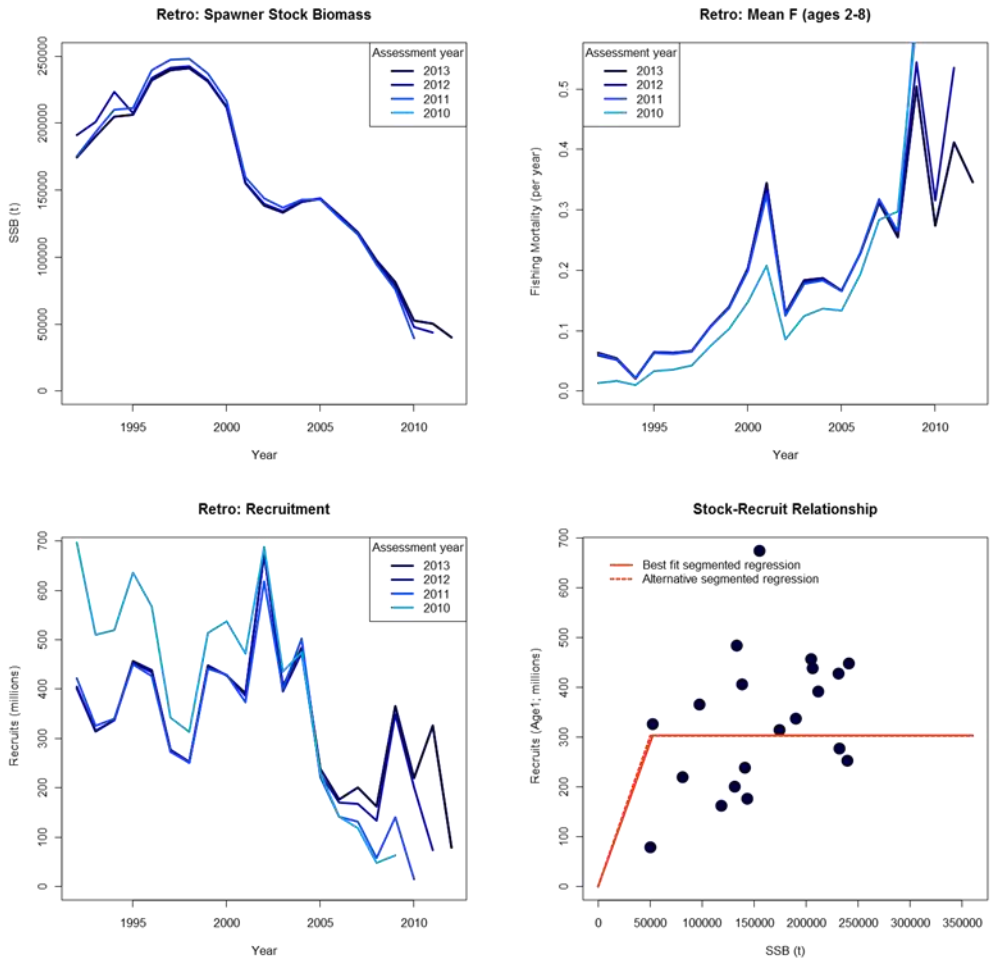
Appendix D: Assessment model data

```
### --------------------------------------------------
### Data file for JAXass model for horse mackerel (JAX)
### --------------------------------------------------
### BIOLOGY
## Natural mortality
# M (matrix, Nyrs by Nages)
0.15

## Weight at age
# WAA (matrix, Nyrs by Nages)
0.074 0.111 0.129 0.143 0.161 0.175 0.192 0.213 0.227 0.29
0.074 0.111 0.129 0.143 0.161 0.175 0.192 0.213 0.227 0.29
0.074 0.111 0.129 0.143 0.161 0.175 0.192 0.213 0.227 0.29
0.076 0.126 0.125 0.133 0.146 0.164 0.161 0.178 0.165 0.265
0.107 0.123 0.143 0.156 0.177 0.187 0.203 0.195 0.218 0.262
0.063 0.102 0.126 0.142 0.16 0.175 0.199 0.231 0.25 0.308
0.063 0.102 0.126 0.142 0.16 0.175 0.199 0.231 0.25 0.308
0.063 0.102 0.126 0.142 0.16 0.175 0.199 0.231 0.25 0.308
0.075 0.101 0.136 0.152 0.166 0.194 0.198 0.213 0.247 0.305
0.055 0.072 0.071 0.082 0.12 0.183 0.197 0.201 0.235 0.279
0.066 0.095 0.129 0.154 0.172 0.195 0.216 0.227 0.228 0.305
0.073 0.105 0.123 0.137 0.166 0.181 0.195 0.212 0.238 0.298
0.076 0.104 0.12 0.147 0.174 0.198 0.225 0.229 0.256 0.321
0.079 0.077 0.103 0.132 0.158 0.196 0.251 0.27 0.28 0.336
0.069 0.095 0.116 0.124 0.141 0.177 0.21 0.244 0.231 0.294
0.073 0.082 0.105 0.115 0.13 0.164 0.191 0.197 0.256 0.354


### CATCH
## Prop VIId weightings
# VIId_wt (vector, length Nyrs)
2.033028 0.7549019 1.193121 1.028615 1.065855 1.536029 0.9992934 0.5342763 1.141851
0.3787924 1.153308 0.7292386 1.13323 1.021887 0.7078032 0.5887713

## Total catch
# totC (Vector, length Nyrs)
15043 13617 5689 16756 18843 19540 30500 37224 48425 46356 23379 32078 35154 29711 35626
41164

## Catch at age
# CAA (matrix, Nyrs by Nages)
1760 3120 7190 10320 12080 13160 11430 12640 7250 19290
4580 13780 11040 11870 9640 12490 7960 6600 1480 23810
12560 27240 14070 14930 14580 12380 10120 8640 2450 2720
2300 22130 36690 38820 20790 12100 13990 10790 8260 14670
12420 31450 23130 17590 23120 26190 20640 21750 12910 19990
70230 77980 28410 21420 31270 19640 19470 9000 11500 32840
```

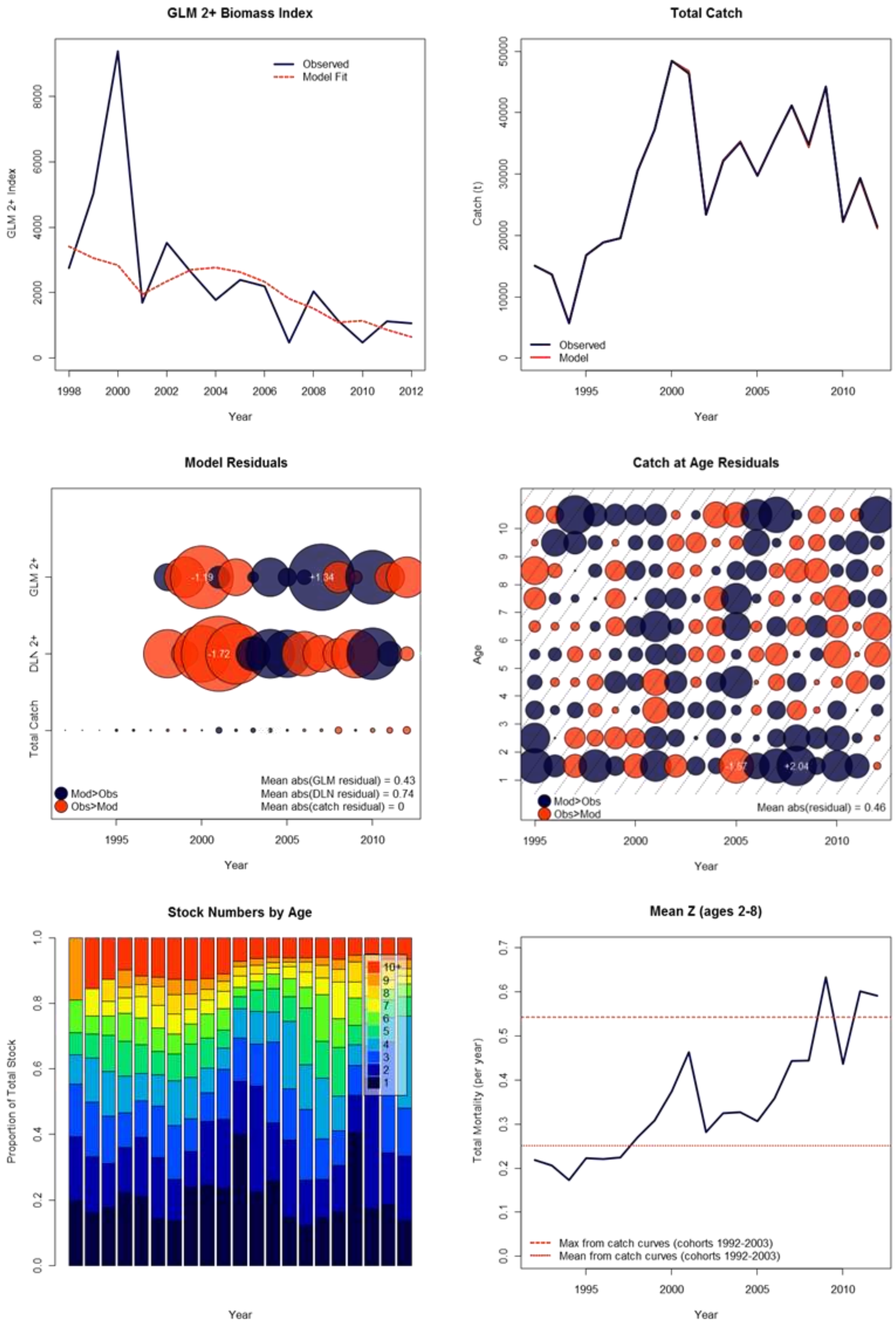
```
12810 36360 174340 87810 18510 11490 18250 14700 10220 36400
60420 16820 19270 11900 5610 5830 5540 10480 6330 21060
13810 56150 23440 33210 26930 10590 6330 9560 10900 18580
15650 17540 34380 14510 27770 20170 10580 3820 5370 38570
52390 29820 27800 12580 16660 5190 2860 2430 3800 34110
5010 23720 61470 40860 72950 23380 13730 5860 1580 5640
3400 15460 22830 82640 71230 30520 23930 17270 7890 3890

### SURVEY INDICES
## Time of the IBTS (fraction of year)
# time_IBTS (number)
0.6

## DLN 2+ indices
# DLN (vector, Nyrs-DLNdelay)
1792.906198
1197.634235
2576.618948
5015.648218
3155.816486
739.0232445
480.1234036
448.1095757
1490.556679
834.9018496
894.7003865
1568.083462
356.5396045
634.3984254
709.4766763
70.37777647

## GLM index
# GLM (vector, Nyrs-GLMdelay)
2752.89939
5030.838782
9382.911928
1692.669403
3523.605056
2617.735223
1777.417902
2391.021899
2196.044838
474.6777906
```

E. Appendix E: Assessment model fits

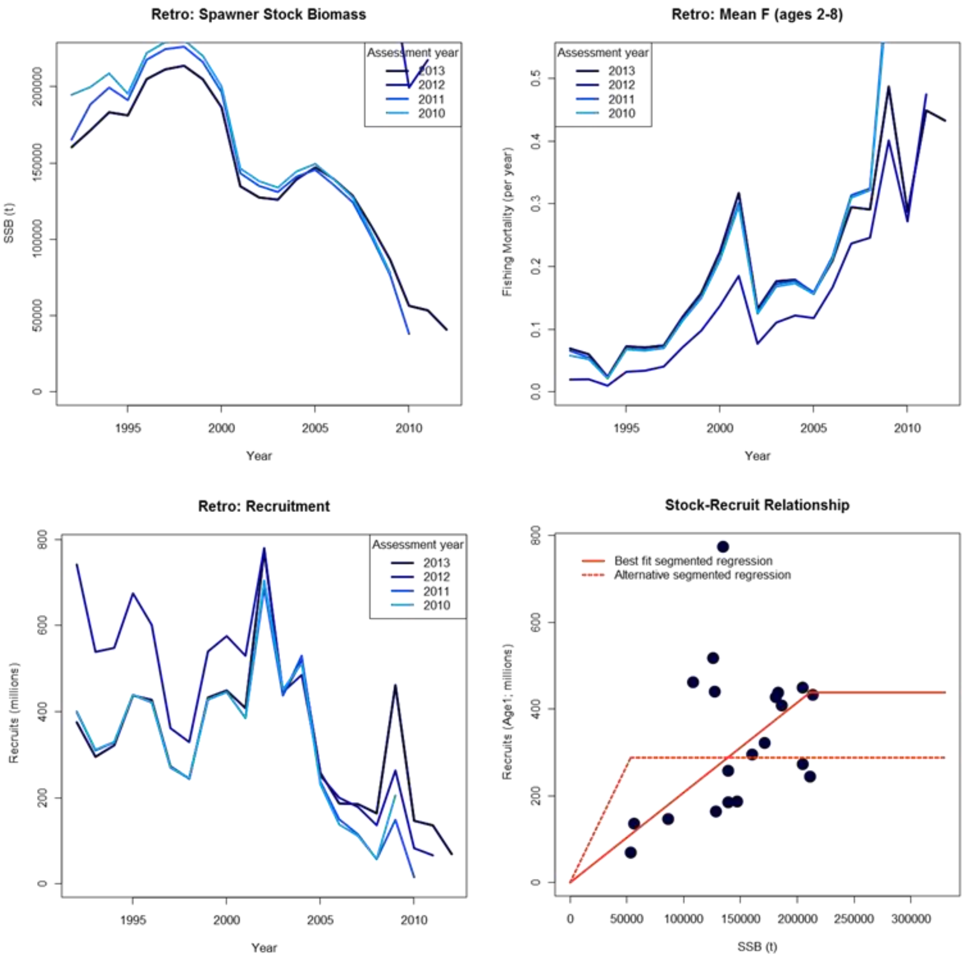
E.1a. GLM_catch_weighted Retrospective and SRR



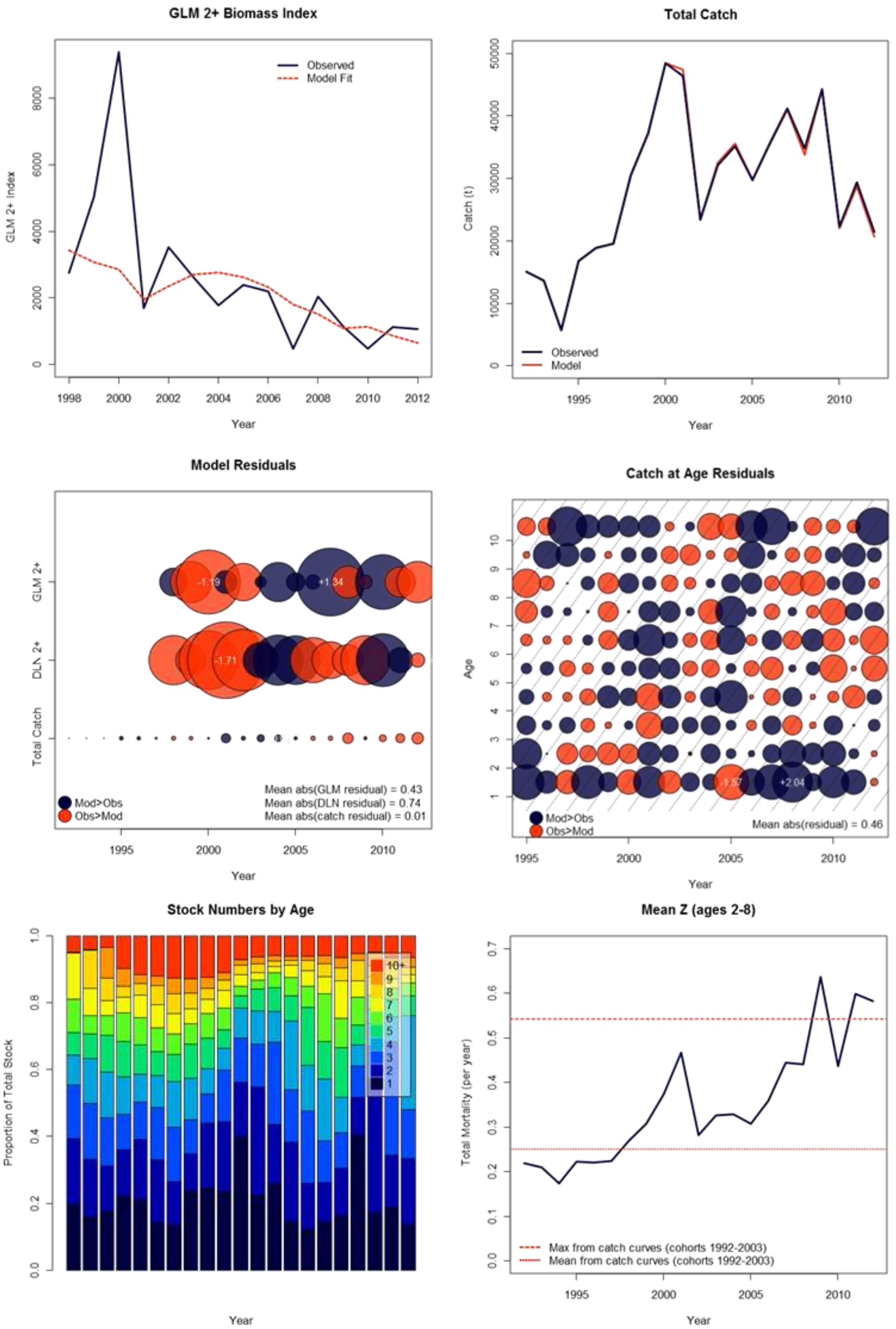
E.1b. GLM_catch_weighted Model fit



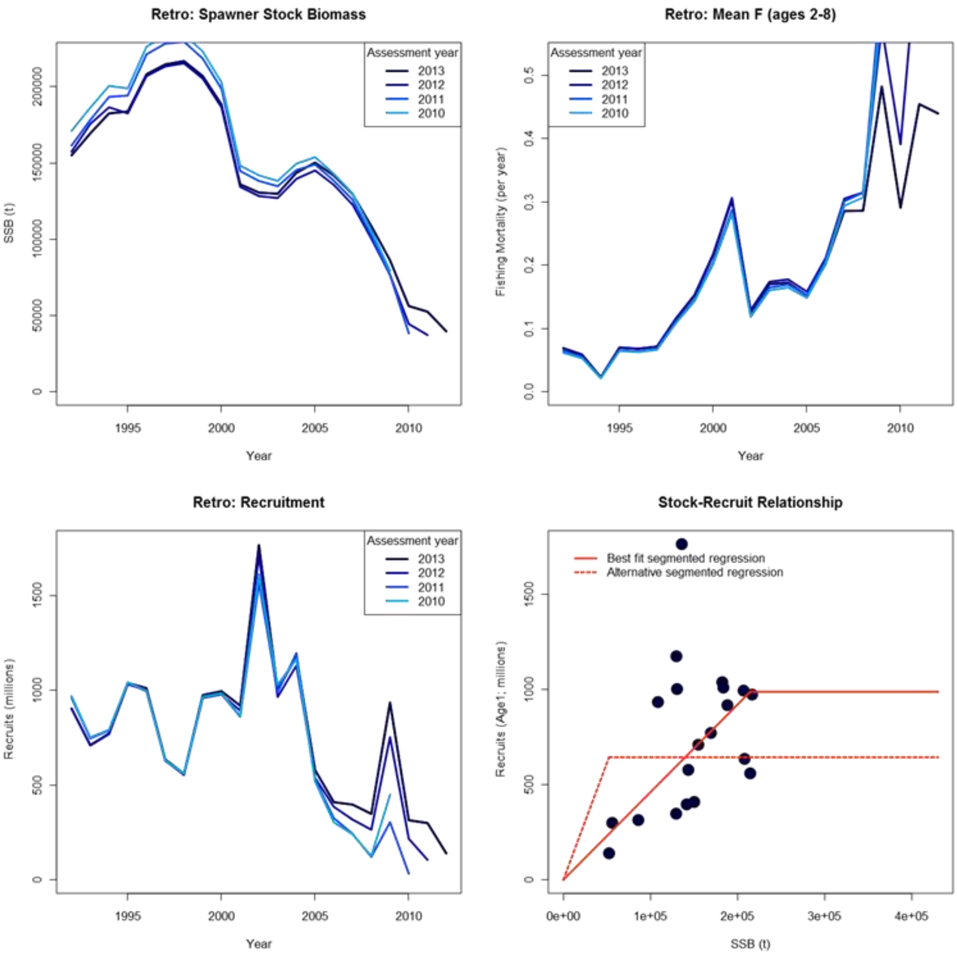
E.2a. GLM_Whm Retrospective and SRR



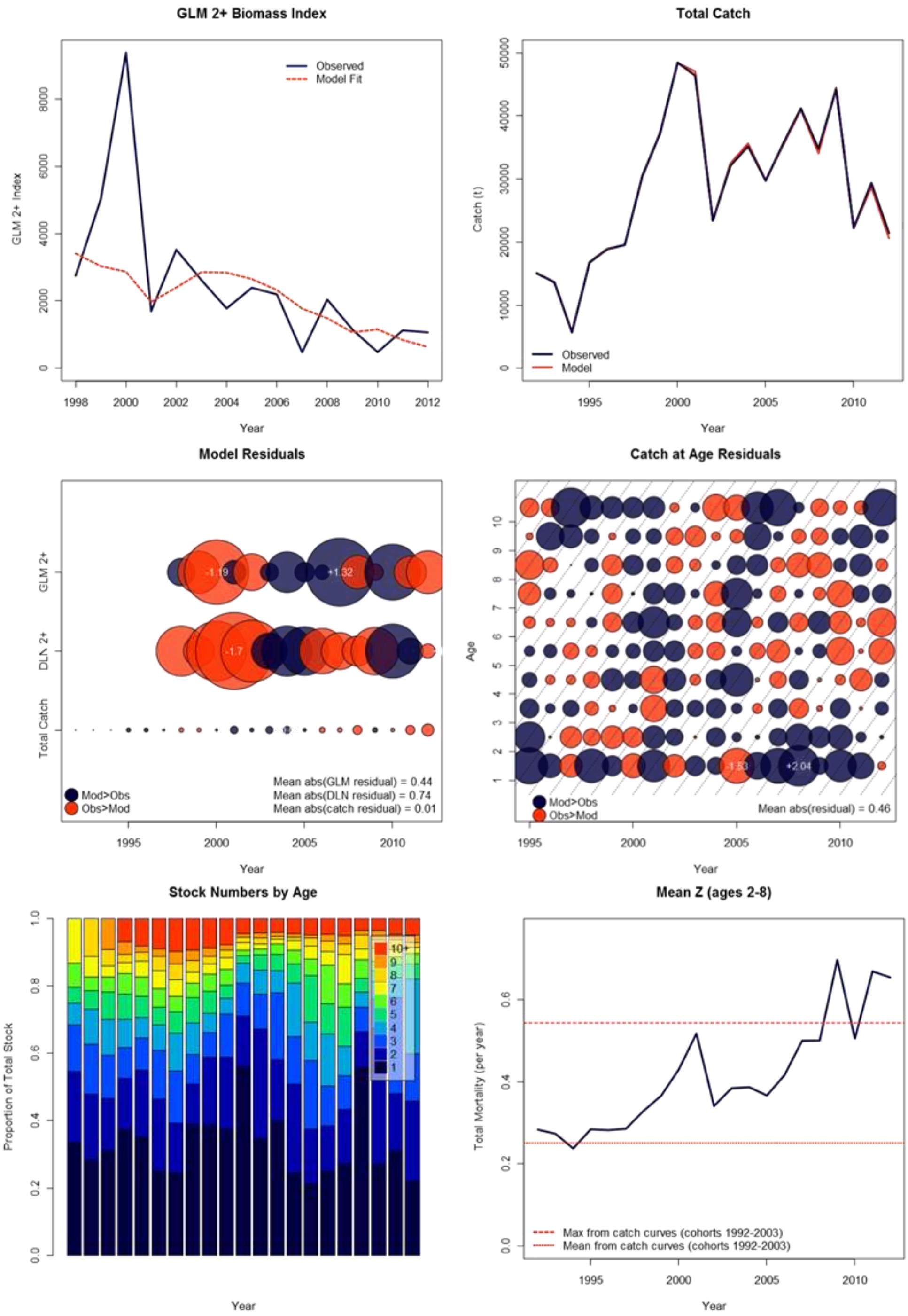
E.2b. GLM_Whm Model fit



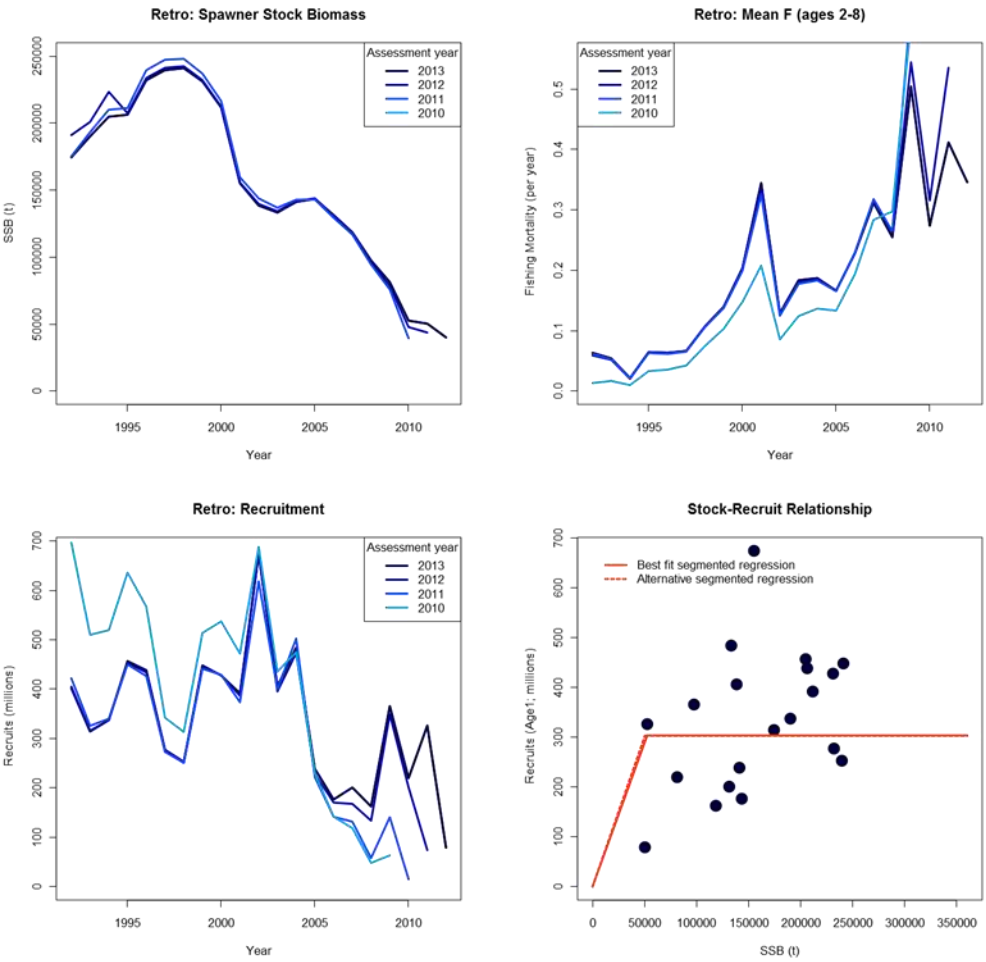
E.3a. GLM_Shm Retrospective and SRR



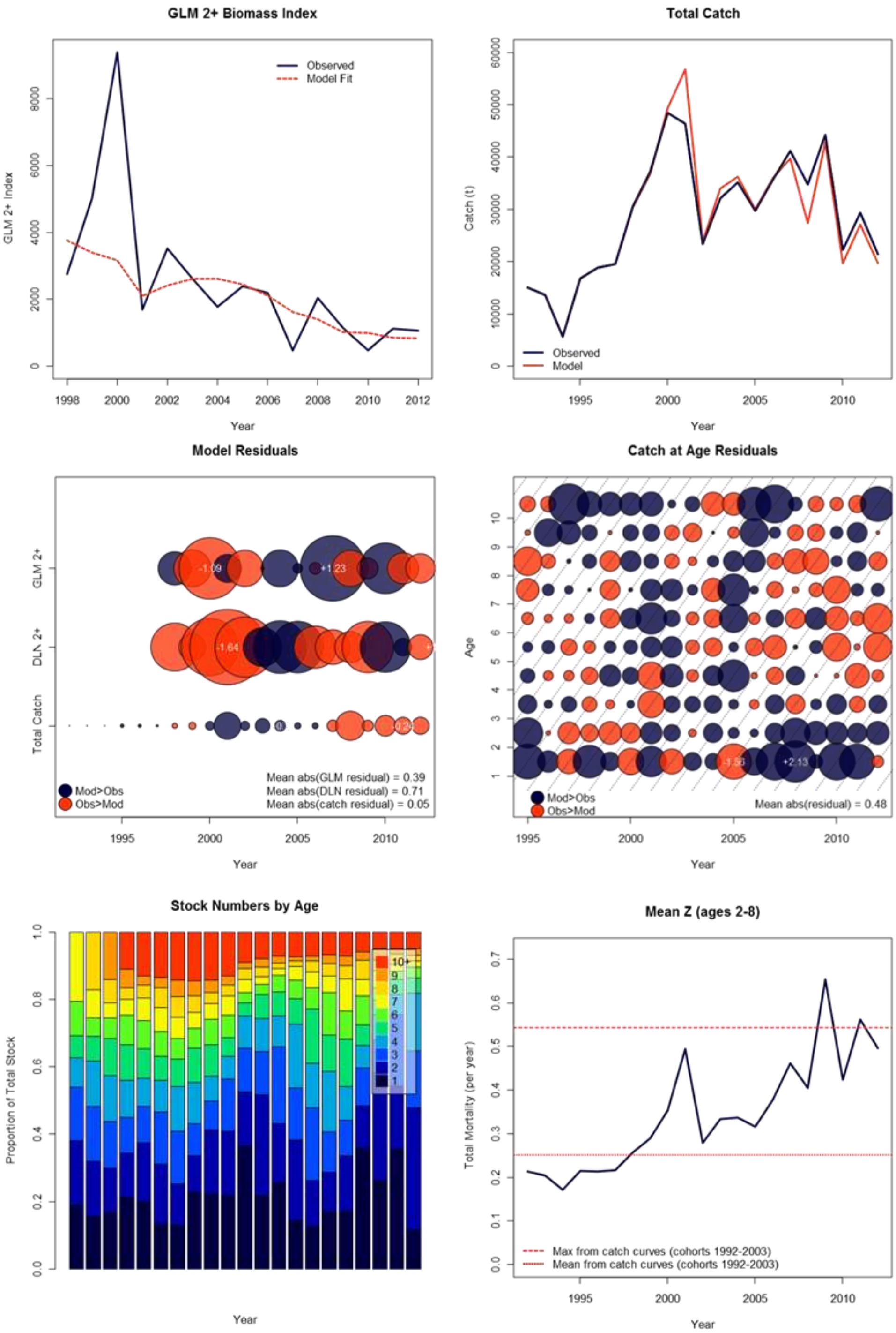
E.3b. GLM_Shm Model fit



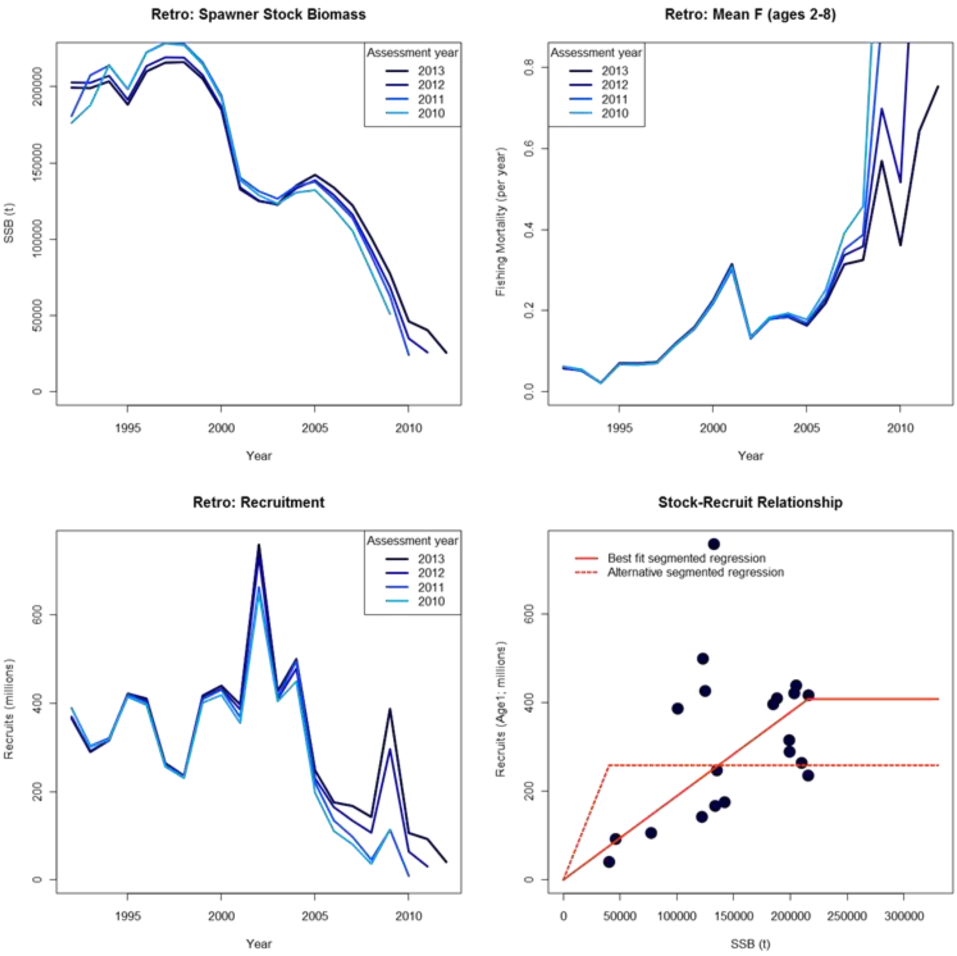
E.4a. GLM_index_weighted Retrospective and SRR



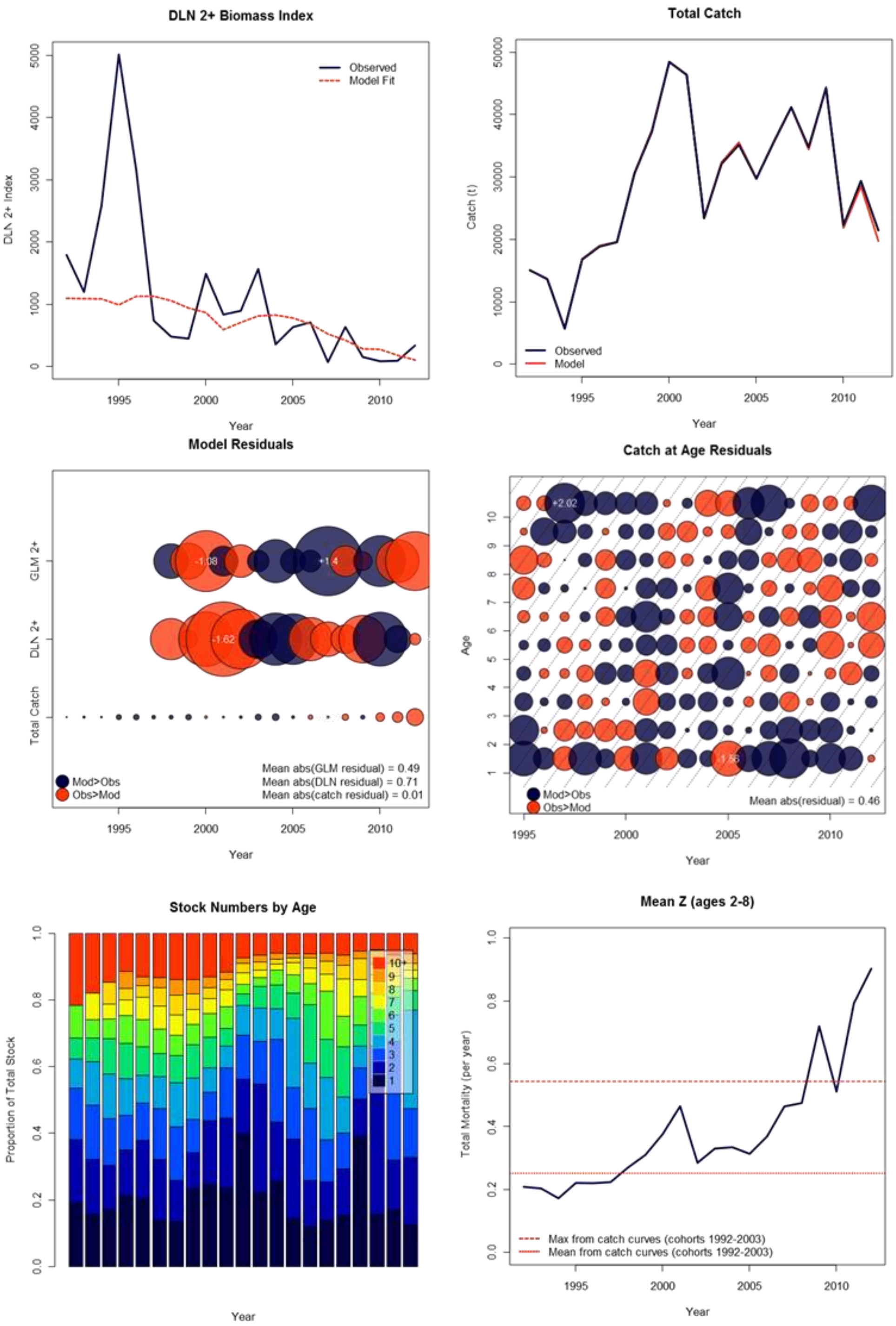
E.4b. GLM_index_weighted Model fit



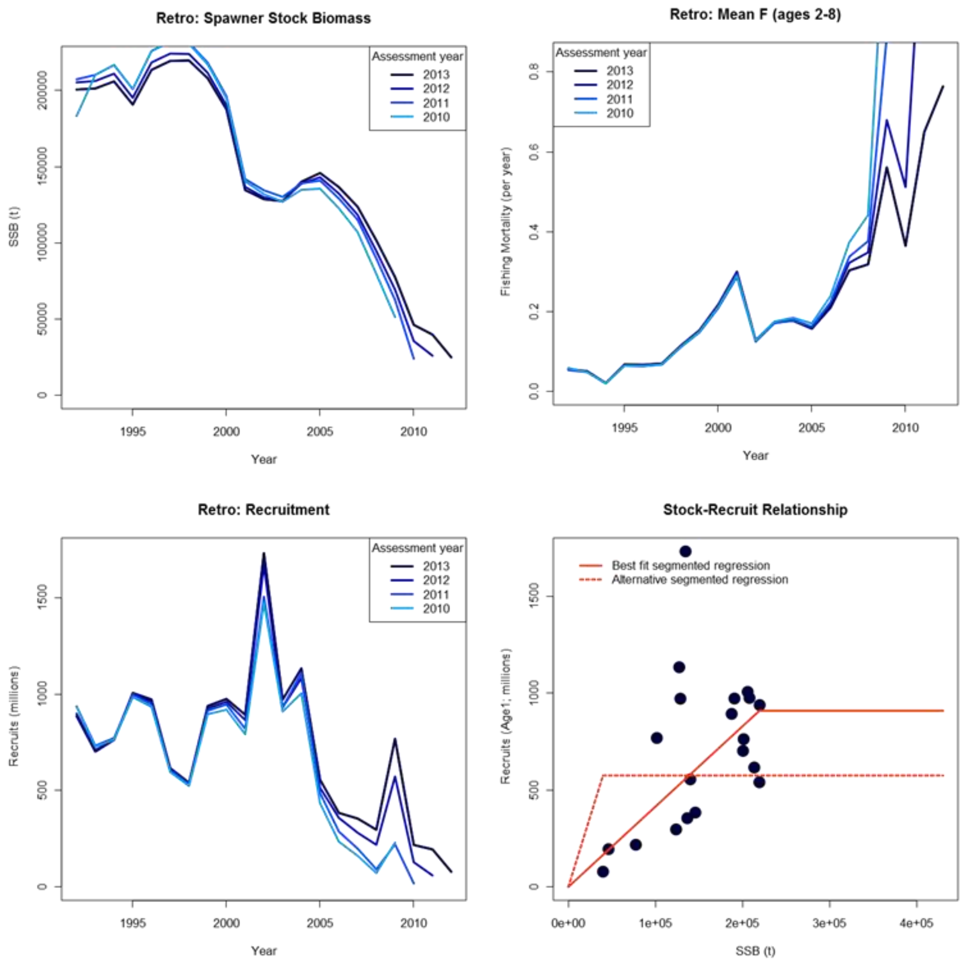
E.5a. DLN_Whm Retrospective and SRR



E.5b. DLN_Whm Model fit



E.6a. DLN_Shm Retrospective and SRR



E.6b. DLN_Shm Model fit