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Report of the Workshop on Guidance on Development of Operational Methods for the Evaluation of the MSFD Criterion D3.3 (WKIND3.3i)

14–17 March 2016

Copenhagen, Denmark

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CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

WKIND3.3i was held from 14–17 March, 2016 at ICES headquarters in Copenhagen, Denmark. The meeting was chaired by W. Nikolaus Probst and attended by 19 participants from 12 countries.

The workshop analysed and evaluated indicators for Criterion 3.3 of Descriptor 3 (D3) of the Marine Strategy Framework Directive (MSFD) considering three aspects of size (and age) structure of exploited fish stocks:

- Size distribution of the species (state);
- Selectivity pattern of the fishery exploiting the species (pressure);
- Genetic effects of exploitation on the species (state).

For the size distribution of the species within a stock several size-based indicators (SBI) were calculated using data from scientific research vessels. Though the calculations were technically feasible, the assessment of SBI was not possible due to the lack of meaningful assessment benchmarks. WKIND3.3i concluded that three SBI should be further developed: the 95%-percentile of the length–frequency distribution (L_{95}), the proportion of mega-spawners (P_{mega}) and the abundance of mega-spawners ($cpue_{mega}$).

The selectivity pattern of the fishery was analysed by two indicators: The size-at-first-capture (L_c) and the mean-size-in-the-commercial-catch (L_{mean}). Both indicators could be calculated and assessed against biological reference points for a wide range of stocks covering different geographical ranges and life-history types. WKIND3.3i therefore considers these indicators to be generally operational und useful within the assessment of single stocks. However, there was a non-resolved disagreement between participants on how to use these indicators within the MSFD: Whereas some participants considered L_c and L_{mean} as appropriate indicators within Criterion 3.3, many others felt that an inclusion of these indicators into a stock-based GES assessment could come into conflict with the assessment results of Criteria 3.1 (level of fishing pressure) and 3.2 (reproductive capacity of the stock). Furthermore, the management (i.e. optimisation) of selectivity was considered to be not feasible for mixed-fisheries situations, for which the improvement of selectivity for large species may compromise the catch of smaller species.

The indicators of genetic effects considered at WKIND3.3i were the size-at-first-maturity (L_{m50}) and the probabilistic maturation reaction norm (PMRN=Lp50). The L_{m50} can be calculated for a wide range of stocks and is less data demanding than the Lp50, which can be calculated only for the main commercial species. Though both indicators can be readily calculated and show clear patterns, their sensitivity to fishing pressure is ambiguous and characterised by slow responsiveness. It is expected that negative impacts of fishing will manifest within few generation times, whereas the recovery from fisheries induced evolution will last for decades and may not evolve back to historic conditions. Thus the establishment of assessment benchmarks was considered difficult, but a time-series based assessment approach (TSBA) is suggested.

TSBA could generally be used for all indicators within D3, which do not have biological reference points and assessment benchmarks, but were not further explored by WKIND3.3i. However, a discussion on TSBA is included into the report of the back-to-back workshop WKGESFish.

In conclusion, WKIND3.3i recommends that due to the lack of assessment benchmarks for SBI on stock size structure and indicators on genetic effects, these indicators should not be included into the 2018-assessment of GES by member states. The majority of the workshop participants refrained from recommending indicators on selectivity for the assessment of GES by 2018.

1 Opening of the meeting

WKIND3.3i was held from 14–17 March, 2016 at ICES headquarters in Copenhagen, Denmark. The meeting was chaired by W. Nikolaus Probst and attended by 19 participants from 12 countries.

2 Introduction

Descriptor 3 (D3) of the EU-Marine Strategy Framework Directive (MSFD) demands Member States to ensure that "populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock." (EU-COM, 2008). The second part of D3 is addressed by criterion 3.3, which requires the assessment of the population size or age structure of exploited populations. In the EU-Commission Decision 477/2010/EU it is further specified what is meant by a 'healthy' size or age structure: "Healthy stocks are characterised by large proportion of old, large individuals" (EU-COM, 2010).

Since the implementation of the MSFD, size-based indicators (SBI) on stock structure have been put under scientific scrutiny for use within the directive. An initial selection of SBI has been put forward by experts as a result of a joint JRC/ICES workshop in 2010 (Piet *et al.*, 2010), but since then these suggestions have undergone substantial revisions. One indicator within D3.3 was considered to be non-suitable for the assessment of single stocks (the mean-maximum-length across all species found in research vessel surveys, indicator 3.3.2) (ICES, 2015c), while others (L_{95} and P_{mat}, for explanations see below) were demonstrated to be not specifically sensitive to fishing pressure, but also to recruitment (Probst *et al.*, 2012; Probst *et al.*, 2013b).

To progress the applicability of Descriptor 3 (D3), ICES was requested to provide advice on the criteria and indicators (ICES, 2012; ICES, 2014a; ICES, 2015c). The result of these workshops evolved into advising that Criterion 3.3 "requires further development; monitoring should continue, but the results cannot currently be used to evaluate GES." And further: "Any new indicators should capture three relevant properties that describe or are directly linked to this criterion:

- Size distribution of the species (state);
- Selectivity pattern of the fishery exploiting the species (pressure);
- Genetic effects of exploitation on the species (state).

The indicators proposed in the initial Commission decision are related to the newly proposed properties of Criterion 3.3 as described above. One "best indicator" needs to be selected for each property based on appropriate criteria. This may be a new and better indicator or one of the previous indicators.

These three properties of the "population age and size distribution that is indicative of a healthy stock" and the provisional suggestions for indicators from the workshop [(ICES, 2014b)] should be the basis for a process involving one or more further workshops aimed to select at least one "best" indicator for each property."

Therefore this workshop aimed to explore the potential of indicators for D3-criterion 3.3 addressing the tree properties by addressing the following ToR:

"Calculate, validate, evaluate and select appropriate indicators to be used in the assessment and evaluation of the GES for the criterion 3.3 on 'Healthy age - and size structure' based on the proposed indicators from previous work (WKMSFDD3_II). The indicators will be calculated exemplary from real data of selected stocks representing different life histories, ecological guilds from different marine regions. The relationships between the state and the pressure indicators will be analysed to explore the potential of obtaining meaningful assessment benchmarks for good environmental status (GES). Procedures of calculations will be documented and provided as technical guidance.

i) Size distribution of the species (state) [referring to the size distribution in the stock]

A) Proportion of fish larger than the mean size of first sexual maturation (Former indicator 3.3.1)

B) 95% percentile of the fish length distribution observed in research vessel surveys (Former indicator 3.3.3)

C) Other size-based indicators (L_{mean}, $L_{max5\%}$, any other)

ii) Selectivity pattern of the fishery exploiting the species (pressure)

A) Length (or age depending on data availability) at first capture (length/age at which 50% of fish are vulnerable to / retained by the gear)

B) Proportion of fish larger than size at which 50% is mature (in the commercial catch)

C) Mean length in the catch

iii) Genetic effects of exploitation on the species (state)

A) Size at first sexual maturation (Former indicator 3.3.4)

B) Length at which half of the (female) population are mature: TL 50″

3 Size distribution in the stock (state)

3.1 Introduction

WKIND3.3i explored six size-based indicators (SBI) from length–frequency distributions of survey data by calculating the time-series of the SBI and evaluating these indicators against the ICES high level criteria for indicator selection (Box 3.1).The subgroup on the state of stock structure (SGSS) decided to focus on SBI and not analyse age-based indicators (ABI), because SBI are applicable to a wider range of stocks than ABI. ABI can only be calculated for stocks for which age data are collected, hence ABI address only the main target species. Contrary, SBI can be obtained from scientific fisheries surveys also for bycatch and non-target species.

Out of all the SBI that were known to the members of SGSS and which were discussed during the workshop, the following six SBI were considered as particularly promising to represent the stock component of "old, large individuals" and thereby addressing the requirements of Criterion 3.3 best:

- the 95%-percentile of the fish length–frequency distribution in research vessel surveys (L_{95})
- the proportion of fish larger than the mean-size-of-first-sexual-maturation (P_{mat})
- the proportion of mega-spawners (P_{mega})
- the absolute abundance of mega-spawners ($cpue_{mega}$)
- the Shannon–Wiener diversity of the length class frequencies (LCH)
- the mean size of the largest *n* observed individuals in the catches (L_{max_n})

More detailed descriptions and specifications on the indicators are provided in Annex 6.

Box 3.1. ICES high level criteria for indicator selection (ICES, 2015c).

- Availability of data. *Measurability*, robust quantifiable data covers range of spatial & temporal natural variability of suitable (historic) duration and resolution, availability of historic data or other reference points for benchmarking,
- Quality of underlying data. Data that are *Sensitive* to the magnitude and direction of response to underlying attribute/pressure with high signal to noise ratio, and *Responsive* at an appropriate timescale. A *tangible* indicator that is intuitive to understand.
- Conceptual, *Theoretical basis*, with indicator behaviour (in response to pressure) that is understood to support management advice,
- Communication, an indicator that is simple, credible, *unambiguous, comprehensible* and can be easily communicated
- Manageable, an indicator that is relevant to management, with estimable targets and thresholds and which is *responsive, sensitive* and *cost-effective* to develop.

3.2 Indicator testing

The SBI were calculated using survey-based length–frequency distributions from several stocks from the Baltic Sea, the North Sea, the Northeast Atlantic and the Mediterranean Sea (Table 3.2.1). The focus of this workshop was mostly directed towards data-rich stocks to ensure that the indicators could be calculated and analysed against the background of stock status on criteria C3.1 (Level of pressure of the fishing activity) and C3.2 (Reproductive capacity of the stock).

Table 3.2.1. List of stock, for which SBI have been calculated.

Candidate stocks	Functional group	Stock Id/area	Advisory body
Western Baltic cod	Demersal	cod-2224	ICES
Eastern Baltic cod	Demersal	cod-2532	ICES
North Sea cod	Demersal	cod-347d	ICES
North Sea herring	Pelagic	her-47d3	ICES
North Sea plaice	Demersal	ple-nsea	ICES
Spurdog	Elasmobranch	dgs-nea	ICES
Northern hake	Demersal	hke-nrtn	ICES
Anchovy	Pelagic	GSA17/18	GFCM
Mediterranean hake	Demersal	GSA9	GFCM
Giant red Shrimp	Demersal	GSA11	GFCM

3.2.1 Indicator calculation

The SG used survey data from the ICES Datras database (datras.ices.dk) and Mediterranean surveys obtained from the Medits survey for demersal species and Medias survey for small pelagics (STECF, 2015a; STECF, 2015b) to calculate SBI using standardised R-functions. These functions require length-based survey data and life-history parameters (LHP), both of which are referenced in Table 3.2.1.1. The LHP for northern Atlantic stocks were derived from an analysis of SMALK-data analysis except for northern hake (see Chapter 4 and Annex 8).

Table 3.2.1.1. Life-history parameters used for the calculation of SBI.

Stock id	$L\infty$ (cm)	Lmega (cm)	Lmat (cm)	Source	Survey data
cod-2224	119.0	87.3	31.0	WKIND3.3i	BITS_Q1Q4
cod-2532	119.0	87.3	31.0	WKIND3.3i	BITS_Q1Q4
cod-347d	117.0	85.8	53.4	WKIND3.3i	IBTS-NS-Q1
her-47d3	34.6	25.4	23.8	WKIND3.3i	IBTS-NS-Q1
ple-nsea	55.0	40.3	22.8	WKIND3.3i	IBTS-NS-Q1
dgs-nea	128.0	93.9	81.4	WKIND3.3i	IBTS_NS_Q1 IBTS_SCW_Q EVHOE_Q4
hke-nrtn	130.0	95.3	42.9	WKLIFE 2015	IBTS_NS_Q1 IBTS_SCW_Q EVHOE_Q4
Anchovy GSA17/18	19.4	14.2	7	STECF – EWG 15-18	Medias
Hake GSA9	103.9	76.2	35.0	STECF – EWG 15-18	Medits
Giant red shrimp GSA11	5.7*	4.2	3.26	GFCM-WGSP 2015	Medits
* Carapace length					

3.2.2 Indicator benchmarking

Currently all suggested SBIs lack validated reference points for an assessment of GES with respect to sustainable levels of exploitation. For two indicators, however, (L_{95} and P_{mega}), reference points exist for the purpose of conservation (see Table 4.2.1): The assessment benchmarks for L_{95}, was set at $0.8*L_{\infty}$, for P_{mega} at 30%. These benchmarks are based on work by WKLIFE-V (ICES, 2015b) and simulation studies on stock length structures (Cope and Punt, 2009) as well as suggestions by Froese (2004). SGSS referred to these WKLIFE-V reference points for the sake of completeness and for illustration but did not consider these reference points as operational for the purpose of a GES assessment, as for many stocks the reference points seemed to be out of the likely value range. For the other SBI (P_{mat}, $cpue_{mega}$, LCH and L_{max_n}) no benchmark proposals were available.

However, the possibility of using time-series-based assessment approaches (TSBA) to derive reference points will be highlighted for the example of North Sea cod. The here used TSBA-benchmarking is based on a modified breakpoint analysis as suggested by Probst and Stelzenmüller (2015). In this report, the benchmarks of the reference period are used to distinguish between a 'bad' (significantly below the worst observed period, t-test), 'not good' (not significantly above the average), 'good' (significantly above the average) and 'very good' (significantly above the best period) status.

It has to be noted, that the here presented TSBA-approach is used just for exemplary purposes and is not intended for direct implementation. During this workshop, but even more so during WKGESFish the potential of TSBA-approaches within the MSFD has been discussed intensively, and while in some frameworks such as second holistic assessment of the ecosystem health of the Baltic Sea by the Helsinki-Commission (HELCOM HOLAS) TSBA-methods are already applied, the general application within the MSFD is associated with strength and weaknesses (see WKGESFish report) and thus requires further scrutiny about if and how they can be applied within Criterion 3.3.

3.2.3 Results

The annual length–frequency-distributions (LFD) were the basis for the calculation of the SBI. The LFD of North Sea cod for example, showed strong interannual differences driven by changes in abundance as well as the proportion between the length classes (Figure 3.2.3.1).

Based on the annual LFD the six SBI could be calculated for all stocks listed in Tables 3.2.1 and 3.2.1.1 (Annex 5). Neither the L_{95} nor the P_{mega} of North Sea cod (cod-347d) achieved its assessment benchmark (Figure 3.2.3.2). For the other three indicators no GES-benchmarks were available, but the time-series of the $cpue_{mega}$ and the L_{max_n} showed a declining trend until 2001. After 2001 the $cpue_{mega}$, the L_{max_n} and the LCH showed a slight to moderate increase, suggesting that the size-structure of cod has changed during the last decade.

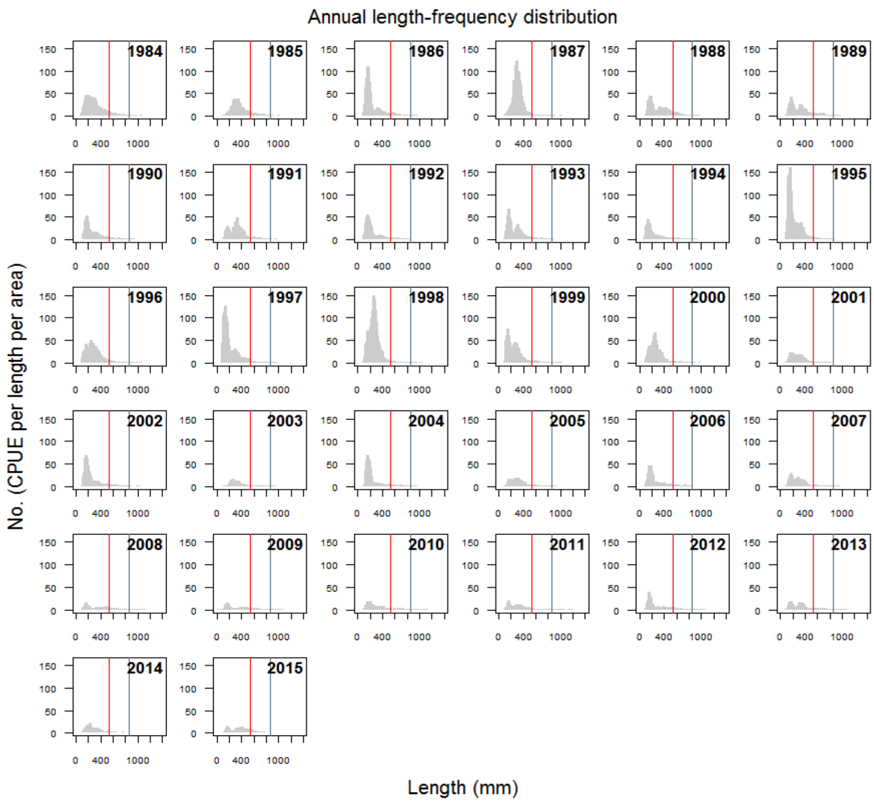

Figure 3.2.3.1. Annual length–frequency distributions (LFD) of North Sea cod (cod.347d) using IBTS-NS_Q1 data. The annual LFD were used to calcualte SBI in Figure 3.2.3.2 and Annex 5. Red vertical lines represents mean-size-at-first-sexual-maturation (L_{mat}=534 mm for North Sea cod) and the grey vertical lines the minimum length of mega-spawners (L_{mega}=858 mm for North Sea cod).

Comparing the time-series of the L_{95} and P_{mega} across the analysed stocks and against their assessment benchmarks, the indicator time-series of many stocks fall well below their WKLIFE V target. This suggests that the conceptual benchmarks of $0.8*L_{\infty}$ (for L_{95}) and 30% (for P_{mega}) may not be appropriate to all species with different life-history strategies for several reasons. First, survey-based indicator metrics will be affected by the catchability of the survey gear for species and size classes (Fraser *et al.*, 2008), and thus a generic threshold for these indicators might not be applicable. Second, life-history parameters (LHP) can change over time, which would affect benchmarks based on e.g. L∞. Therefore SBI using LHP for benchmarking such as L∞, L_{mat} or L_{mega} may have to consider temporal changes.

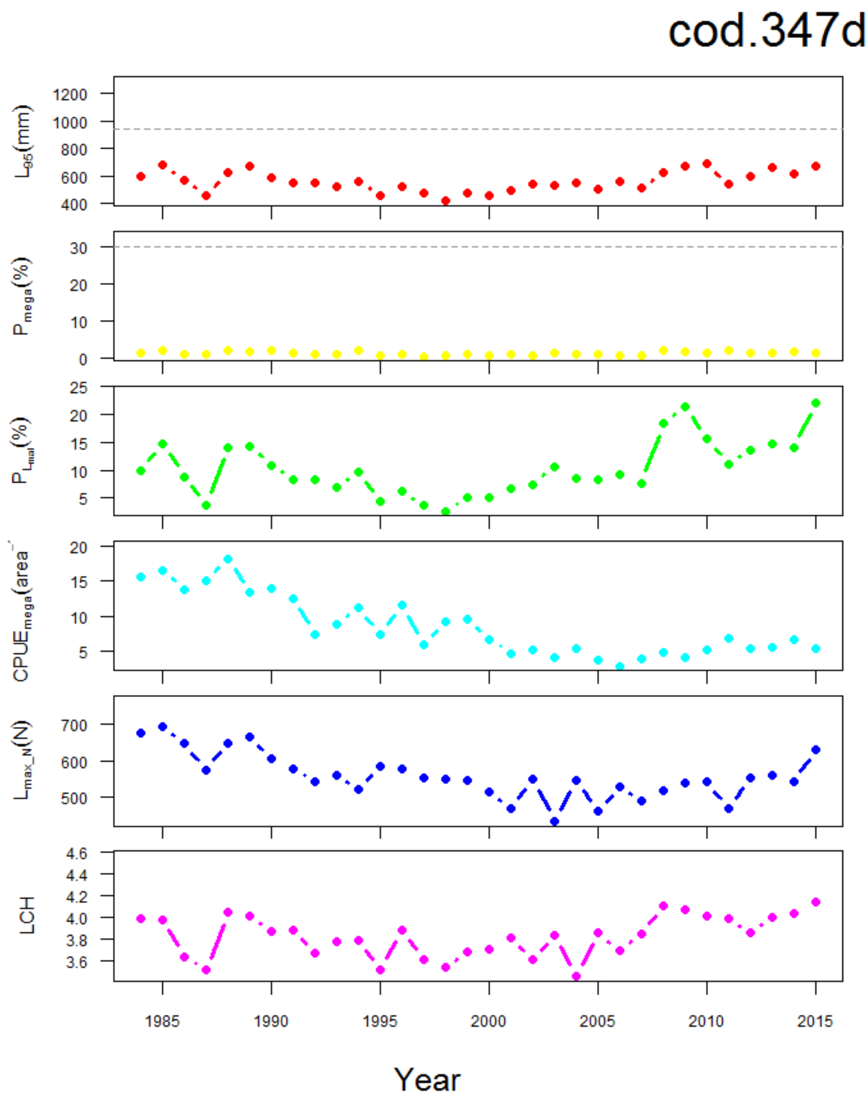

Figure 3.2.3.2. Six size-based indicators for North Sea cod *Gadus morhua*. Explanation of indicator abbreviations are given in Annex 5. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE-V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

Figure 3.2.3.3 illustrates a time-series based assessment approach (TSBA) for the SBI without a conceptual GES-benchmark ($cpue_{mega}$, L_{max_n} and LCH) for North Sea cod and an assessment against WKLIFE V conservation thresholds for L_{95} and P_{mega}. The differing TSBA-results highlight one of the central caveats when using TSBA: as TSBA is not related to a conceptual value of GES (such as MSY), the assessment outcome can be quite different when looking at different SBI. While the LCH displayed a positive assessment outcome, the L_{max-n} and the $cpue_{mega}$ showed negative TSBA results.

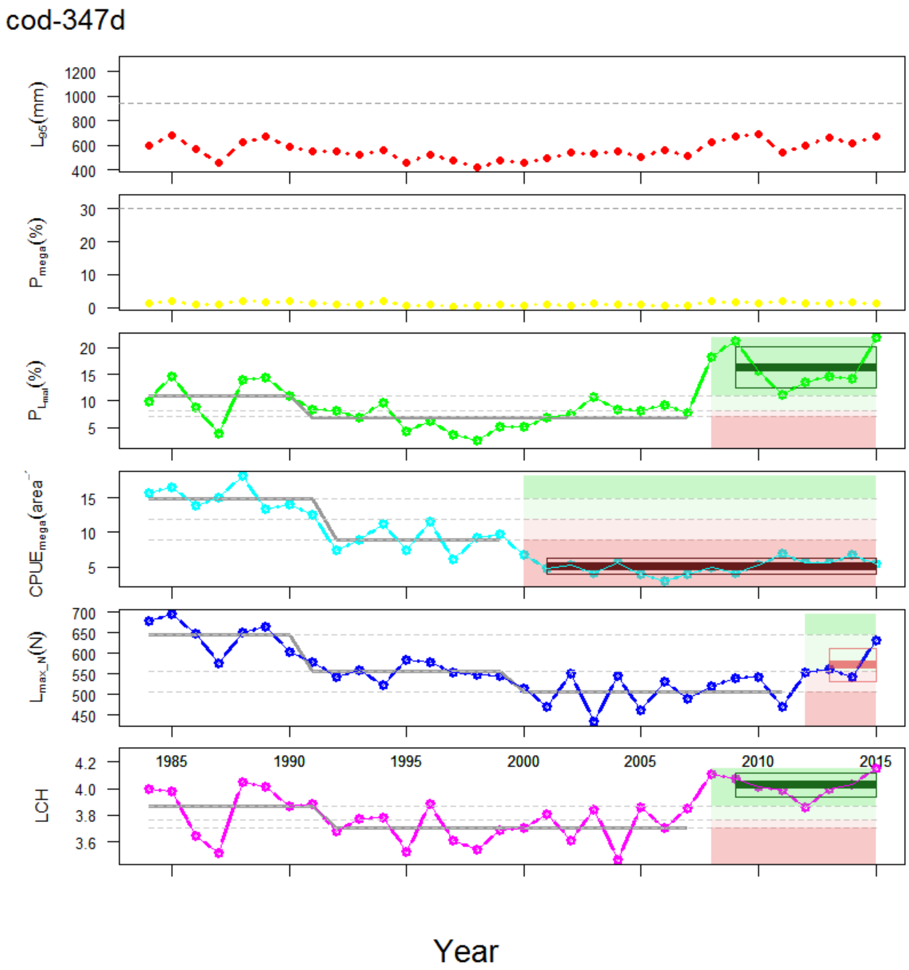

Figure 3.2.3.3. SBI of North Sea cod *Gadus morhua* using time-series-based assessment (TSBA) for $cpue_{mega}$, L_{max_n} and LCH. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

3.3 SBI Indicator evaluation

After the calculation of the SBI, SGSS addressed the selection of "one best" indicator (ICES, 2015a). Throughout the discussion within SGSS it was realized that not all of the six SBI may address the large, and old fish component of a stock equally well. Furthermore, some SBI were considered to have conceptual shortcomings (e.g. P_{mat}) preventing the development of conceptual reference points, which could be used to obtain assessment benchmarks.

3.3.1 Evaluation methods

SGSS undertook a structured evaluation process in which each of the six SBI was described and their concepts and problems were discussed. Eventually each SBI was evaluated against the ICES high level criteria for indicator selection (Box 3.1) using a scoring system from 0 to 3 (0 = not applicable, 1 = low, 2 = medium, 3 = high). An extra criterion was added to account for the requirement of the MSFD that the indicators within C3.3 should relate to the *"abundance of old, large individuals"* (EU-COM, 2010). The scores of each criterion were than summed within each SBI, leading to a maximum possible score of 18.

3.3.2 Evaluation results

Of the six SBI, $cpue_{mega}$ obtained the highest overall score (Table 3.3.2.1). SGSS considered this indicator to relate especially well to the large stock component while not being susceptible to the short-term influences of recruitment (contrary to L_{95}, P_{mat}, P_{mega} and LCH). However, SGSS did not see any possibilities to develop a conceptual reference point for $cpue_{mega}$, therefore TSBA-approaches might be taken into account for this indicator.

P_{mat}, L_{95} and P_{mega} scored lower than $cpue_{mega}$, because consideration of a relative proportion of the size spectrum has been demonstrated to be susceptible to recruitment fluctuations (Probst *et al.*, 2013b). P_{mat} is also lacking a conceptual reference point and is not addressing the large stock component. Thus SGSS recommends that P_{mat} should not further be considered when assessing C3.3.

LCH had the lowest score of all SBI because it was not considered as fully developed, both methodologically and conceptually. SGSS assumed that this indicator may be well suited to describe the overall size-structure of the stock, but not only the large individuals. With further conceptual development some SG-members felt that the LCH could offer potential as a valuable SBI within the MSFD.

Table 3.3.2.1. Summary of size-based indicator (SBI) evaluation. For a description of criteria and indicators refer to Annex 6.

	L_{95}	P_{MAT}	P_{MEGA}	$CPUE_{MEGA}$	LCH	L_{MAX_N}
Relation to "abundance of large old individuals"	2	2	2	3	1	2
Availability of data	2	1	1	1	2	2
Quality of underlying data	1	1	1	2	1	1
Conceptual	1	1	2	2	1	2
Communication	2	2	2	2	1	1
Manageable	2	1	2	2	0	1
Total score	10	8	10	12	6	9
Relative score (100%=18)	55.6%	44.4%	55.6%	66.7%	33.3%	50%

The evaluation process indicated that at the moment all SBI have weaknesses (no indicator obtained a score that was higher than 66% of the maximum score) and none was considered to be fully operational. The major impairment for the operationalisation was the lack of conceptual, theory-based reference points and resulting GES-assessment benchmarks. Under the consideration of short time lines for the upcoming 2018-MSFD-Article 8 assessment, WKIND3.3i concluded that member states should not become obliged to assess C3.3, but that further development and validation of SBI is necessary. During this process, the potential of applying TSBA should be explored.

3.3.3 Conclusions

WKIND3.3i succeeded in identifying three SBI (L_{95}, P_{mega} and $cpue_{mega}$) which could eventually be considered in the assessment of good environmental status (GES).

However, for these indicators to become operational, further research and development is necessary. Ideally, eventually only one best indicator should be chosen for GES assessment.

4 Selectivity pattern of the fishery exploiting the species (pressure)

4.1 Introduction

Commercial fishing affects the size distribution of stocks. Fishing mortality directly truncates the stock's length distribution, and its effects on a cohort accumulate over time. In addition, fishing is often size-selective by targeting larger more valuable individuals and further diminishing their abundance. Many life-history processes such as fecundity and reproductive success are size-dependent, such that a lack of large individuals can diminish the reproductive potential, affect sustainable use or the recovery potential of stocks (Trippel, 1998; Begg and Marteinsdottir, 2003; Berkeley *et al.*, 2004; Walsh *et al.*, 2006; Wright and Trippel, 2009). Truncation of age or size structure was also found to increase variability of population abundance (Aubone, 2004; Hsieh *et al.*, 2006; Anderson *et al.*, 2008). At the same time, overexploitation of juveniles can reduce population productivity (Froese *et al.*, 2008; Edwards and Plaganyi, 2011).

Length–frequency distributions of catches can give some information on the presence of large individuals in the stock. Furthermore, the exploitation of immature individuals can be evaluated when comparing the left side of the length–frequency distribution with the empirical maturation size of the respective stock. The indicators considered by the group represent simple metrics which can describe length distributions to assess changes in catch composition over time. Mean length L_{mean} is assumed to decrease with increasing exploitation rate (Maunder and Deriso, 2007).

4.2 Knowledge base for the evaluation process

The material on which the evaluation process was based is presented below in sections that correspond to the ICES high-level criteria for indicator selection (see Box 3.1), though not with a one-to-one match.

In the following sections we introduce:

- The theoretical basis for each indicator and potential reference levels, in reference to the ICES high-level criteria "Conceptual" and "Communication".
- The data that were used and which are assumed to be representative for the type of data on which further calculations of indicators or benchmarks can be based. Both the availability and quality of the data will be considered and the results of the actual calculation of indicators and reference levels for a suite of stocks is presented. This section therefore links to the ICES high-level criteria "Availability of data" and "Quality of underlying data".
- Finally the relevance for management of the indicator and any potential targets or thresholds is interpreted in terms of their suitability to be applied as part of an assessment of the selectivity of the fishery against GES. This is therefore supposed to link to the ICES high-level criteria "Manageable".

For this evaluation to select indicators and reference levels that refer to the size (and related age) structure of the stock, we considered two relevant indicators based on the work of ICES WKLIFE (see Table 4.2.1), i.e. L_c and L_{mean}, and three relevant reference levels, L_{mat} and L_{opt}, L_{c_opt} (for definitions see Chapter 4.3) with the strongest theoretical basis in the literature.

Table 4.2.1. Selected indicators and potential reference levels considered for stock status assessment by WKLIFE (ICES, 2015). Note that L_{mean} is similar to L_{mean_c} in this report.

Indicator	Calculation	Reference point	Indicator ratio	Expected value	Property
Lmax5%	Mean length of largest 5%	Linf	Lmax5%/Linf	>0.8	Conservation (large individuals)
L95%	95th percentile		L95%/Linf		
Pmega	Proportion of individuals above Lopt+10%	0.3–0.4	Pmega	>0.3	
L25%	25th percentile of length distribution	Lmat	L25%/Lmat	>1	Conservation (immatures)
Lc	Length at first catch (length at 50% of mode)	Lmat	Lc/Lmat	>1	
Lmean	Mean length of individuals larger Lc	Lopt = 2/3 Linf	Lmean/Lopt	≈1	Optimal yield
Lmaxy	Length class with maximum biomass in catch	Lopt = 2/3 Linf	Lmaxy/Lopt	≈1	
Lmean	Mean length of individuals larger Lc	LF=M = (0.75Lc+0.25Linf)	Lmean/LF=M	≥1	MSY

L_{mean_c}

4.3 Indicators

Initially WKIND3.3i considered four potential indicators for the assessment of the length–frequency distribution in the commercial catch data:

- Length at first capture (L_c)
- Mean length in the catch (L_{mean_c})
- Mode length (= length class with largest number of individuals) (L_{peak})
- Maximum length (= length of largest individual) (L_{max})

and five potential reference levels:

- Asymptotic length L_∞ from the von Bertalanffy growth function:

$$L_t = L_\infty(1 - e^{-K(t-t_0)})$$

- Length where cohort biomass is maximum without fishing (L_{opt})

$L_{opt} = L_\infty \frac{3}{3+M/K}$ or for M/K ~1.5 $L_{opt} = \frac{2}{3} L_\infty$

- Length at first capture L_{c_opt} that, for a given F, results in a mean length of L_{opt}

$$L_{c\_opt} = L_\infty \frac{2+3F/M}{(1+F/M)\,(3+\frac{M}{K})}$$ or for F ~M $L_{c\_opt} = 0.56\, L_\infty$

- Length where 50% of females have reached maturity (L_{m50})
- Length where 90% of females have reached maturity (L_{m90})

From these four initial indicators, two indicators, the length-at-first-capture (Lc) and the mean-length-in-the-catch above L_C were (L_{mean_c}) were considered as most promising (Figure 4.3.1). Both indicators and their assessment benchmarks are described in the following sections.

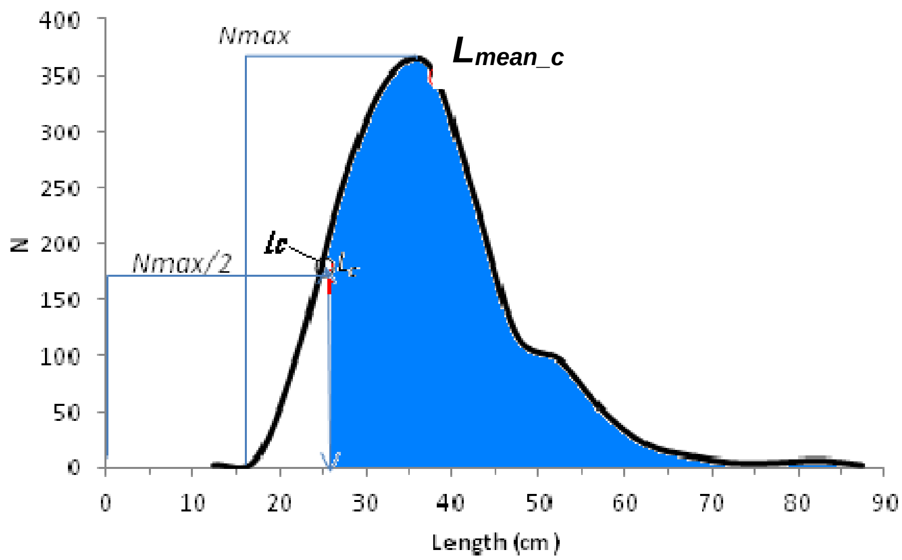

Figure 4.3.1. Plot of length–frequency distributions summed for North Sea turbot showing calculation of L_c and L_{mean_c}; the blue area is used to calculate L_{mean} (ICES, 2015b).

4.3.1 Length-at-first-capture-of-the-fishery (L_c)

4.3.1.1 Definition and calculation

L_c is the length class where 50% of the individuals are vulnerable to and retained by the gear. In a length–frequency curve (see Figure 4.3.1), L_c can be determined as the length at half of the maximum frequency (represented by N_{max}) in the ascending part of the curve. When calculating the length at first capture of the fishery, discards data should be included.

Different calculation methods, however, may exist. All methods only consider lengths and frequencies left of the maximum frequency. WKLIFE used the length closest to the first mode larger than half of the maximum frequency, as the latter method is sensitive to strong recruitment events. To reduce such sensitivity, the analyses presented in this report used the mean length of all lengths associated with frequencies falling within 20–80% on the left side of the mean maximum frequency, where the mean maximum was taken from the three largest frequencies around the first mode.

4.3.1.2 Rationale

L_c is predominantly a function of the size selectivity of the respective gear. It is the most specific pressure indicator considered in this section, showing the length at which fishing mortality begins to affect the population (before this length it is mostly natural mortality). It applies to gears like traps and gillnets, where fishing mortality may decrease once fish become too large to be captured by the gear, or to trawls, where all sizes above Lc remain vulnerable to the gear. However, by design, determination of L_c is based on lengths below the maximum frequency and thus L_c does not contain information about the length distribution on the right side. L_c is firmly based in standard fisheries science equations (see Beverton and Holt, 1957 and a recent review in Froese *et al.*, 2016). Yield is maximised if L_c is close to L_{c_opt} at which the biomass obtained from a cohort is maximised.

4.3.2 Mean-length-in-commercial-catch (L_{mean})

4.3.2.1 Definition and calculation

Mean length of catch (L_{mean} or L_{bar}) is calculated as:

$$L_{mean} = \frac{\sum_{l=1}^{L} C_l * l}{C}$$

Where l is the length and C_l is the catch-at-length represented by N in Figure 4.3.1. As with L_c different calculation methods may exist. In WKLIFE the mean length of the catch above the length at first capture (L_{mean_c}) was calculated as:

$$L_{mean\_c} = \frac{\sum_{l=L_c}^{L} C_l * l}{C}$$

This is represented by the shaded blue area in Figure 4.3.1.

4.3.2.2 Rationale

In the analysis of this report we used L_{mean} across all length classes, to make its estimation independent of L_c, which tends to be more variable. In other words, while L_c only analyses the left side of the frequency distribution (including discarded individuals if catch data are complete), L_{mean} represents the length–frequency distribution of the catch including the largest individuals. With gears like trawls, the mean length in the catch is also the mean length in the exploited part of the population (Beverton and Holt, 1957). Thus, L_{mean} summarizes, after a time-lag, the size distribution response of the stock to selectivity and total mortality and thus the state of the stock. L_{mean}can therefore be considered as a state indicator.

Rochet and Trenkel (2003) found that L_{mean} is a powerful population indicator but remark that it should be based on combined landings and discards. L_{mean} is firmly based in fisheries science equations (Beverton and Holt, 1957).

4.4 Reference levels

4.4.1 Length-at-maturity (L_{mat})

4.4.1.1 Definition and calculation

Length-at-maturity refers to length above which most individuals have ripe or spent gonads. In fisheries, the length at which 50% of the individuals are mature (L_{m50} which is identical with the often used L_{mat}) is typically established from the inflection point of a sigmoid curve fitted to the fraction of females with ripe or spent gonads over the respective length or age (see proportion mature-at-length curves). Another measure of relevance to conservation is the length where 90% of the individuals have reached maturity (L_{m90}). Both L_{m50} and L_{m90} can be estimated from a logistic curve fitted to proportion-mature-at-age data. If direct estimation of L_{m90} is not possible, it can be assumed to be approximately 20% larger than L_{m50}, i.e. $L_{m90} = 1.2 * L_{m50}$ (Froese *et al.*, 2015). If no estimation of L_{m50} is available, values from stock assessment documents or from the literature can be used. There are also empirical equations connecting maturation with asymptotic length (Froese and Binohlan, 2000; Gislason *et al.*, 2008; Le Quesne and Jennings, 2012).

4.4.1.2 Rationale

Overfishing is theoretically impossible if all individuals are allowed to reproduce at least once (Myers and Mertz, 1998). Length-at-maturity can therefore be used to test whether enough individuals reach maturity before becoming vulnerable to fishing mortality (Caddy and Mahon, 1995). The goal of letting all fish spawn at least once before capture is achieved with 50% or 90% probability if L_c is larger than these lengths, respectively.

Also, if L_{mean} falls below L_{m90} or L_{m50}, this is an indication of strong truncation of the size and age structure of the stock which is considered an undesirable property if a stock is to be sustainably exploited. L_{m50} is firmly based in fisheries science, and is used regularly in stock assessments to determine spawning–stock biomass from total biomass.

4.4.2 Optimum harvest length (L_{opt})

4.4.2.1 Definition and calculation

The optimum harvest length (L_{opt}) is calculated as a proportion of L_∞ (or L_{inf}):

$L_{opt} = L_\infty \frac{3}{3+\frac{M}{K}}$ based on Beverton (1992)

In case information on M and/or K is missing the following proxy can be used:

$L_{opt} = 2/3 * L_\infty$

Where L_∞ is the asymptotic length, K is the rate by which L_∞ is approached, both from the von Bertalanffy growth function, F is fishing mortality, and M is natural mortality. As a check L_∞ should not be (much) smaller than the largest specimens found in the data, as these are often an indication of the size that fish can reach if they manage to escape from fishing. Fitting a growth curve to length-at-age data may be problematic if length classes are missing due to lack of availability or catchability in the fishing or survey area.

4.4.2.2 Rationale

L_{opt} is the length where cohort biomass reaches a maximum in an unexploited stock, and where therefore egg production and cohort fecundity are also at maximum. L_{opt} is the average length of parents under unexploited conditions and the corresponding age is equal to generation time. In most species L_{opt} is also near the length where the maximum growth rate in body weight occurs and where the potential for production of gonads is maximum. The theoretical maximum catch can be obtained with infinite fishing effort if all fish were caught as soon as they reach L_{opt} (Beverton and Holt, 1957; Froese *et al.*, 2016). This also means that, for a given fishing mortality, catch will increase as length at first capture is increased towards L_{opt}.

In an exploited stock, L_{mean} can reach L_{opt} if L_c is adjusted accordingly (see rationale for L_{c_opt} below). If L_{mean} equals L_{opt} and the stock size is such that recruitment is not likely to be impaired, then the average length, age, and reproductive output will be similar to an unexploited stock and the likelihood of fisheries induced selection for early maturation should be low (Barot *et al.*, 2004b; Barot *et al.*, 2004a).

4.4.3 Optimum length at first capture (L_{c_opt})

4.4.3.1 Definition

The optimum length at first capture L_{c_opt} is the length at first capture L_c that results in a mean length in the catch and in the exploited part of the population equal to L_{opt} (see above). L_{c_opt} is derived from standard fisheries equations, where the mean length in the catch is predicted from length at first capture L_c, natural mortality M, fishing mortality F, and growth parameters L_∞ and K. Setting the mean length to L_{opt} and solving for L_c then gives L_{c_opt} (Froese *et al.*, 2016) which is calculated as:

$$L_{c\_opt} = L_\infty \frac{2 + 3\,F/M}{(1 + F/M)(3 + M/K)}$$

If estimates for F, M or K are missing, L_{c_opt} can be approximated as 0.56 L_∞ if F ~ F_{MSY} or as 0.59 L_∞ if F ~ 2 * F_{MSY}.

4.4.3.2 Rationale

Starting fishing at L_{c_opt} will, after a time-lag, result not only in L_{mean} in the catch and exploited part of the population reaching L_{opt}, but also in the highest yield-per-recruit and cohort biomass for the given fishing mortality.

4.5 Analyses to calculate indicators and reference levels

4.5.1 Data sources

L_c and L_{mean} can be readily estimated from length–frequency data derived from commercial catches. These data are available in principle for all exploited stocks sampled by the national programmes of the Data Collection Framework (DCF). However, so far length–frequency data are not reported in standard stock assessments and are not readily available in stock assessment or regional DCF-databases [e.g. InterCatch or FishFrame].

Reference levels for maturity (L_{m50}, L_{m90}) and growth (L_{∞}, K) can be derived from scientific fisheries surveys such as DATRAS SMALK data for many ICES stocks. Alternatively, estimates can be obtained from stock assessment documents or from the scientific literature. During the workshop it was not a problem to find estimates for these values, either from the full equations or as proxies, for all examined stocks. The analysed stocks ranged from Baltic cod and North Sea cod and plaice to deep-sea fish (roundnose grenadier), Atlantic swordfish, spurdog, Atlantic and Mediterranean hake, Mediterranean anchovy and giant red shrimp and were assumed to cover the main issues relevant to the evaluation of the indicators and reference levels (Table 4.5.1).

Table 4.5.1. Overview of stocks analysed for evaluation of indicators reflecting the selectivity of the fishery.

Name	Species	Stock	Area	Life-history source	Comment
Eastern Baltic cod	*Gadus morhua*	cod-2532	25–32	DATRAS SMALK BITS	Very low Linf of 90 cm assumed
North Sea cod	*Gadus morhua*	cod-347d	1–7	DATRAS SMALK IBTS	
North Sea plaice	*Pleuronectes platessa*	ple-nsea	1–7	DATRAS SMALK IBTS	
Northern hake	*Merluccius merluccius*	hke-nrtn	ICES 3a, 5, 6 and 8abd	Stock assessment report	
Mediterranean hake	*Merluccius merluccius*	hke-med	GSA 9	STECF EWG 15–18	Probably the adult portion of the stock is not completely vulnerable.
Mediterranean anchovy	*Engraulis encrasicolus*	anc-GSA1718	GSA 17, 18 Adriatic Sea	GFCM-WGSP 2015	
Giant red shrimp	*Aristaeomorpha foliacea*	GRShrimp11	GSA 11	STECF EWG 15–18	Carapace length
Roundnose grenadier	*Coryphaenoides rupestris*	rng-5b67	5b, 6, 7	Literature	Length type is pre-anal fin length
Spurdog, Males	*Squalus acanthias*	dgs-nea	NEA	Stock assessment report and literature	
Spurdog, females	*Squalus acanthias*	dgs-nea	NEA	Stock assessment report and literature	
Swordfish	*Xiphias gladius*	swo-sa	South Atlantic	ICCAT documents	

4.5.2 Software

Two pieces of software in R were available to and used by the group:

SMALK_Analysis_28c.r analyses SMALK-type of data as downloaded from DATRAS. The software first identifies and removes outliers and then provides a length–weight relationship, an estimate of asymptotic length L_{inf} based on the Wetherall method, estimation of von Bertalanffy growth parameters K and t_0, length-at-maturity (L_{m50} and L_{m90}), proportion mature by age class, and L_c and L_{mean} of the survey gear. Quarter, area, time-period, species, and sex can be selected by the user.

LFCOM_10.r analyses time-series of length–frequency data from a user created csv file with mandatory headers: Stock, Year, Length, CatchNo, with lengths in mm. As output it produces a csv file with headers Stock, Year, L_c, L_{mean}, L_{peak}, L_{max} and a time-series of the respective indicators. Users can determine StartYear and EndYear of the analysis. Another required input is an estimate of Linf. Optional inputs are K, M, L_{m50}, L_{m90}. These life-history parameters are used to calculate benchmarks which are then shown on screen and in graphs.

Both pieces of R code are available from the Software folder of the WKIND3.3i SharePoint. The respective data files are available either in the Software folder or under the respective stocks in the Data folder.

4.6 Indicator evaluation

The potential selectivity indicators were evaluated against the ICES high-level criteria (see Box 3.1). Based on the above, the subgroup considered two indicators, each with two potential reference levels for evaluation:

- L_c with L_{m50} as a lower limit and L_{c_opt} as a potential target;
- L_{mean} with L_{m90} as a lower limit and L_{opt} as a potential target.

The outcome of this evaluation is captured in the Table 4.6.1.

Table 4.6.1. Evaluation results for selectivity indicators length-of-first-capture (L_c) and mean-length-in-commercial-catches (L_{mean}).

ICES CRITERIA	EVALUATION
Availability of data. Measurability, robust quantifiable data covers range of spatial and temporal natural variability of suitable (historic) duration and resolution, availability of historic data or other reference points for benchmarking.	The availability of data is similar. Both indicators (Lc and Lmean) require length–frequency data from commercial catches. The reference levels proposed for the indicators require the so-called SMALK (Sex, Maturity, Age, Length key) data from fisheries surveys or can be taken from the literature. Principle availability of these data is good.
Quality of underlying data. Data that are sensitive to the magnitude and direction of response to underlying attribute/pressure with high signal to noise ratio, and responsive at an appropriate time-scale. A tangible indicator that is intuitive to understand.	Both indicators are based on length frequencies derived from catch data, typically by observer programmes. Lc requires that the data reflect the main gears used in the fishery and Lmean requires in addition that all length classes above Lpeak are sampled in correct proportion to their occurrence in the stock. Lc will respond immediately to a change in gear selectivity. Lmean will respond, after a time-lag, to changes in Lc and/or F. Both indicators are intuitive to understand.
Conceptual. Theoretical basis, with indicator behaviour (in response to pressure) that is understood to support management advice.	Both indicators are firmly rooted in theoretical fisheries science and can be expected to reflect management-induced changes in the selectivity of fishing. Lmean, in addition, will respond to changes in F.
Communication. an indicator that is simple, credible, unambiguous, comprehensible and can be easily communicated	Due to its simplicity and the fact that it represents only the size-selectivity of the fishery (i.e. not the size structure of the stock) Lc is probably slightly easier to communicate. But "mean length in the fished stock" is also unambiguous and easy to communicate.
Manageable. An indicator that is relevant to management, with estimable targets and thresholds and which is responsive, sensitive and cost -effective to develop.	Both indicators and their proposed reference values are in principle relevant to the management process as they come with estimable targets and thresholds and are responsive, sensitive and cost - effective to develop. However, there were different perceptions of how both indicators are related to GES. More detail on their suitability to be used as part of the GES assessment is in the discussion section(Chapter 4.7).

The evaluation lead to the conclusion that based on science, all indicators and reference levels are suitable to reflect the selectivity of the (combined) fishery, and where L_c would be near L_{c_opt} and L_{mean} near L_{opt}, this would indicate a selectivity resulting in a "healthy" age- and size structure. By contrast, L_c below L_{m50} or L_{mean} below L_{m90} would indicate a selectivity that results in a truncated size structure of the stock and a loss of large, old individuals. WKIND3.3i found L_{opt} to be the preferred reference level for L_{mean} and L_{c_opt} for L_c.

The suitability of the indicators and reference levels as part of the assessment against GES is discussed in the next chapter.

4.7 Discussion and conclusions

L_c and L_{mean} were both operational indicators for the assessment of the length–frequency distribution within the catches. Both indicators and their reference levels were tested for a suite of commercial species covering a wide geographical range and different life-history types (demersal, pelagic, deep-water, late-maturing, early maturing, etc.).

L_c is a pressure indicator, whereas L_{mean} can be considered as a state indicator (given that the commercial catch data are representative of the stock). To that end it is not yet resolved if L_{mean} and any SBI from survey catches would contain redundant information (see Chapter 3). During the workshop, there was also disagreement whether it was possible to choose only one indicator for the assessment of the length–frequency distribution in commercial catches. Some participants argued that if only one indicator should be chosen, L_c would provide a better insight into the pressure exerted by the fisheries, while others argued that L_c and L_{mean} should be used in combination.

WKIND3.3i discussed the utility of the selected indicators and reference levels for application in the GES framework. While both indicators can be considered as suitable to reflect the selectivity of the fishery, there was no consensus within the group as to how much the assessment of selectivity is suitable for the assessment of GES with regards to a *"healthy age- and size-distribution"*. Most participants of WKIND3.3i concluded that these indicators should not be used as part of the MSFD-GES assessment in 2018 for the following reasons:

- F, when based on F_{MSY} already accounts for the currently operated selectivity. F_{MSY} is modified as selection changes across time within the assessment and benchmarking process. Hence fisheries induced mortality on small and juvenile fish ($<L_{mat}$) should still be sustainable (see next bullet point) if F is $\leq F_{MSY}$.
- In some fisheries the selectivity may not be manageable i.e. improvable. For example in the Mediterranean hake fishery, the mature fish are less accessible to the trawl fisheries and thus cannot be exploited. Increasing mesh sizes are therefore not an option if this fisheries is to be continued. However, if F_{MSY} is accounting for juvenile mortality the exploitation of juveniles could still be sustainable.
- Many stocks are exploited within mixed species fisheries. The species have differing growth rates and maximum length, and juveniles of the larger species may be caught within the fisheries for smaller species. The spatial overlap of (target) species will not allow the selectivity to be optimised for all stocks simultaneously as gears which can sufficiently separate the species do not exist. If fisheries selection were to be applied as a GES criterion, either the larger species would be in a permanent status of GES non-compliance or the gear used would not select for the smaller species and the yield from them would be negligible.

Proponents of the use of D3.3-indicators on commercial length–frequency distributions argued that…

- …fishing of juveniles even at F_{MSY} will still reduce the proportion of mature and large individuals (see Figure 5 in Froese *et al*., 2016).
- …Mediterranean hake may not be a good example for denying the utility of L_C and L_{mean}_c, because the adults of this stock are actually targeted with other gears, that size structure in this stock is severely truncated, and this problem was correctly represented by the proposed indicators and refer-

ence points. Furthermore, the assessment results from L_C vs. L_{m50} and L_{mean_c} vs. L_{m90} are not in contradiction to F vs. F_{MSY} as this stock is currently overfished (STECF, 2015a).

- …an increase of L_c towards L_{c_opt} for the smaller target species in a mixed fishery would actually increase catches of the smaller species while simultaneously reducing discards of the larger species (if L_c approaches or exceeds their minimum landing lengths).

Despite the disagreement described above, all members of WKIND3.3i recommend that L_c and L_{mean} could be used for surveillance purposes within regular single-species stock assessments to inform on the selectivity pressure acting upon the stock. Both indicators do provide useful metrics for monitoring patterns of change in selectivity and therefore guidance as to when F_{MSY} reference points may need to be updated. Stock assessment WG could use the software developed by WKLIFE or WKIND3.3i for this purpose.

5 Genetic effects of exploitation on the species (state)

5.1 Introduction

An ever increasing number of experimental and field-based studies (Jørgensen *et al.*, 2007) strongly suggest fisheries-induced evolution (FIE), i.e. changes in the genetic composition of fish stocks as a result of exploitation pressure. This appears to be particularly the case when fishing selectively removes the largest individuals of a population (Law, 2000). Of particular concern is the observed decrease in age and size-at-maturity in many stocks (Sharpe and Hendry, 2009). Consequences of a decrease in age and size-at-maturity on yield are multiple. First, because maturation marks a change in energy allocation from growth to reproduction (Stearns, 1992), early maturing fish will have a lower investment into growth. Second, female size determines fecundity, therefore smaller females will produce fewer eggs, and hence a decrease in age and size-at-maturity would impact recruitment and more generally the demography of a population (Law, 2000).

In accordance, indicators related to size- and age-at-maturity have been proposed as candidates for the evaluation of the Marine Strategy Framework Directive (MSFD) Criterion 3.3.

The proposed indicators were:

- Size at first sexual maturation (Former indicator 3.3.4, equal to L_{mat} in Chapters 3 and 4);
- Length at which half of the (female) population are mature: TL_{50} (Hereafter termed L_{m50} for consistency with other subgroups).

Initial discussions raised the issue that these two indicators might be influenced by growth and demography, and therefore make the assessment of the genetic status of stock difficult. Accordingly, it was concluded that there was a need to include an age dimension in the "size-at-first-sexual maturation" which would be achieved through the use of the Probabilistic Maturation Reaction Norm (PMRN) framework (Heino *et al.*, 2002a; Heino *et al.*, 2002b). The PMRN describes the genetic tendency of an organism to mature, dependent on both its size and its age (see e.g. (Stearns, 1992) on the concept of maturation reaction norms). Since Heino *et al.* (2002a), the PMRN has been refined to account for interannual differences in growth (Barot *et al.*, 2004a) and is considered to be the closest we can get to a size- and age-based genetic indicator. The indicator "size-at-first-sexual-maturation" is now replaced by the PMRN midpoint or L_{p50} (Figure 6.1).

Previous studies revealed that despite accounting for growth related plastic responses, PMRNs cannot account for all environmental effects, but once potential environmental covariates have been accounted for, fisheries induced evolution remains the most parsimonious explanation to the observed decrease in PMRN midpoints (Grift *et al.*, 2003; Wright *et al.*, 2011). It has also been suggested that while size and age-at-maturity might evolve rapidly (on the evolutionary time-scale) under high fishing pressure, the rates of evolution would be very low and show little signs of reversal in response to restorative management (Dunlop *et al.*, 2009; Devine *et al.*, 2012).

Such a characteristic of fitness related traits is important to bear in mind when evaluating indicators of genetic change against the recommended criteria for indicator selection (Box 3.1).

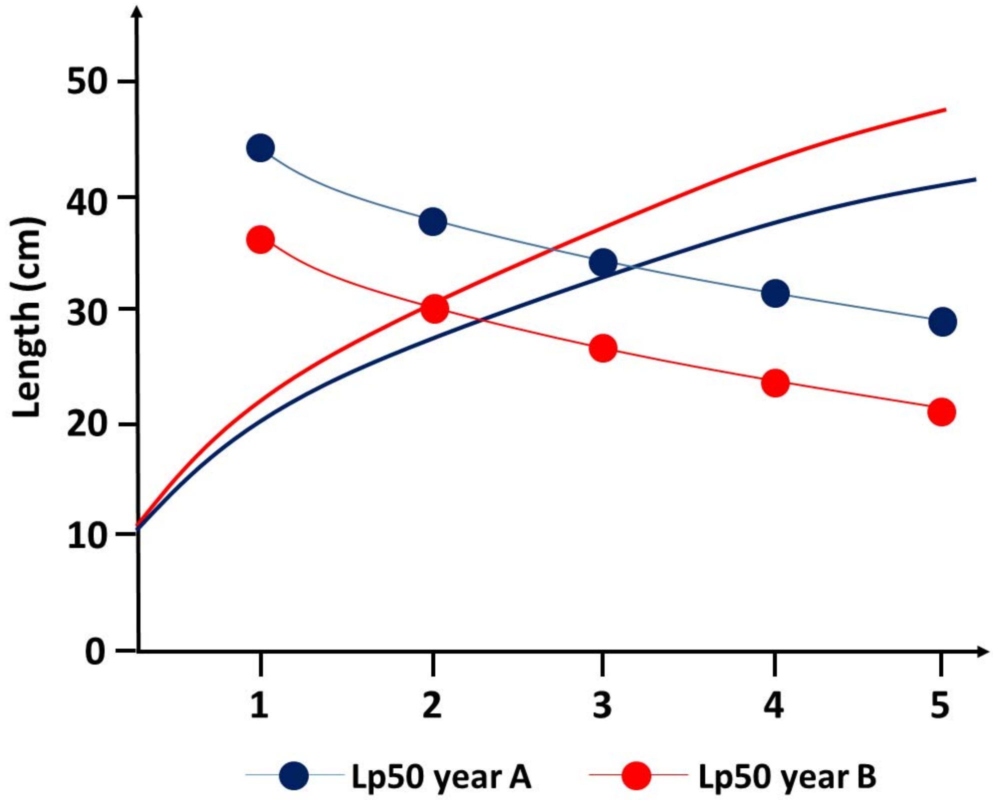

Figure 6.1. Graphical representation of probabilistic maturation reaction norm (PMRN). The Red and Blue monotonically increasing lines represent growth of a given stock measured in years A and B respectively. The points connected by thin lines correspond to Lp50 for a given age, which is the length at which 50% of individuals of a given age mature for the first time. For example, at age 3, Lp50 is at 33 cm for Year A and at 25 cm for Year B. The difference between the lines connecting the Lp50 between age 1 and 5 for Year A and B represents the reduction at which maturity occurs at these ages during the period A–B.

5.2 Indicator calculation

5.2.1 Definition and theoretical basis

L_{m50}: Length at which 50% of females are mature.

Data used for this indicator are Sex-Maturity-Age–Length-Keys (SMALK) for a given stock. To calculate the indicator, a generalized linear model (GLM) can be used with binomial error distribution and logit link of the form:

$$Log_e(p/1-p) = I_1 + S_1.\mathit{length} + I_2.\mathit{year} + S_2.\mathit{length} * \mathit{year}$$

Where p is the probability of being mature. Length at 50% probability is therefore:

$$L_{m50} = (I_1 + I_2)/(S_1 + S_2)$$

This indicator is easy to understand and communicate and, in practice, requires data giving size and maturity status. It can therefore be applied to stocks for which fish age is unknown or difficult to estimate through sclerochronology.

A pitfall of this indicator is its dependence on growth rates. Indeed, interannual differences in growth as a result of temperature and/or food availability are likely to influence the size at which maturation occurs.

This problem is illustrated by the Norwegian spring-spawning herring stock, which has shown major abundance fluctuations (high in 1930s–1950s, collapsed in late 1960s–early 1980s, high following recovery since late 1980s), accompanied by changes in L_{m50} (higher during the 1970s–1980s when the stock was collapsed, as a result of release from density-dependent competition for food and hence better growth conditions; so-called 'compensatory growth'; Engelhard and Heino (2004a). Marked changes in L_{m50} (and in A50, the age at 50% maturity) were attributable to compensatory growth, rather than to genetic change (Engelhard and Heino, 2004b).

<u>Lp50</u>: Length at which 50% of the females of a given age mature for the first time.

Lp50 is calculated using the estimation of probabilistic maturation reaction norm (PMRN) first introduced by (Heino *et al*., 2002a; Heino *et al*., 2002b) and then refined by (Barot *et al*., 2004a). In surveys, data concerning immature or newly matured fish are often lacking, and data correspond to a snapshot of the maturity status of the population at the time of the survey. In other words, due to the impossibility to follow an individual, a fish observed as mature at age *a* might have matured at age *a*, or at age *a*-1, or at age *a*-n. The objective behind the refined PMRN (Barot *et al*., 2004a) is to estimate the probability of maturing conditional on the fact that a fish was immature at a previous age.

The PMRN is calculated as follows:

$$m(a,s) = \frac{o(a,s) - o(a-1, s-\Delta s(a))}{1 - o(a-1, s-\Delta s(a))}$$

where m(a,s) the probability of maturing at age a and size s depends on o(a,s), the age-specific maturity ogive, and Δs(a) the growth increment between age a-1 and age a. The expression 1-o(a-1,s-Δs(a)) is therefore the probability of being immature at age a-1.

The calculation is performed by cohort (e.g. cohort 2000 is age 1 in 2001, age 2 in 2002 etc.) and growth increments between each age class are assumed to be identical among cohort members (estimated with a simple linear model with age used as a factor).

Finally, a GLM with quasibinomial error distribution and logit function is used to measure Lp50 for age a:

$Log_e(m(a,s) /(1- m(a,s))) = I_1 + S_1.\mathit{length} + I_2.\mathit{age} + I_3.\mathit{cohort}$
With $Lp50a = (I_1 + I_2.\mathit{age}\ a + I_3.\mathit{cohort}) / S_1$

This indicator is relatively easy to understand and communicate but requires data-giving size, age and maturity status (i.e. SMALK data). In addition, the method is robust when 100 individuals or more are sampled per age class within a cohort. It therefore requires a large amount of data.

5.2.2 Examples

L_{m50} and Lp50 were calculated using SMALK data obtained from DATRAS for four different stocks: North Sea Cod (*Gadus morhua*) from 1975 to 2015, Western Baltic Cod (Subdivisions 22–24) from 1991 to 2015, North Sea Herring (*Clupea harengus*) from

1991 to 2015 and North Sea Plaice (*Pleuronectes platessa*) from 1991 to 2016. Confidence intervals (95%) were calculated for each descriptor using a bootstrap resampling method.

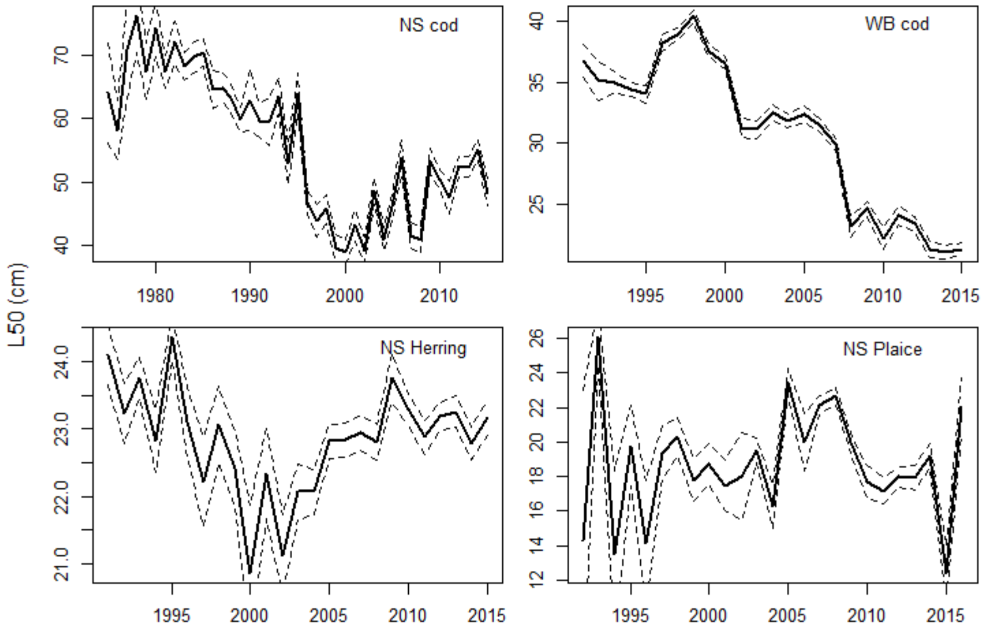

Figure 5.2.2.1. L_{m50} (=L50) indicator (solid line) and 95%CI (dashed line) for North Sea cod, Western Baltic cod, North Sea herring and North Sea plaice.

L_{m50} time-series (Figure 5.2.2.1) show a clear decrease in both North Sea Cod and Western Baltic Cod with current length at 50% maturity oscillating around 50 cm for NS cod and close to 20 cm for WB Cod. For comparisons L_{m50} was situated around 70 cm for NS Cod and around 35 cm in WB Cod in 1975 and 1991 respectively. For Herring and Plaice in the North Sea, current L_{m50} value are similar to the ones observed at the beginning of the time-series, though showing an strong decreasing and then increasing trend for herring and strong interannual variations for plaice.

Lp50 time-series show the same pattern for NS Cod, WB Cod and NS Herring (Lp50 age3), but tend to indicate an overall increase for NS Plaice (Lp50 age 4) (Figure 5.2.2.2). This pattern not observed in L_{m50} results from interannual variation in growth and is observed in Lp50 as this source of variation is accounted for.

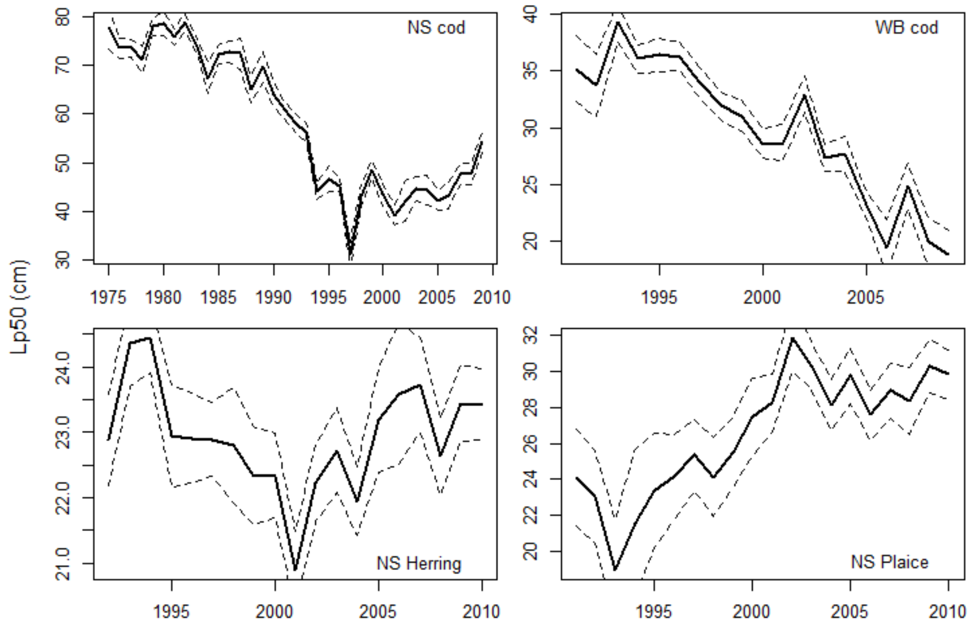

Figure 5.2.2.2. Lp50 indicator (solid line) and 95%CI (dashed line) for North Sea cod (Lp50 age3), West Baltic cod (Lp50 age3), North Sea herring (Lp50 age3) and North Sea plaice (Lp50 age4).

The two indicators, L_{m50} and Lp50 are not correlated when a weak or no temporal trend is observable; however when a trend is evidently present, the two indicators co-vary (Figure 5.2.2.3).

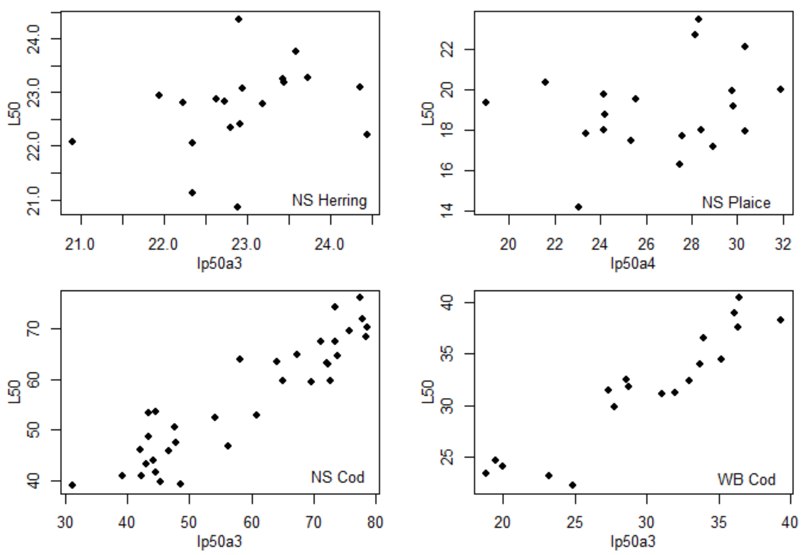

Figure 5.2.2.3. Covariation between L_{m50} and Lp50 in the four Stocks considered.

5.2.3 Responsiveness to pressure

To qualify as operational, an indicator has to be responsive and sensitive to pressure and respond to management. The response to fishing mortality (pressure) was tested using cross-correlations to identify the relevant time-lag(s) to investigate the covariation. Cross-correlations were pre-whitened with ARIMA(1,1,0) models fitted to the fishing pressure and to the indicators in order to first achieve stationarity of the time-series. Significant cross-correlations then belong to four groups (Probst *et al.*, 2012):

1) Positive cross-correlation with a negative time-lag: An increase in the pressure drives an increase in the indicator.
2) Positive cross-correlation with a positive time-lag: An increase in the pressure follows an increase in the indicator.
3) Negative cross-correlation with a negative time-lag: An increase in the pressure drives a decrease in the indicator. ***This is the expected pressure–state relationship***.
4) Negative cross-correlation with a positive time-lag: An increase in the pressure follows a decrease in the indicator.

Results obtained for the four stocks considered did not present a clear responsiveness to pressure. In some cases, negative cross-correlations at negative time-lags were identified but (i) if present, they were multiple and (ii) a positive cross-correlation was present at a nearby time-lag (e.g. for NS cod and WB cod, Figure 5.2.3.1). Therefore, there was no clear relationship identified between pressure and the indicators. However, as these indicators stand as proxies for genetic change, it is very unlikely to observe an immediate response to fishing pressure. As a genetic change is the result of selection acting over many generations, a single cross-correlation at a particular time-lag is unexpected. Also, as previous studies suggest (Law, 2000; Devine *et al.*, 2012) such indicators will respond relatively rapidly to high fishing pressure (though over several generations) but very slowly to low fishing pressure (Coltman, 2008), making correlations difficult to observe. In addition, such a long-term response cannot generally be observed or assessed on such short time-series on the evolutionary time-scale.

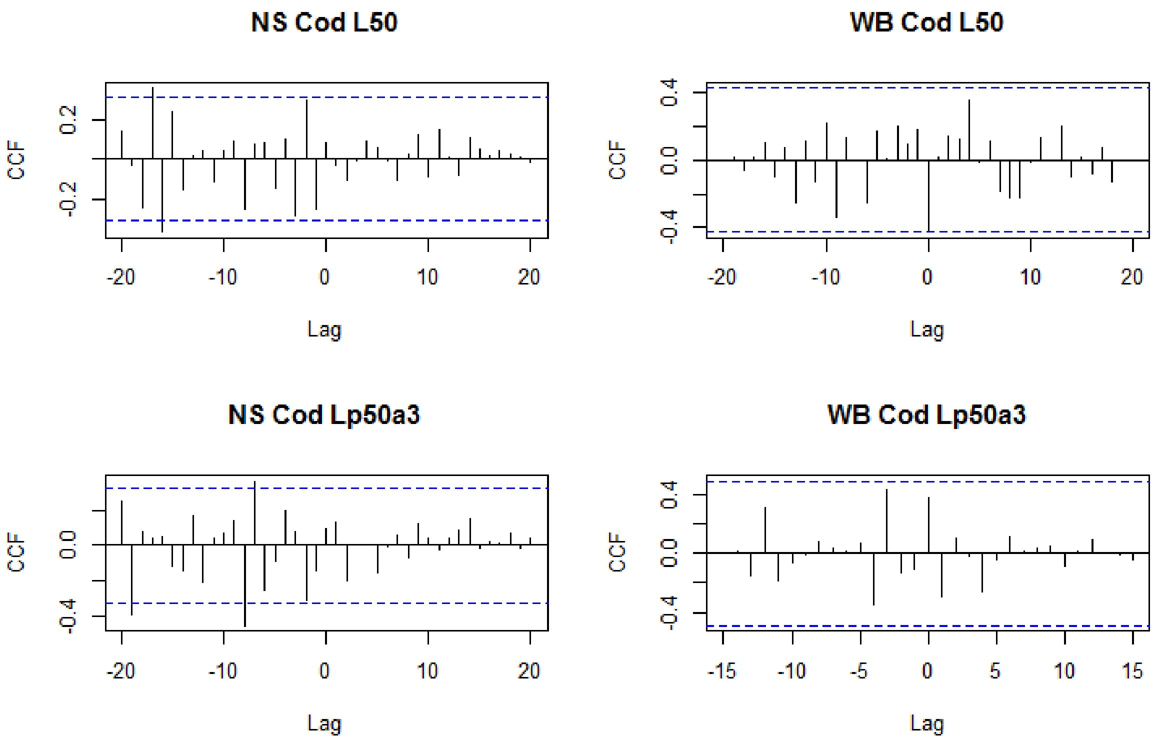

Figure 5.2.3.1. Cross-correlation between fishing mortality F(Pressure) and the indicators L_{m50} (=L50) and Lp50 age 3 for NS cod and WB cod. Time-series were pre-whitened using ARIMA(1,1,0) models.

5.2.4 Alternative methods of interpretation

As no clear relationship between pressure (F) and state indicators (L_{m50}, Lp50) could be identified and as, for proxies of genetic change, no targets (i.e. reach a previous state) could be identified and/or reached on a time-scale realistic for assessment of GES, alternative methods are required to monitor change in these indicators. A common agreement when it comes to genetic effect is that no signs of significant negative genetic effects should be observed, and genetic effects should show trends in the direction of recovery. Therefore, analysing the trend of the indicator, its current status, should be informative of the propensity of a stock to decline, stabilise or improve with regards to its genetic basis for maturation. Accordingly, time-series based assessment (TSBA) approaches appears suitable for this purpose and have been recently proposed and used in this context (Probst and Stelzenmüller, 2015; Shephard *et al.*, 2015). The underlying idea here is to quantify current trend, identify if breakpoints are present in the time-series and compare the potential changes in the dynamic of the indicator with regard to exploitation.

The approach used here was to decompose the time-series according to changes in the trend of the indicator. The R package "bfast" (Verbesselt *et al.*, 2010) was used to identify breakpoints in the time-series. Breakpoints are identified using an iterative structural change test (identifying significant change in the slope parameter of linear regressions along the time-series). The current trend is then analysed between the last breakpoint identified and the last datapoint in the time-series using a linear regression.

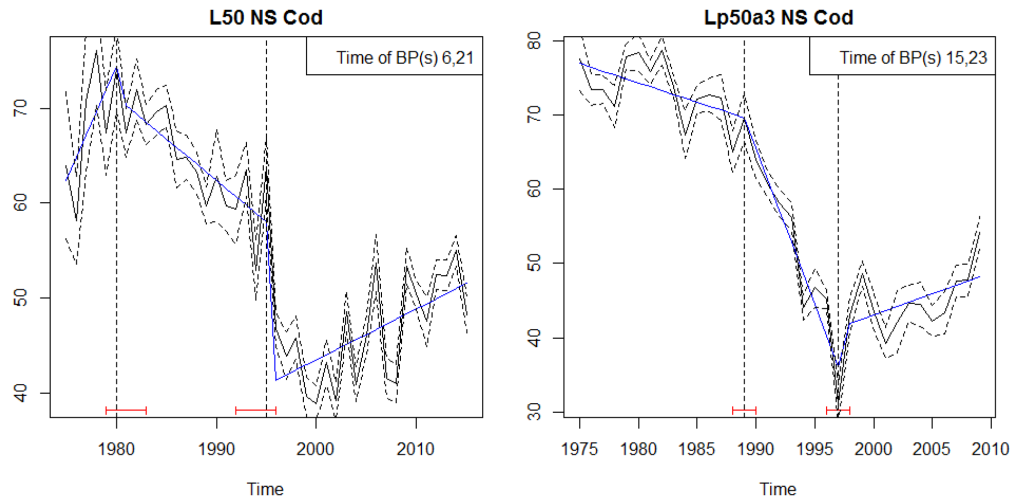

Figure 5.2.4.1. Examples of time-series decomposition using the bfast package for L_{m50} and Lp50 in NS Cod. Breakpoints are indicated by the vertical black lines and the trends by the blue lines.

Table 5.2.4.1. Summary of the current state of four stocks from time-series decomposition.

Stock	Breakpoints	L50	Lp50	Current state
NS Cod	yes	Significant positive trend	No significant trend	Stabilised/Increasing = improvement
WB Cod	no	Significant negative trend	Significant negative trend	Decreasing = Negative genetic effects
NS Plaice	no	No significant trend	Significant positive trend	Stabilised/Increasing = improvement
NS Herring	no	No significant trend	No significant trend	Stabilised= no change

For the stocks considered, results show that both indicators have undergone an important decrease in North Sea cod between 1975 and 2015 but since the last breakpoint in 2000, the situation seems to have stabilised. In Western Baltic cod, both indicators show signs of a continuous decline since 1991 (Figures 5.2.2.1 and 5.2.2.2). In North Sea herring indicators are fluctuating but stable since 1991 while in North Sea plaice, L_{m50} seems stable but Lp50 age 4 shows signs of improvement.

5.3 Indicator evaluation

L_{m50} and Lp50 were evaluated against the five recommended ICES criteria for indicator selection (Box 3.1).

5.3.1 Availability of data

L_{m50} requires data on size, sex and maturity status and is therefore available for many commercially exploited species. Lp50 is much more restrictive and requires a substantial amount of data on size, sex, age, and maturity status with about 100 individuals required within an age class belonging to a cohort. However, communication with members of the WGEVO working group allowed establishment of a list of suitable stocks by region/subregion for which Lp50 could be calculated (Table 5.3.1.1).

Table 5.3.1.1. Stocks with available data for calculation of PMRN and Lp50.

North Sea	Baltic Sea	Eastern Channel
Plaice	Cod (West)	Plaice
Sole	Cod (East)	Sole
Cod	Herring (East)	
Saithe		
Whiting	*Bay of Biscay*	*Western Channel*
Haddock	Sole	Plaice
Norway pout		Sole
Herring		
Sandeel		

Therefore data are available for both indicators, but only L_{m50} could be applied to a wide range of stocks for which additional data could be collected at a minimum cost (in parallel with length based measures).

5.3.2 Quality of underlying data

Together with published evidence, the present report highlights a lack of clear response of the two indicators to pressure (fishing mortality) at the time-scales typically considered within the MSFD. However, it is important here to highlight that it is the very nature of genetic indicators, and the particularly traits susceptible to fisheries induced evolution (FIE), that make them fail when rated against this particular criterion. Indeed, as (1) FIE is the result of selection acting over multiple generations, (2) the rates of evolution do not vary linearly with fishing pressure, and (3) fisheries time-series are most often too short to allow a response to management to be observed, it is unlikely that indicators of genetic change will be rated as sensitive and responsive to pressure. There is, however, a fairly extensive body of published work indicating that in various stocks, fisheries-induced evolution led to genetic change (Heino *et al*., 2002c; Grift *et al*., 2003; Barot *et al*., 2004b; Olsen *et al*., 2004; Mollet *et al*., 2007; Hard *et al*., 2008).

The indicators have a relatively high signal to noise ratio, as evident trends were identified for some of the stocks considered. Therefore, the indicators are considered to succeed at reflecting the state of the stocks.

5.3.3 Conceptuality

Lp50 is based on the strong theoretical basis of probabilistic maturation reaction norms and accounts for interannual variations in growth. It is therefore considered to be the most appropriate indicator of genetic change in age and size-at-maturity. L_{m50}, however, does not account for growth-related sources of variation in maturation and is less tightly related to genetic change. The here presented results highlights that if an evident trend is observed in Lp50, it is also likely to be observed in L_{m50}.

5.3.4 Communication

The definitions of both indicators are simple, unambiguous and comprehensible to non-experts. The calculation of Lp50 however, requires some statistical knowledge and is less communicable than the L_{m50}.

5.3.5 Manageable

These indicators are relevant to management as the genetic state of a stock has potential consequences for both fishing yields and the long-term dynamic of the considered stocks. However it is not possible to define accurate or realistic targets and thresholds, because a genetic response toward improvement is very slow in the absence of a strong driver (e.g. reduced fishing pressure associated with management as opposed to degradation under a strong fishing pressure). In addition, setting historical levels as reference is unrealistic, because due to depleted genetic variance (assumed in the case of strong FIE) such levels might not be reached again. Instead methods such as time-series based assessments could be used to assess the current status qualitatively and inform on the current state of the considered stock (stability/improvement/degradation).

5.4 Conclusions

Both L_{m50} and Lp50 fail to fulfil the ICES criteria for selection of both primary and secondary indicators. This conclusion is a direct consequence of the nature of indicators of genetic change and tightly related to both the difficulty to identify a simple pressure–state relationship and the long lag expected between any management measure and the observation of a response. In addition, it proved difficult to set any realistic target values for these indicators. However, these indicators fulfil the important role of reflecting the state of the stocks with, in some cases, the identification of long-term negative effects on the age and size-at-maturity. Therefore, these indicators bring important information on the status of stocks, and if they are to be included for GES assessment, selection criteria should be revised.

While Lp50 represents the most relevant measure of genetic effects on the size and age at maturation, it requires substantial sample sizes (i.e. data on sex, maturity, age and length) which may not be available for all stocks of interest. L_{m50} however, requires less data (age not required) and is therefore a manageable target. L_{m50} has been considered to be set as a reference or be used in the calculation of a number of size-based indicators. Maturity ogives (the data used for the L_{m50} calculation) are also used in the assessment of Spawning–Stock Biomass (SSB). The present report highlights the dynamic nature of L_{m50} (and Lp50), thus acquiring new data for its estimation is much required for the appropriate calculation of reference points, size-based indicators and SSB.

6 Recommendations

RECOMMENDATION	ADRESSED TO
1. At the moment, no SBI is considered to be fully operational thereby not allowing the assessment of a stocks size structure againts GES. Member states should thus not be required to include criterion 3.3 into their Article-8-assessment, until fully operational indicators are available.	EU-Commmission, Member States
2. The potential of improving indicator metrics and developing GES-thresholds for L95, Pmega, $cpue_{mega}$ should be further explored for applicability within the MSFD. Population models used for the calculation of F_{MSY} (EQSIM) might be helpful in estimating length–frequency distributions in the stock exploited at $F=F_{MSY}$.	ICES SCICOM, EU-Commisson
3. Calculation and assessment of SBI should be performed by expert working groups on stock assessments, because the members of these groups know best pitfalls and caveats associated with survey data	ICES ACOM
4. P_{mat} was not evaluated to be an appropriate indicator for the assessment of GES and should not be considered any further within the MSFD.	EU-Commmission, Member States
5. Explore the potential to use time-series based assessment approaches (TSBA) for assessment of SBI under Criterion 3.3.	ICES SCICOM
6. Data on length–frequency distribution in the catch should become a routine part of the national ICES data calls.	ICES ACOM
7. The use of Lc and Lmean should be explored within stock assessment working groups using the software developed in WKIND/WKLIFE to provide routine monitoring of selection by the fishery.	ICES ACOM
8. Lp50 (as primary indicator) and Lm50 (as secondary indicator) could be used for the surveillance of genetic change. Their further operationalisation using time-series based assessment methods should be explored. For the 2018 assessments indicators of genetic change should not be included.	EU-Commission, ICES SCICOM

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Annex 2: Agenda

14.03.2016 (Select indicators)

13:00 Opening of the meeting

13.00–14.00 Plenary: Introduction to the workshop objectives

14.00–15.00 Split-up into subgroups on indicator types:

- Selectivity indicators (Rainer Froese)
- Indicators of stock size-structure (Manica Azevedo, Nik Probst)
- Indicators on genetic change (Peter Wright)

15.00–15.30 Coffee break

15.30–17.00 Work in subgroups:

- Decide indicators to be calculated
- Describe indicators (include formula if possible)
- Describe data requirements (type and format needed)
- Calculate indicators

17.00–18.30 Plenary: Present results of indicator selection

15.03.2016 (Calculating indicators)

09.00–13.00 Plenary: Present indicators of subgroups

10.00–13.00 Work in subgroups:

- Calculate indicators for all stocks

13.00–14.00 Lunch break

14.00–17.00 Work in subgroups:

- Continue calculating indicators

17.00–18.30 Plenary: Present results

16.03.2016 (Setting assessment benchmarks)

09.00–11.00 Plenary: Introduce & discuss methods for GES-benchmarks

11.00–11.15 Coffee break

11.15–13.00 Split-up in subgroups by stocks:

- Discuss which benchmarks may be most appropriate
  - Theoretical
  - Pressure–state relationship
  - Time-series based
- Decide on best GES-benchmark to be used for assessment
- Analyse indicators against benchmarks

13.00–14.00 Lunch break

14.00–17.00 Work in subgroups:

- Continue development of GES-benchmarks

- Perform assessment (if possible)

17.00–17.15 Coffee break

17.15–18.30 Plenary: Discussion on GES-benchmarks and assessments

17.03.2016 (Evaluate indicators)

09.00–10.30 Introduce & discuss indicator evaluation procedure

10.30–11.00 Coffee break

11.00–13.00 Evaluate indicators (within indicator subgroups)

13.00–14.00 Lunch break

14.00–16.00 Plenary:

- Compile and present evaluation results
- Decide on best indicators for each type
- Wrap-up

16.00 Closing of meeting

Annex 3: Terms of reference for potential next meetings

Future workshops on the use of indicators on Criterion 3.3 of MSFD-Descriptor 3 should address the following topics:

- Explore the potential for improving indicator metrics and developing GES-thresholds for L_{95}, P_{mega}, $cpue_{mega}$ e.g. by using population models.
- Explore the potential to use TSBA for assessment of SBI under Criterion 3.3.
- Investigate on the redundancy between indicators from length–frequency distributions of commercial and survey catches to inform on the status of stock size distribution.

Annex 4: Overview on SBI

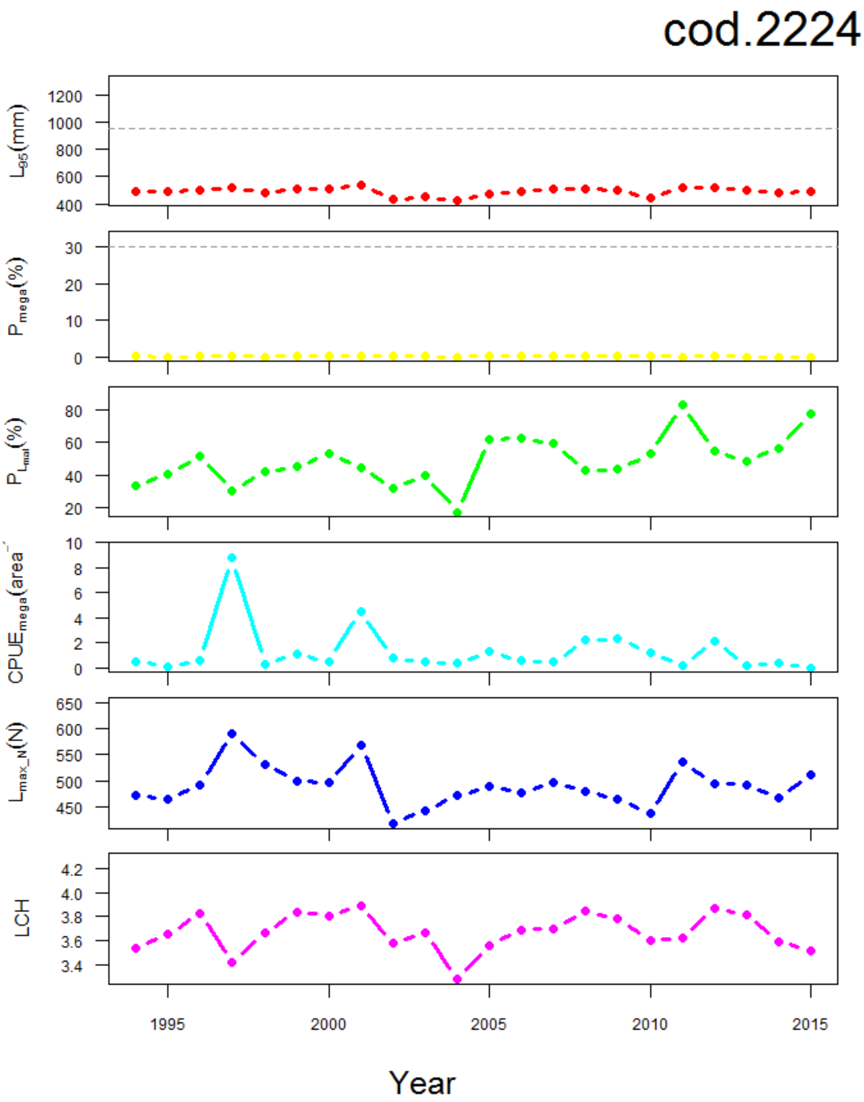


Figure A.5.1. Six size-based indicators for western Baltic cod *Gadus morhua*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

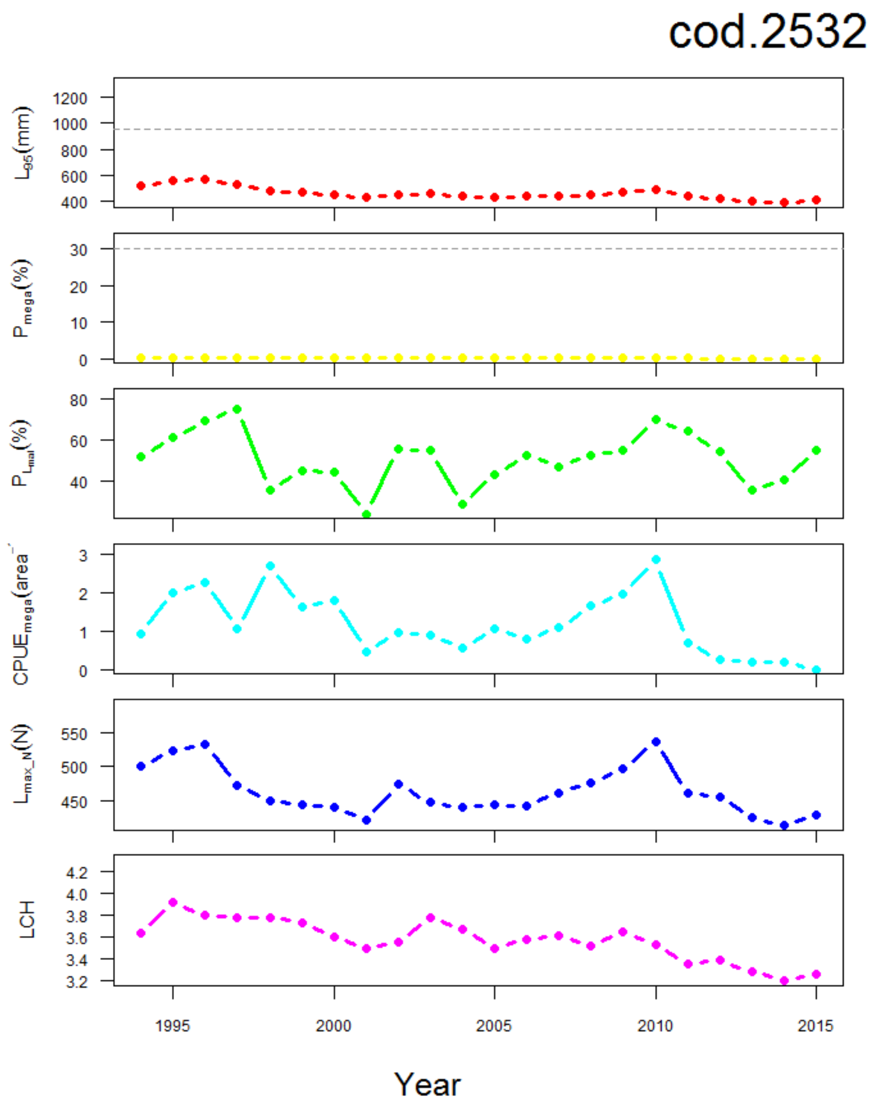


Figure A.5.2. Six size-based indicators for eastern Baltic cod *Gadus morhua*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

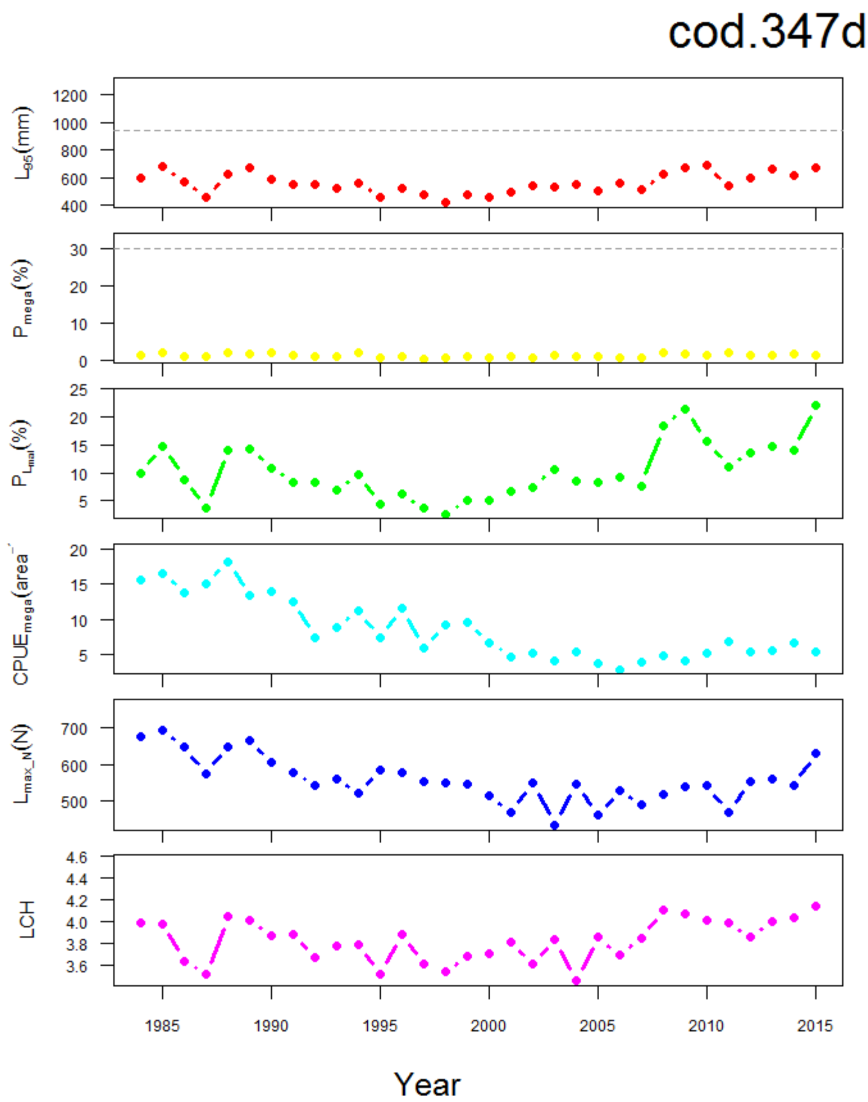


Figure A.5.3. Six size-based indicators for North Sea cod *Gadus morhua*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

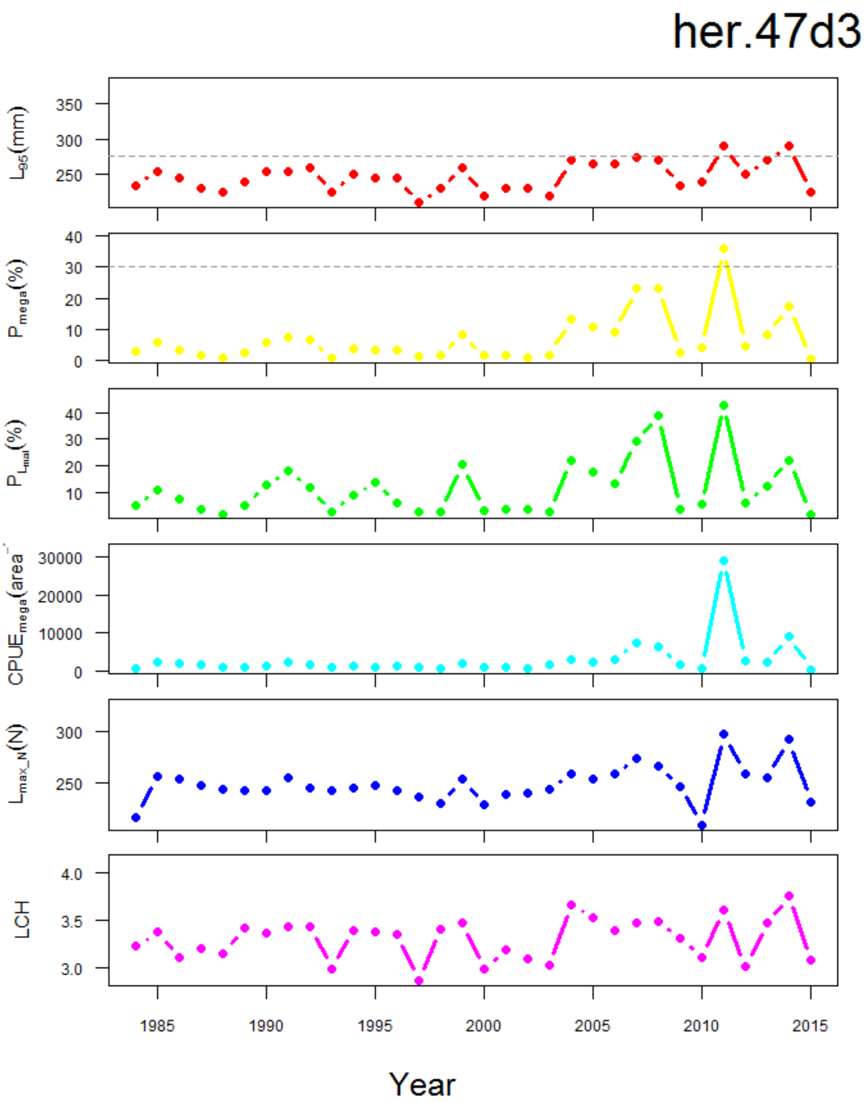


Figure A.5.4. Six size-based indicators for North Sea herring *Clupea harrengus*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

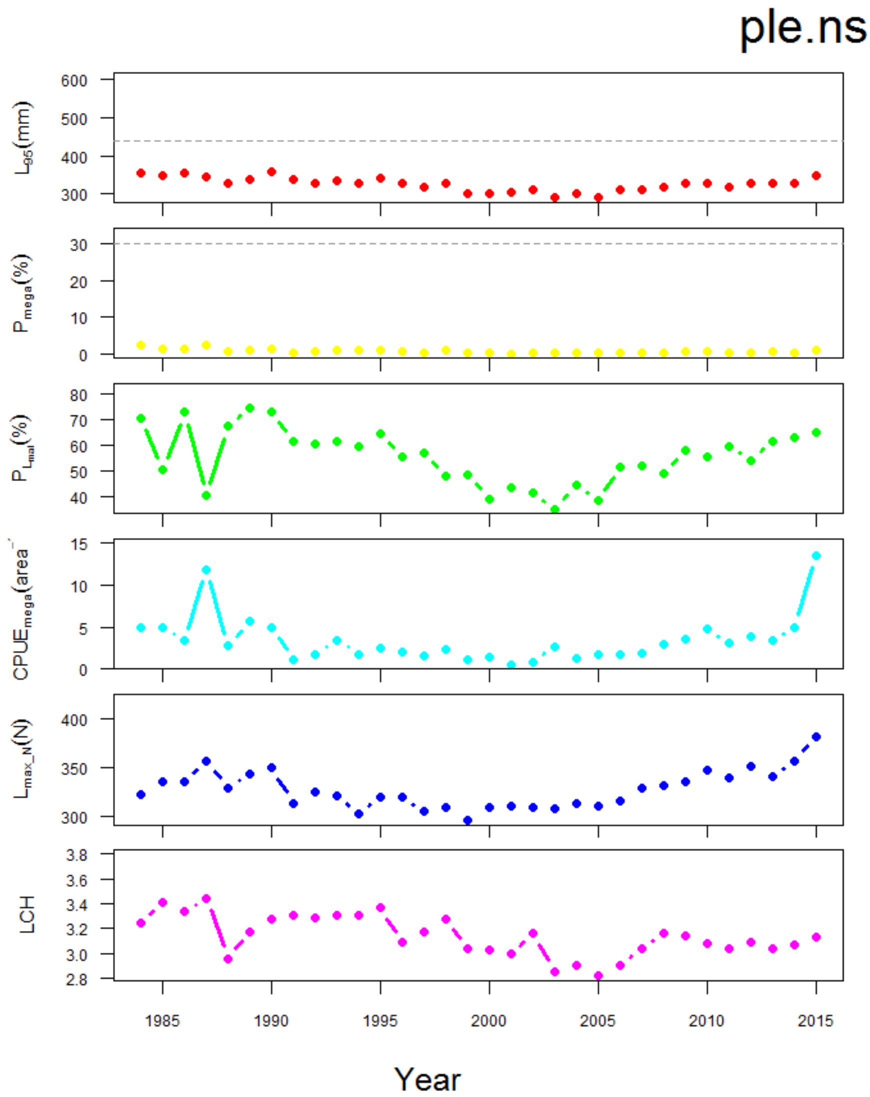


Figure A.5.5. Six size-based indicators for North Sea plaice *Pleuronectes platessa*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

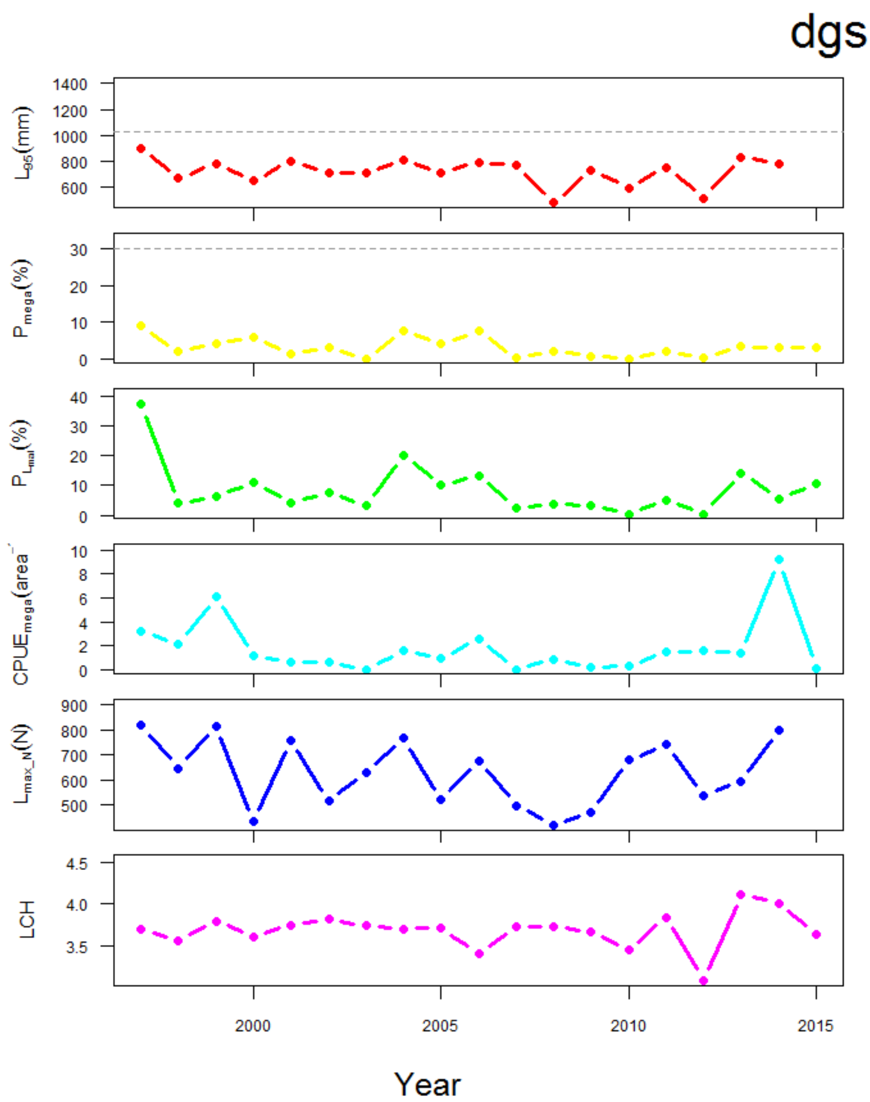


Figure A.5.6. Six size-based indicators for Northeast Atlantic spurdog *Squalus acanthias*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

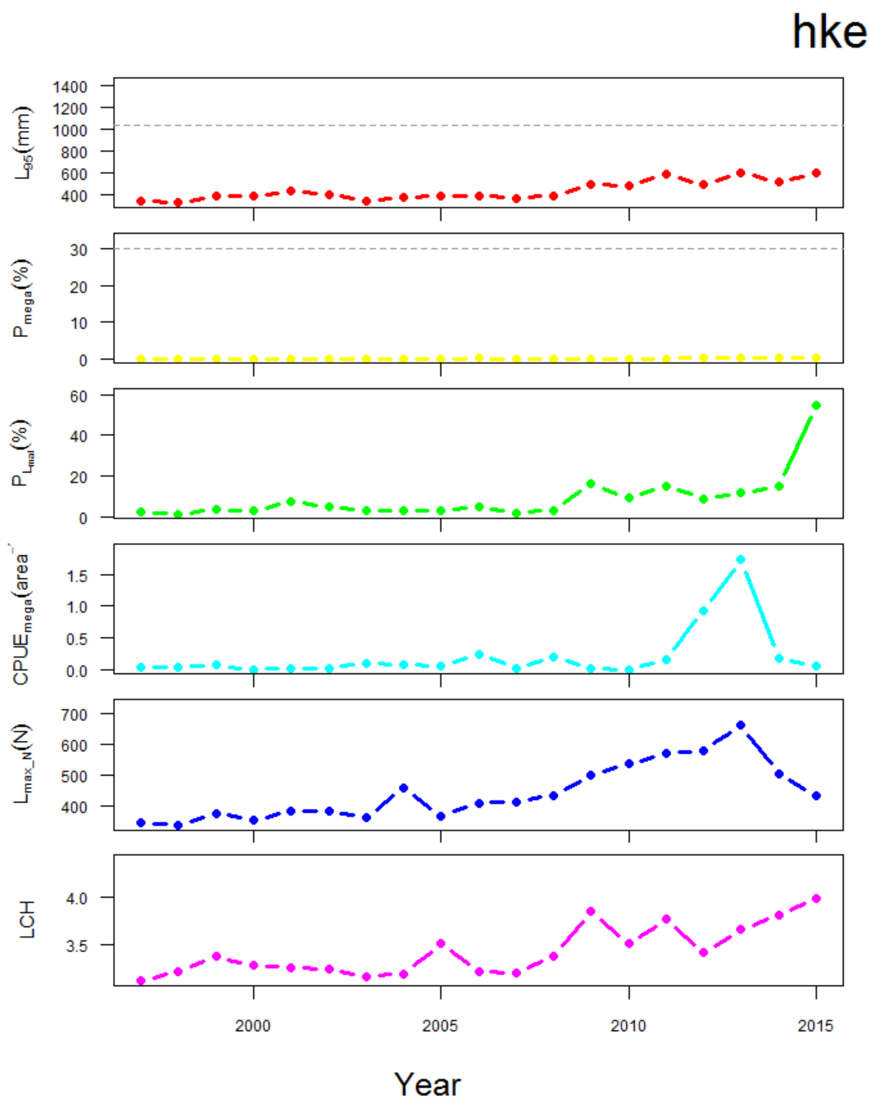


Figure A.5.7. Six size-based indicators for Northeast Atlantic hake *Merluccius merluccius*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

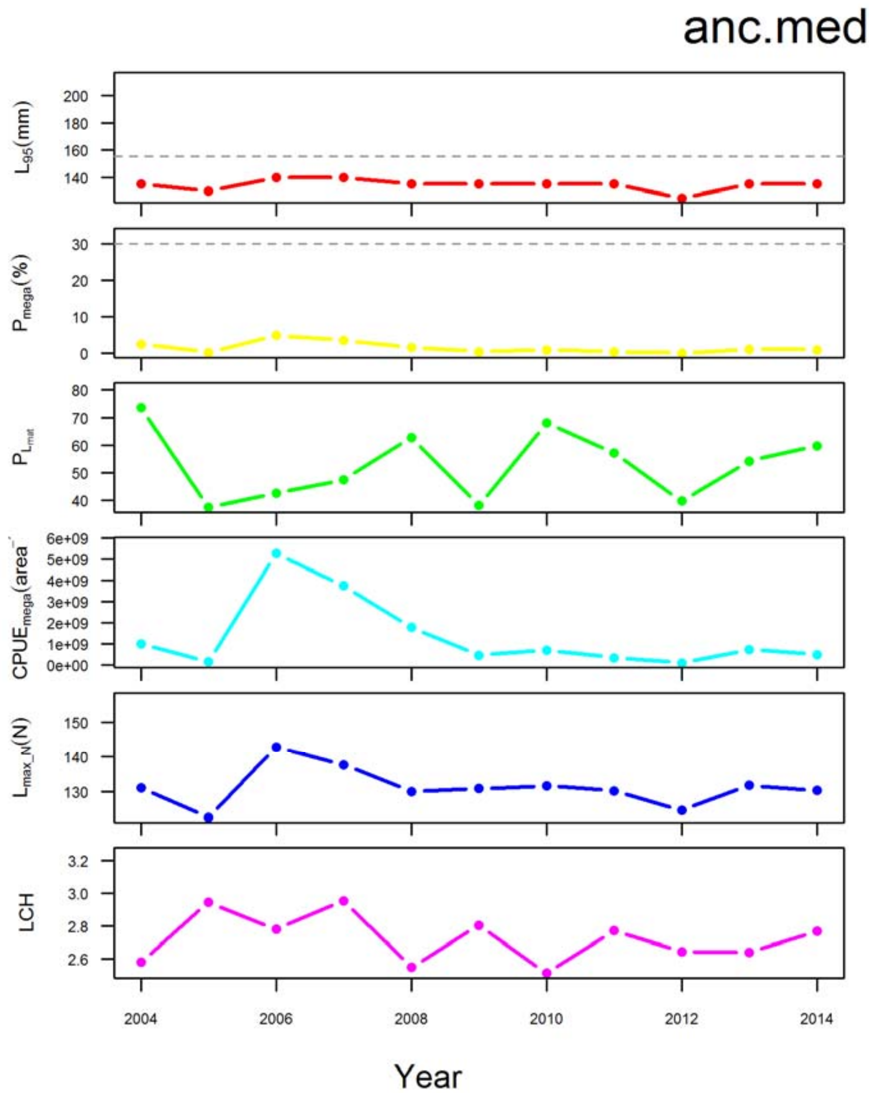


Figure A.5.8. Six size-based indicators for Adriatic anchovy *Engraulis encrasicolus*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

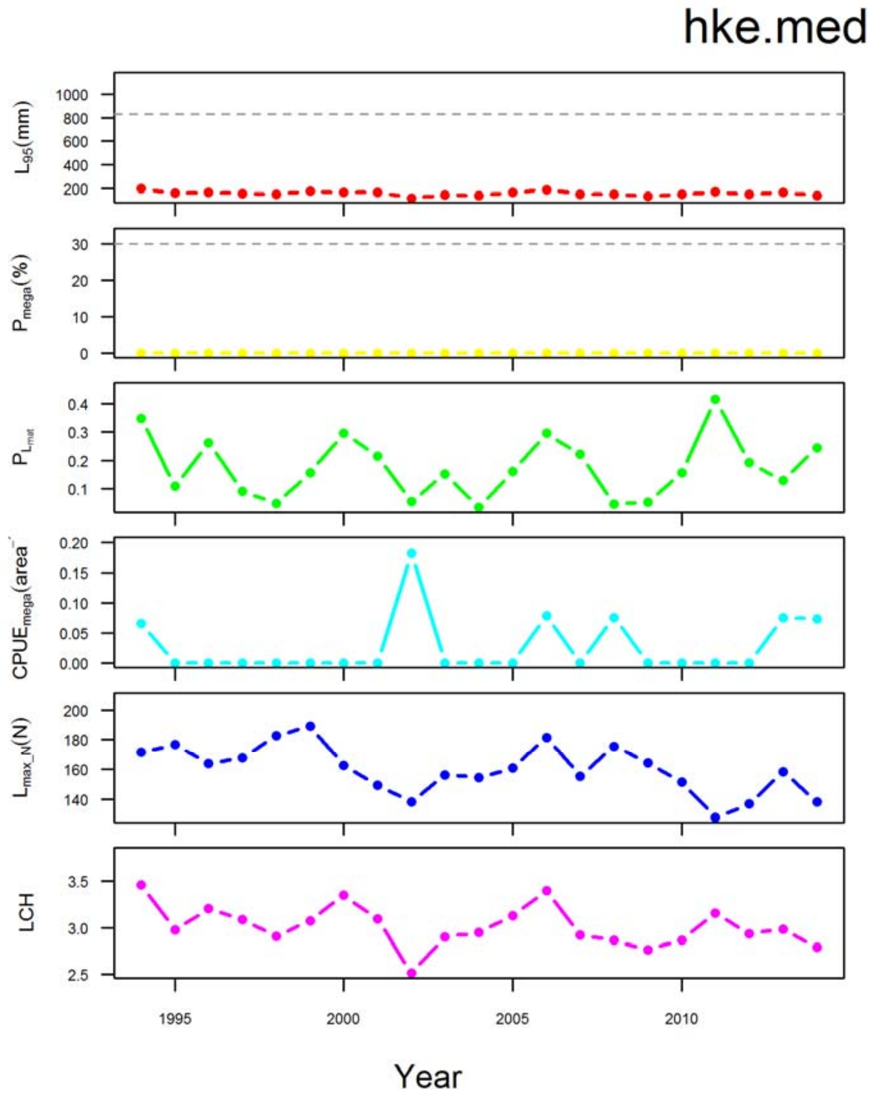


Figure A.5.9. Six size-based indicators for Mediterranean hake *Merluccius merluccius*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

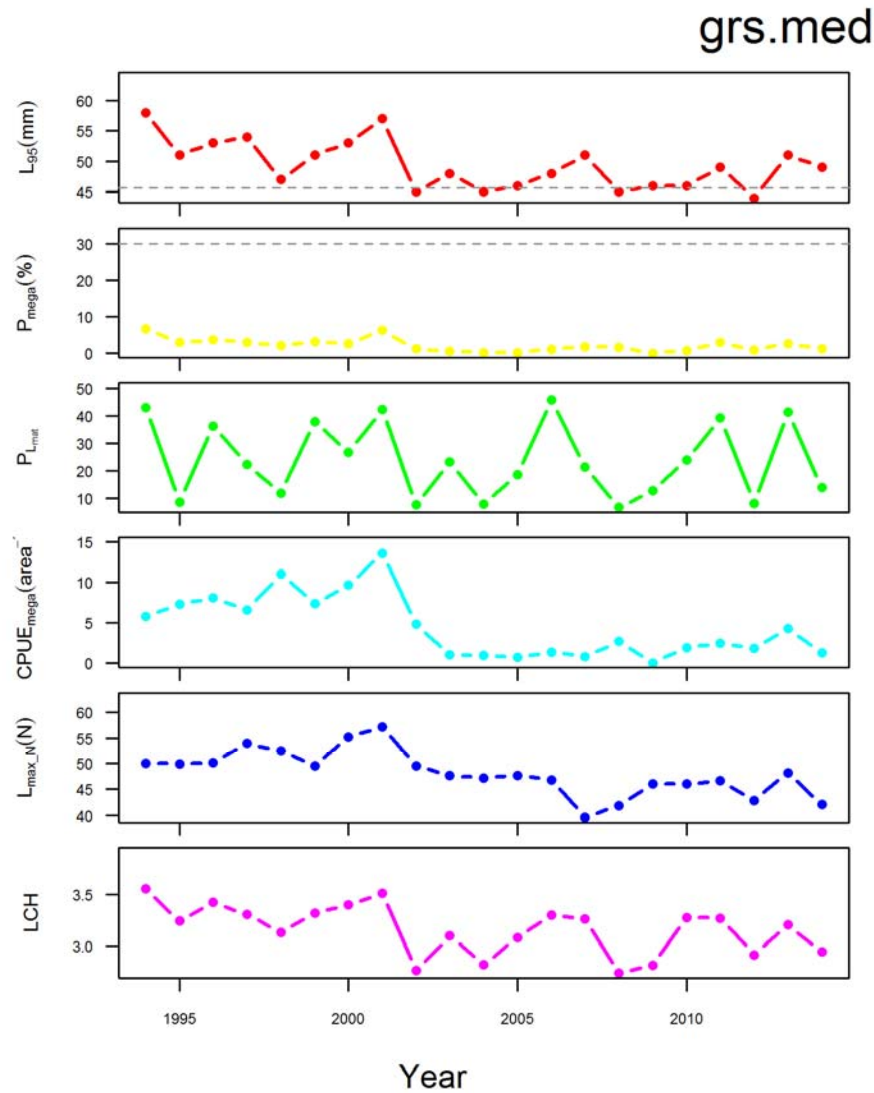


Figure A.5.10. Six size-based indicators for Mediterranean Giant Red Shrimp *Aristeomorpha foliacea*. Explanation of indicator abbreviations are given in Annex 6. Note that assessment benchmarks (grey dashed lines) for L_{95} and P_{mega} are based on conservation reference points by WKLIFE V (ICES, 2015b) and require further development to be adapted to MSFD GES-targets.

Annex 5: Descriptions and evaluation results of SBI

Indicator name	95%-percentile of the fish length–frequency distribution in research vessel surveys
Abbreviation	L_{95}
Description	The 95%-quantile (percentile) of the length–frequency distribution.
Formula	$L_{95} = L \text{ at which } \sum_{i=L_{min}}^{L_{max}} \frac{L_i N_{L_i}}{\sum_{i=L_{min}}^{L_{max}} L_i N_{L_i}} = 0.95$ A good approximation is: $L_{95} = L \text{ at which } \frac{\sum_{i=L_{min}}^{L_{max}} N_{L_i}}{N} = 0.95$
Rational	The L95 is a non-parametric summary metric of the stock size structure intending to capture the distribution in the upper (right hand) part of the length–frequency distribution. It is assumed to be sensitive to fishing pressure, with an increase in fishing pressure causing a decline in the L95 (Piet *et al.*, 2010; Rochet *et al.*, 2010; Trenkel and Rochet, 2010). Though reflecting properties of length classes not affected directly by recruitment, the L95 has been shown to be sensitive to the abundance of small individuals (Probst *et al.*, 2013b)
Relation to "abundance of large old individuals" (0–3)	2 - (Low-Moderate) Though reflecting properties of length classes not affected directly by recruitment, the L95 has been shown to be sensitive to the abundance of small individuals (Probst *et al.*, 2013b).
Availability of data. Measurability, robust quantifiable data cover range of spatial and temporal natural variability of suitable (historic) duration and resolution, availability of historic data or other reference points for benchmarking. (0–3)	2 - Survey data str usually considered as adequate, but there may be issues with the catchability of certain size groups or species. Historic data on length may be scarce for many species. Some species are not represented by adequate surveys.
Quality of underlying data. Data that are sensitive to the magnitude and direction of response to underlying attribute/pressure with high signal to noise ratio, and responsive at an appropriate time-scale. A tangible indicator that is intuitive to understand. (0–3)	1 – Signal-to-noise ratio (SNR) can be relatively high, impacts of other influential factors (e.g. recruitment) can cause changes in indicator value.
Conceptual. Theoretical basis, with indicator behaviour (in response to pressure) that is understood to support management advice. (0–3)	1 - L95 is a statistical metric, but is not further rooted in theory of population dynamics. Response to pressure may be masked by effects of recruitment.

Communication. an indicator that is simple, credible, unambiguous, comprehensible and can be easily communicated. (0–3)	2 – The L95 is easy to understand and communicate, but it is not necessarily unambiguous.
Manageable. An indicator that is relevant to management, with estimable targets and thresholds and which is responsive, sensitive and cost - effective to develop. (0–3)	2 – The L95 does not only respond to manageable factors (F, selectivity), but also to population dynamics (recruitment). The suggested WKLIFE V conservation-threshold (>Linf*0.8) needs further validation and its applicability for an assessment of GES within the MSFD has to be tested. Depending on species' generation time the indicator may need several years to respond to recovery management measures.
Score	10

Abbreviations:

N: Numbers of individuals caught in any given survey year

N_{L_i}: Numbers of individuals in length class Li caught in any given survey year

n: Number of largest individuals in any given survey year

L_i: Length of size class i

L_{max}: largest occupied (observed) size class in a survey year

L_{min}: Smallest occupied (observed) size class in a survey year

Indicator name	Proportion of fish larger than the mean-size-of-first-sexual-maturation
Abbreviation	P_{mat}
Description	Percentage of individuals larger than Lmat in the annual survey catch
Formula	$P_{mat} = \frac{\sum_{i=L_{mat}}^{L_{max}} N_{L_i}}{N}$
Rational	A healthy stock should be characterized by the abundance of mature individuals. Recruitment overfishing can reduce the number of mature individuals, but as this indicator is proportional (=relative), it will also be affected by recruitment.
Relation to "abundance of large old individuals"	2 – (Low-moderate) – this indicator has been shown to be sensitive to the abundance of small individuals (Probst *et al.*, 2013b). Lmat may change over time due to environmental conditions or fisheries induced evolution.
Availability of data. Measurability, robust quantifiable data cover range of spatial and temporal natural variability of suitable (historic) duration and resolution, availability of historic data or other reference points for benchmarking. (0–3)	1 - Survey data are usually considered as adequate, but there may be issues with the catchability of certain size groups or species. Historic data may be scarce for many species. Some species are not represented by adequate surveys. Data basis on Lmat may be weak or not available for several stocks.
Quality of underlying data. Data that are Sensitive to the magnitude and direction of response to underlying attribute/pressure with high signal to noise ratio, and Responsive at an appropriate time-scale. A tangible indicator that is intuitive to understand. (0–3)	1 – Signal-to-noise ratio (SNR) can be relatively high, impacts of other influential factors (e.g. recruitment or changes in Lmat) can cause changes in indicator value.
Conceptual. Theoretical basis, with indicator behaviour (in response to pressure) that is understood to support management advice. (0–3)	1 - %mat is implicating a fixed ("healthy") ratio of immature/mature within a stock that should be representative for GES. There is no scientific evidence of defining such a ratio, which may differ between stocks, but also within stocks depending on population dynamics and environmental influences.
Communication. an indicator that is simple, credible, unambiguous, comprehensible and can be easily communicated. (0–3)	2 – The indicator is easy to understand and communicate, but it is not necessarily unambiguous.
Manageable. An indicator that is relevant to management, with estimable targets and thresholds and which is responsive, sensitive and cost - effective to develop. (0–3)	1 – The indicator does not only respond to manageable factors (F, selectivity), but also to population dynamics (recruitment). There is no GES-threshold for this indicator. Depending on species' generation time the indicator may need some years to respond to recovery management measures.
Score	8

Abbreviations: N: Numbers of individuals caught in any given survey year. N_{L_i}: Numbers of individuals in length class Li caught in any given survey year. n: Number of largest individuals in any given survey year.

L_i: Length of size class i

L_{max}: largest occupied (observed) size class in a survey year

L^{min}: Smallest occupied (observed) size class in a survey year

Indicator name	Proportion of mega-spawners
Abbreviation	P_{mega}
Description	Percentage of individuals which are larger than or equal to the size of mega-spawners (Lmega = 1.1*Lopt = 2/3 Linf+ 0.1*2/3 Linf) in the annual survey catch(Froese, 2004; ICES, 2015b)
Formula	$P_{mega} = \frac{\sum_{l=L_{mega}}^{L_{max}} N_{l_i}}{N}$
Rational	A high abundance mega-spawners should ensure good recruitment because large and experienced spawners produce offspring with a higher survival probability. Simulation studies indicate that %mega should be above 30 % as a conservation of large individuals (WKLIFE V). However, it remains to be tested whether this threshold is applicable for GES.
Relation to "abundance of large old individuals"	2 – (moderate – high), as a relative indicator %mega may still be sensitive to the abundance of small individuals but less than L95% once it is based on a less variable defined length class (Lmega). Definition of Lmega can be quite sensitive to changes in life-history parameters. When computing the indicator, if senescence occurs should be taken into account. There is no scientific basis for considering 1.1*Lopt.
Availability of data. Measurability, robust quantifiable data cover range of spatial & temporal natural variability of suitable (historic) duration and resolution, availability of historic data or other reference points for benchmarking. (0–3)	1 - Survey data are usually considered as adequate, but there may be issues with the catchability of certain size groups or species. Historic data on proportion of mega-spawners are missing, further simulation studies are necessary. Databases to determine Lmega may be weak or missing. Overall, Pmega is more data demanding than many other indicators.
Quality of underlying data. Data that are Sensitive to the magnitude and direction of response to underlying attribute/pressure with high signal to noise ratio, and Responsive at an appropriate time-scale. A tangible indicator that is intuitive to understand. (0–3)	1 – Signal-to-noise ratio (SNR) can be relatively high in some stocks, impacts of other influential factors (e.g. recruitment or changes in Lmega) can cause changes in indicator value.
Conceptual. Theoretical basis, with indicator behaviour (in response to pressure) that is understood to support management advice. (0–3)	2 - %mega intends to assess the status of large spawners. As an indicator expressing a proportion, it is susceptible to influences of other factors (recruitment, changes in life-history parameters). Proxy value for Lmega is based on empirical evidence (1.1*Lopt).
Communication. an indicator that is simple, credible, unambiguous, comprehensible and can be easily communicated (0–3)	2 – The indicator is fairly easy to understand and communicate, but the definition of Lopt may be more difficult to communicate managers and stakeholders. %mega is not necessarily unambiguous.

Manageable. An indicator that is relevant to management, with estimable targets and thresholds and which is responsive, sensitive and cost - effective to develop. (0–3)	2 – The indicator does not only respond to manageable factors (F and selectivity), but also to population dynamics (recruitment). There is a suggested conservation-threshold of 0.3 for this indicator (WKLIFE-V). This threshold needs further validation and its applicability for an assessment of GES within the MSFD has to be tested. Depending on species' generation time the indicator may need several years to respond to recovery management measures.
Score	10

Abbreviations:

N: Numbers of individuals caught in any given survey year

N_{Li}: Numbers of individuals in length class Li caught in any given survey year

n: Number of largest individuals in any given survey year

L_i: Length of size class i

L_{max}: largest occupied (observed) size class in a survey year

L_{min}: Smallest occupied (observed) size class in a survey year

Indicator name	Absolute abundance of mega-spawners
Abbreviation	$cpue_{mega}$
Description	The sum of individuals larger than or equal to Lmega in annual survey catch.
Formula	$CPUE_{mega} = \sum_{i=L_{mega}}^{L_{max}} N_{L_i}$
Rational	The absolute abundance of mega spawners should be specifically sensitive to fishing pressure. Thus a decline in the absolute abundance of mega-spawners should be attributable to fishing and not be a result of strong recruitment.
Relation to "abundance of large old individuals"	3 - High. But sensitive to survey design and sampling gear.
Availability of data. Measurability, robust quantifiable data cover range of spatial and temporal natural variability of suitable (historic) duration and resolution, availability of historic data or other reference points for benchmarking. (0–3)	1 - Survey data are usually considered as adequate, but there may be issues with the catchability of certain size groups or species. Historic data on proportion of mega-spawners are missing, further simulation studies are necessary. Databases to determine Lmega may be weak or missing. Due to this cpue mega is more data demanding than many other indicators.
Quality of underlying data. Data that are Sensitive to the magnitude and direction of response to underlying attribute/pressure with high signal to noise ratio, and Responsive at an appropriate time-scale. A tangible indicator that is intuitive to understand. (0–3)	2 – Values of $cpue_{mega}$ are not directly affected by recruitment, therefore the signal-to-noise ratio (SNR) is lower than for other SBI. Impacts of other influential factors (growth) may affect Lmega and thus the indicator. As an absolute metric, $cpue_{mega}$ may be especially sensitive to changes in survey design and gear.
Conceptual. Theoretical basis, with indicator behaviour (in response to pressure) that is understood to support management advice. (0–3)	2 - $Cpue_{mega}$ intends to assess the status of large spawners. $Cpue_{mega}$ is sensitive to changes in life-history parameters. Proxy value for Lmega is based on empirical evidence (1.1*Lopt).
Communication. an indicator that is simple, credible, unambiguous, comprehensible and can be easily communicated (0–3)	2 – The indicator is fairly easy to understand and communicate, but the definition of Lopt may be more difficult to communicate managers and stakeholders.
Manageable. An indicator that is relevant to management, with estimable targets and thresholds and which is responsive, sensitive and cost-effective to develop. (0-3)	2 – The indicator is sensitive to changes in growth or M. There is no threshold for this indicator, but stability or improvement of status may be a valid management target, yet this needs further exploration. Depending on species' generation time the indicator may need several years to respond to recovery management measures.
Score	12

Abbreviations: N: Numbers of individuals caught in any given survey year. N_{L_i}: Numbers of individuals in length class Li caught in any given survey year. n: Number of largest individuals in any given survey year.

L_i: Length of size class i

L_{max}: largest occupied (observed) size class in a survey year

L_{min}: Smallest occupied (observed) size class in a survey year

Indicator name	Length class diversity
Abbreviation	LCH
Description	The Shannon–Wiener diversity of the annual length–frequency distribution.
Formula	$LCH = -\sum_{i=L_{min}}^{L_{max}} \frac{N_{L_i}}{N} \ln(\frac{N_{L_i}}{N})$
Rational	The LCH should increase if distribution between the length class-frequencies is even and if many length classes are present in the LFD. Fishing should reduce LHS by decreasing evenness in the stock. However, recruitment will also have an impact on LCH.
Relation to "abundance of large old individuals"	1 – (Low- moderate). High values of the indicator may not reflect a non-impacted size structure.
Availability of data. Measurability, robust quantifiable data cover range of spatial & temporal natural variability of suitable (historic) duration and resolution, availability of historic data or other reference points for benchmarking. (0–3)	2 – Survey data are usually considered as adequate, but there may be issues with the catchability of certain size groups or species. Historic data for this indicator are not available for many stocks.
Quality of underlying data. Data that are Sensitive to the magnitude and direction of response to underlying attribute/pressure with high signal to noise ratio, and responsive at an appropriate time-scale. A tangible indicator that is intuitive to understand. (0–3)	1 – Signal-to-noise ratio (SNR) can be relatively high, impacts of other influential factors (e.g. recruitment) can cause changes in indicator value.
Conceptual. Theoretical basis, with indicator behaviour (in response to pressure) that is understood to support management advice. (0–3)	1 - The LCH should be adapted to focus on the properties of the mature component of the stock. This could be done by including only individuals > Lmat. Diversity indicators may be potentially interesting for characterising the structure of the population, but more research effort is needed.
Communication. An indicator that is simple, credible, unambiguous, comprehensible and can be easily communicated (0–3)	1 - The meaning of diversity indicators and their actual metric value such as Shannon–Wiener (H) may be difficult to explain.
Manageable. An indicator that is relevant to management, with estimable targets and thresholds and which is responsive, sensitive and cost-effective to develop. (0–3)	0 - There is no threshold for this indicator. Due to the weak conceptual basis, the development of a conceptual threshold may difficult. The application of time-series based methods would need to be explored. Thus this indicator may not be relevant to management at this stage.
Score	6

Abbreviations:

N: Numbers of individuals caught in any given survey year

N_{L_i}: Numbers of individuals in length class Li caught in any given survey year

n: Number of largest individuals in any given survey year

L_i: Length of size class i

L_{max}: largest occupied (observed) size class in a survey year

L_{min}: Smallest occupied (observed) size class in a survey year

Indicator name	Mean length of the largest observed n individuals in annual survey catches
Abbreviation	L_{max_n}
Description	The Lmax_n is the arithmetic mean size of the largest n individuals within the stock. The n is a fixed number of individuals representing the largest individuals within the stock. N can be determined e.g. as averaged percentage of the mean annual catch (by individuals across all years), e.g. Lmax_5%)(Probst *et al*., 2013a; Probst *et al*., 2013b). Thus n will differ between stocks.
Formula	$L_{max\_n} = \frac{\sum_{i=1}^{n} L_i}{n}$
Rational	The Lmax_n is a derivate of the Lmax. As an absolute SBI it is also not affected by recruitment, but by including several individuals into its calculation, it aims to reduce the susceptibility to sampling error.
Relation to "abundance of large old individuals"	2 - Moderate. The Lmax_n is not susceptible to recruitment, but depending on the stock size, the representativeness of the n largest fish can vary.
Availability of data. Measurability, robust quantifiable data cover range of spatial & temporal natural variability of suitable (historic) duration and resolution, availability of historic data or other reference points for benchmarking. (0–3)	2 – Survey data are usually considered as adequate, but there may be issues with the catchability of certain size groups or species. Historic data for this indicator are not available for many stocks.
Quality of underlying data. Data that are Sensitive to the magnitude and direction of response to underlying attribute/pressure with high signal to noise ratio, and responsive at an appropriate time-scale. A tangible indicator that is intuitive to understand. (0–3)	1 – Signal-to-noise ratio (SNR) is affected by annual variations in stock size. Changes in growth may affect the indicator value.
Conceptual. Theoretical basis, with indicator behaviour (in response to pressure) that is understood to support management advice. (0–3)	2 – Instead of the mean the median may be used to account for skewed distribution of the n largest fish. Also, n may need to be defined to minimise the impacts of sampling stochasticity.
Communication. An indicator that is simple, credible, unambiguous, comprehensible and can be easily communicated (0–3)	1 - The way of how n is determined, is difficult to communicate. The strong influence of stock size suggest that this indicator may have credibility issues if stock abundance is highly variable between years.

Manageable. An indicator that is relevant to management, with estimable targets and thresholds and which is responsive, sensitive and cost - effective to develop. (0–3)	1 - There is no threshold for this indicator, but stability or improvement of status may be a valid management target, yet this needs further exploration. The indicators susceptibility to stock size reduce its applicability for management. The possibility of using L∞ as a reference point could be explored. Depending on species' generation time the indicator may need several years to respond to recovery management measures.
Score	9

Abbreviations:

N: Numbers of individuals caught in any given survey year

N_{Li}: Numbers of individuals in length class Li caught in any given survey year

n: Number of largest individuals in any given survey year

L_i: Length of size class i

L_{max}: largest occupied (observed) size class in a survey year

L_{min}: Smallest occupied (observed) size class in a survey year

Annex 6: Detailed results of selectivity indicators for the analysed stocks

Baltic cod (I)

Results of LFCOM analysis, Fri Mar 18 15:48:02 2016
Species = *Gadus morhua*, stock = cod-2532

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 90 cm
Growth parameter K = 0.3 1/year
Length at 50% maturity Lm50 = 32.9 cm
Length at 90% maturity Lm90 = 42.2 cm
Natural mortality of adults M = 0.3 1/y
Commercial fishing mortality F = NA 1/y
M/K (expected 1.0-2.0) M/K = 1
Comment: Low Linf enforced

Lopt, Lc_opt and L(F=M) based on Linf

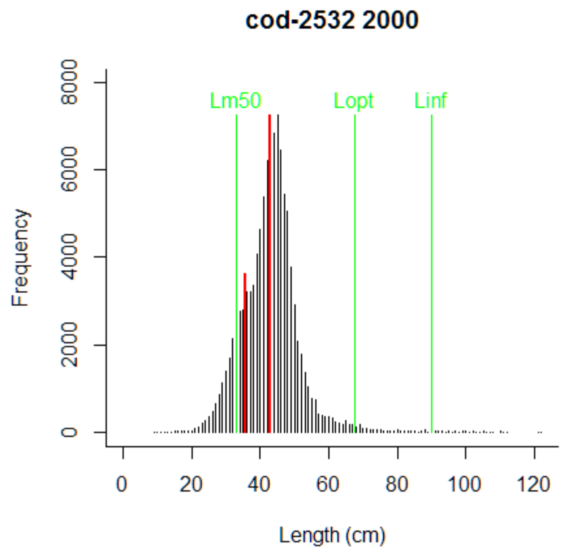
Length at max cohort biomass Lopt = 60 cm, assuming b ~ 3 and M/K ~ 1.5
Lc resulting in Lopt Lc_opt = 45 cm, if F ~ M
Lc resulting in Lopt Lc_opt = 49.5 cm, if F ~ 2 M
Mean length in catch if F=M L(F=M) = 46.5 cm

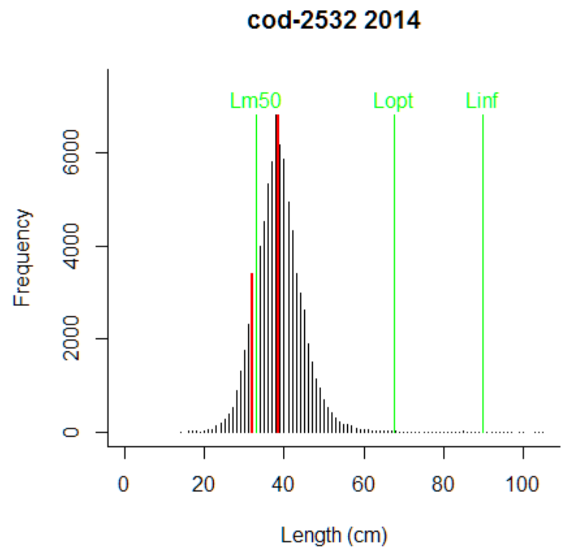
Observed Lc and Lmean in 2014

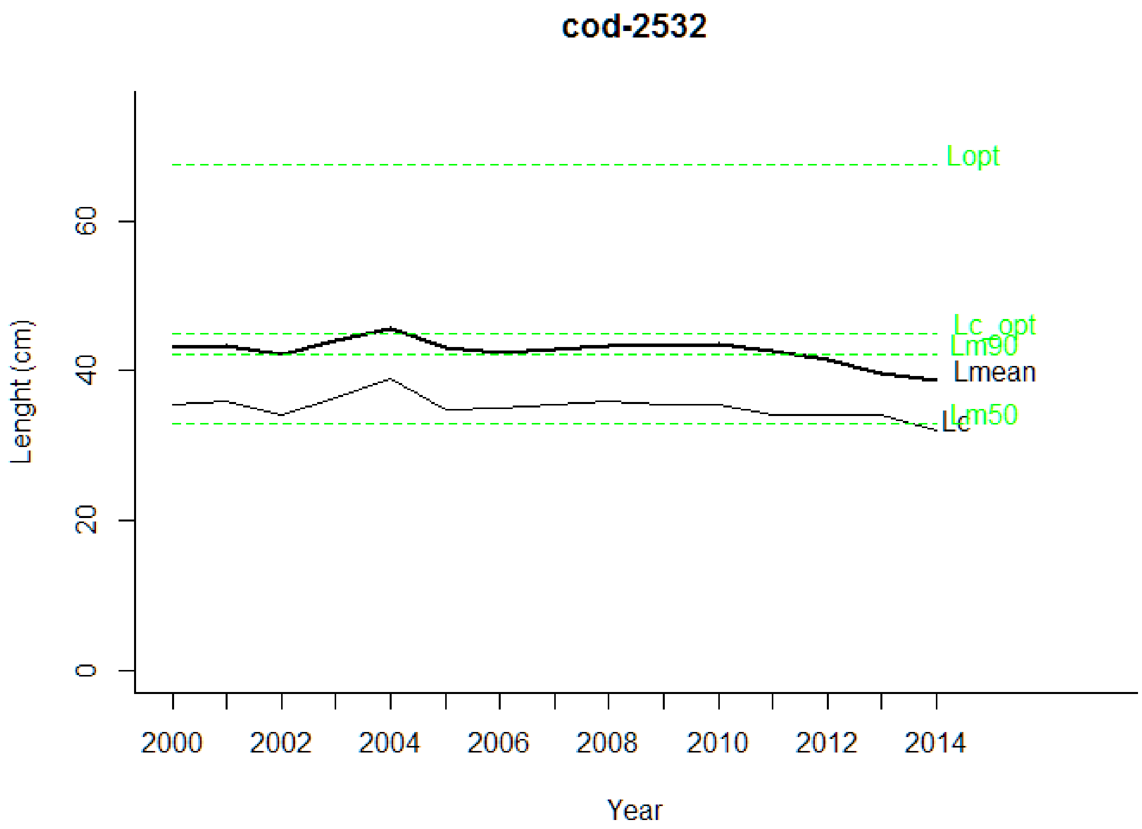
Mean length at first capture Lc = 32 cm
Mean length in catch Lmean = 38.6 cm

Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	cod-2532	2000	35.5	43.0	44.0	122
2	cod-2532	2001	36.0	43.3	43.0	115
3	cod-2532	2002	34.0	42.2	43.0	118
4	cod-2532	2003	36.5	44.0	42.7	132
5	cod-2532	2004	39.0	45.7	44.0	128
6	cod-2532	2005	34.9	43.1	44.0	129
7	cod-2532	2006	35.0	42.4	40.0	122
8	cod-2532	2007	35.5	42.9	42.0	118
9	cod-2532	2008	36.0	43.2	42.0	122
10	cod-2532	2009	35.5	43.4	42.0	132
11	cod-2532	2010	35.5	43.6	43.0	126
12	cod-2532	2011	34.0	42.6	41.0	119
13	cod-2532	2012	34.0	41.5	39.7	113
14	cod-2532	2013	34.0	39.6	40.0	104
15	cod-2532	2014	32.0	38.6	39.0	105


cod-2532 2000
Lm50
Lopt
Linf
Frequency
Length (cm)


cod-2532 2014
Lm50
Lopt
Linf
Frequency
Length (cm)


cod-2532
Lopt
Lc_opt
Lm90
Lmean
Lm50
Lc
Lenght (cm)
Year

NORTH SEA COD (I)

Results of smalk analysis, fri mar 18 15:20:33 2016

File = smalk_ns-ibts_2016-02-19_q1.csv

Survey = ns-ibts

Species = *Gadus morhua*

Sex = f

Years = 2000–2015

Quarter = 1

Areas = 1 2 3 4 5 6 7

Summary stats of weighted mixed w~l regression

----

21 outliers (beyond 4 sd) were removed.

Number of remaining observations = 5961

Length range = 10–133 cm

Weight range = 8–25 000 g

Log10(a) = -2.25 , se = 0.00499

Geometric mean a = 0.00566 , 95% cl = 0.00554–0.00579

B = 3.15 , 95% cl = 3.15 - 3.16

Standard deviation of estimated log10(w) = 0.0578

Coefficient of determination (r2) = 0.995

Mean length = 45.7 cm, predicted weight = 970 g (747–1259) g

Wetherall estimation of linf

Records used = 5647

Observed maximum length = 133 cm

Median of annual maximum lengths = 116 cm

Proposed linf = 117 cm

Estimate of von Bertalanffy growth function

Number of observations = 5936

Observed maximum age = 12 years

Observed maximum length (including specimens without age)= 133 cm

Wetherall linf = 117 cm, chosen linf = 117

K = 0.205 , 95% cl = 0.202 - 0.208

T-zero = 0.154 , 95% cl = 0.134 - 0.174 (restricted to -3 and + 0.5 or usert0)

Sd of log(residuals) and of predicted log(length) = 0.205

Maturity analysis from proportion-mature-at-length data

Available maturity codes = 61 62 63 64

Number of observations = 4691

Largest immature = 83 cm

Smallest mature = 12 cm

Ogive length at 50% maturity = 53.4 cm

Ogive length at 10% and 90% maturity 26.8–79.9 cm

Maturity analysis from proportion-mature-at-age data

Number of observations = 4325

Youngest mature = 1 years

Oldest immature = 7 years

Proportion mature at ages 1-6 = 0.2 0.5 0.7 0.9 1.0 1.0

Other lf results for this survey gear

Fully selected length (peak+1) lv = 33 cm

Length at first capture lc = 15 cm

NORTH SEA COD (II)

WEIGHTED MEAN LENGTH LMEAN = 44.3

LENGTH AT MAX COHORT BIOMASS LOPT = 87.1

LC RESULTING IN LOPT LC_OPT = 77

MEAN SURVEY LENGTH IF F=M L(F=M) = 48.4 CM

EXTERNAL ESTIMATES OF MORTALITY

NATURAL MORTALITY OF ADULTS M = 0.21 1/Y

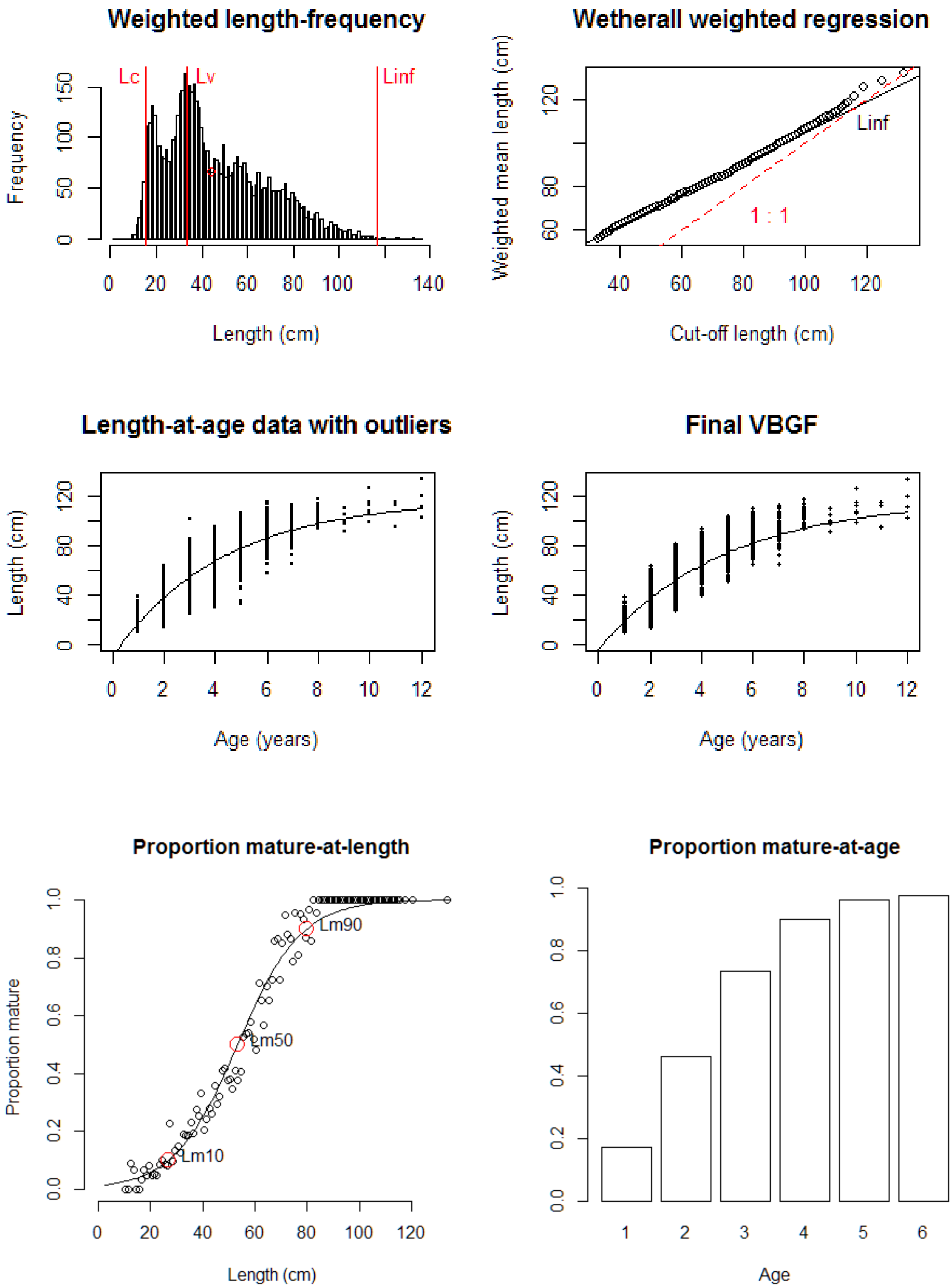
COMMERCIAL FISHING MORTALITY F = 0.393 1/Y

COMMENT:

SUMMARY, FORMATTED FOR PASTING INTO OTHER R-CODE

```
------------------------------------------------
SPECIES  <- GADUS MORHUA
SEX      <- F
AREA     <- C( 1 2 3 4 5 6 7 )
A        <- 0.00566
B        <- 3.15
LINF     <- 117
K        <- 0.205
T0       <- 0.15
LM50     <- 53.4
LM90     <- 79.9
M        <- 0.21
FM       <- 0.393
LOPT     <- 87.1
LC_OPT   <- 77
```

NORTH SEA COD (III)



NORTH SEA COD (IV)

Results of LFCOM analysis, Fri Mar 18 15:51:03 2016

Species = *Gadus morhua*, stock = cod-347d

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 114 cm

Growth parameter K = 0.213 1/year

Length at 50% maturity Lm50 = 53.4 cm

Length at 90% maturity Lm90 = 79.9 cm

Natural mortality of adults M = 0.21 1/y

Commercial fishing mortality F = 0.393 1/y

M/K (expected 1.0-2.0) M/K = 0.986

Comment: Linf, K, Lopt, Lc_opt for combined sex; Lm50 and Lm90 for females

----

Lopt, Lc_opt and L(F=M) based on Linf, M, K, F

Length at max cohort biomass Lopt = 85.8

Lc resulting in Lopt Lc_opt = 75.8

Mean length in catch if F=M L(F=M) = 59.7 cm

Lopt, Lc_opt and L(F=M) based on Linf

Length at max cohort biomass Lopt = 76 cm, assuming b ~ 3 and M/K ~ 1.5

Lc resulting in Lopt Lc_opt = 57 cm, if F ~ M

Lc resulting in Lopt Lc_opt = 62.7 cm, if F ~ 2 M

Mean length in catch if F=M L(F=M) = 52.6 cm

Observed Lc and Lmean in 2014

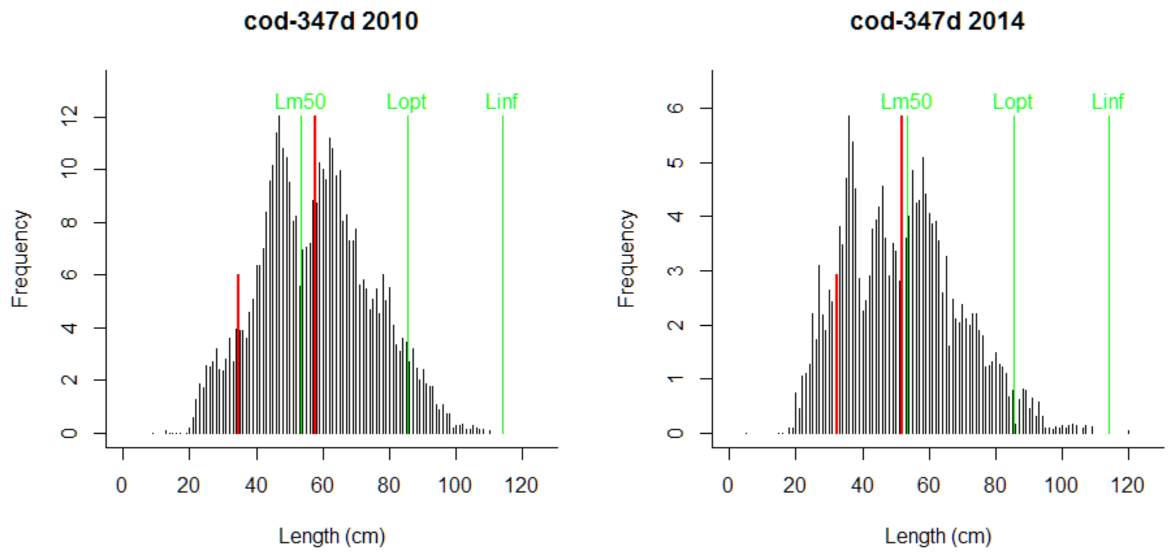
Mean length at first capture Lc = 32.2 cm

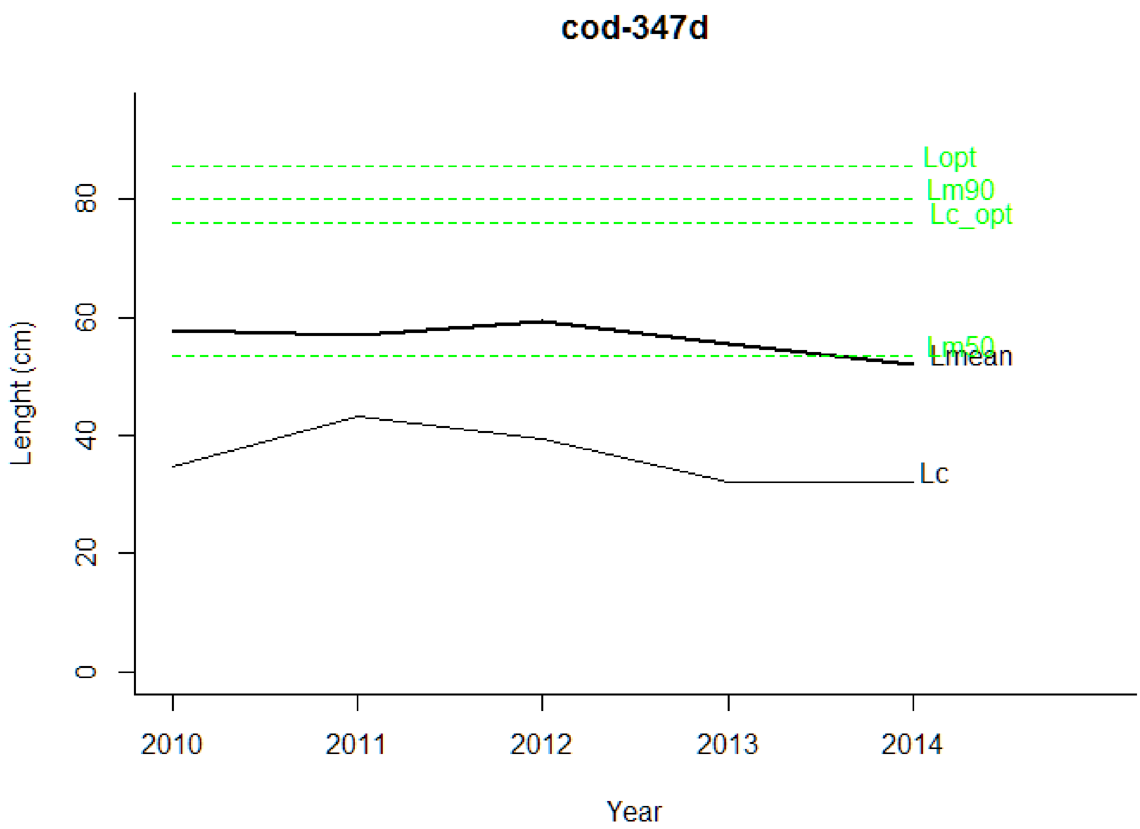
Mean length in catch Lmean = 52 cm

Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	cod-347d	2010	34.9	57.9	51.7	110
2	cod-347d	2011	43.1	57.1	58.0	118
3	cod-347d	2012	39.3	59.1	56.7	121
4	cod-347d	2013	32.1	55.5	46.7	122
5	cod-347d	2014	32.2	52.0	43.7	120

NORTH SEA COD (V)





NORTH SEA PLAICE (I)

Results of LFCOM analysis, Fri Mar 18 15:52:58 2016

Species = *Pleuronectes platessa*, stock = ple-nsea

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 49.9 cm

Growth parameter K = 0.153 1/year

Length at 50% maturity Lm50 = 22.8 cm

Length at 90% maturity Lm90 = 30.7 cm

Natural mortality of adults M = 0.1 1/y

Commercial fishing mortality F = 0.22 1/y

M/K (expected 1.0-2.0) M/K = 0.654

Comment: Linf, K, Lopt and Lc_opt for combined sex; Lm50 and Lm90 for females

----

Lopt, Lc_opt and L(F=M) based on Linf, M, K, F

Length at max cohort biomass Lopt = 41

Lc resulting in Lopt Lc_opt = 36.7

Mean length in catch if F=M L(F=M) = 33.2 cm

Lopt, Lc_opt and L(F=M) based on Linf

Length at max cohort biomass Lopt = 33.3 cm, assuming b ~ 3 and M/K ~ 1.5

Lc resulting in Lopt Lc_opt = 24.9 cm, if F ~ M

Lc resulting in Lopt Lc_opt = 27.4 cm, if F ~ 2 M

Mean length in catch if F=M L(F=M) = 27.9 cm

Observed Lc and Lmean in 2014

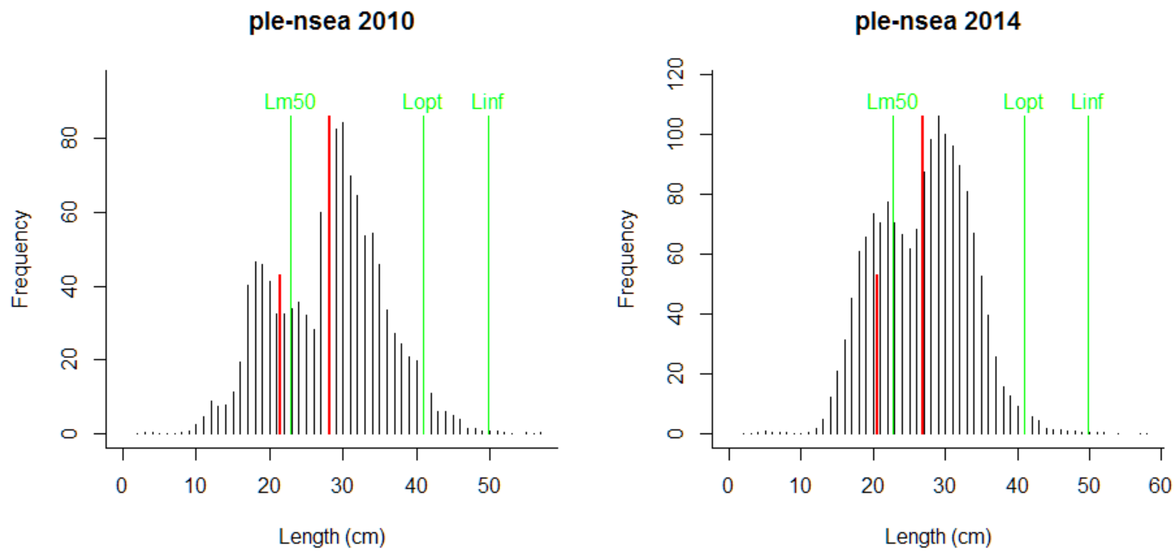
Mean length at first capture Lc = 20.5 cm

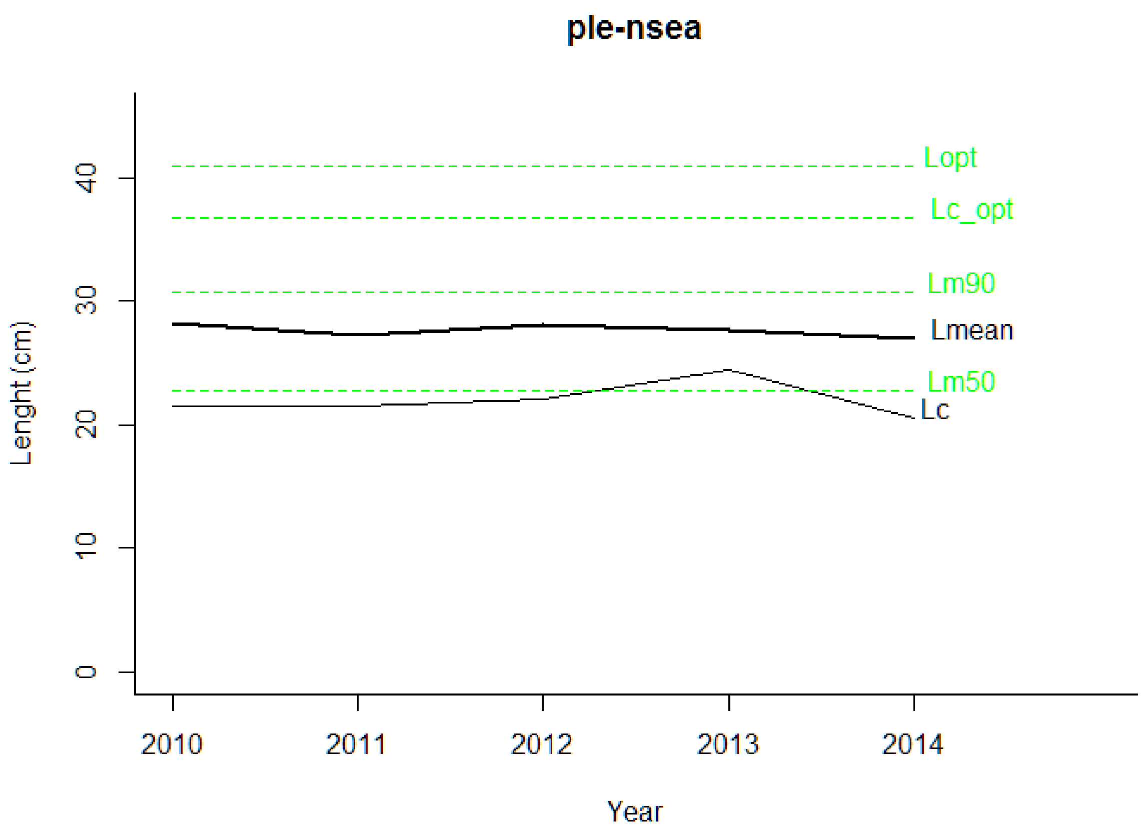
Mean length in catch Lmean = 26.9 cm

Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	ple-nsea	2010	21.5	28.2	29	57
2	ple-nsea	2011	21.5	27.2	28	62
3	ple-nsea	2012	22.0	28.0	28	60
4	ple-nsea	2013	24.5	27.6	28	52
5	ple-nsea	2014	20.5	26.9	29	58

NORTH SEA PLAICE (I)





NORTHERN HAKE (I)

Results of LFCOM analysis, Fri Mar 18 15:58:27 2016

Species = *Merluccius merluccius*, stock = hke-nrtn

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 130 cm

Growth parameter K = 0.177 1/year

Length at 50% maturity Lm50 = 42.9 cm

Length at 90% maturity Lm90 = 51.4 cm

Natural mortality of adults M = 0.4 1/y

Commercial fishing mortality F = 0.31 1/y

M/K (expected 1.0-2.0) M/K = 2.26

Comment: Linf, K, M, Lm50 from assessment; Lm90 assumed as 1.2*Lm50

Lopt, Lc_opt and L(F=M) based on Linf, M, K, F

Length at max cohort biomass Lopt = 74.1

Lc resulting in Lopt Lc_opt = 60.2

Mean length in catch if F=M L(F=M) = 48.9 cm

Lopt, Lc_opt and L(F=M) based on Linf

Length at max cohort biomass Lopt = 86.7 cm, assuming b ~ 3 and M/K ~ 1.5

Lc resulting in Lopt Lc_opt = 65 cm, if F ~ M

Lc resulting in Lopt Lc_opt = 71.5 cm, if F ~ 2 M

Mean length in catch if F=M L(F=M) = 55.8 cm

Observed Lc and Lmean in 2013

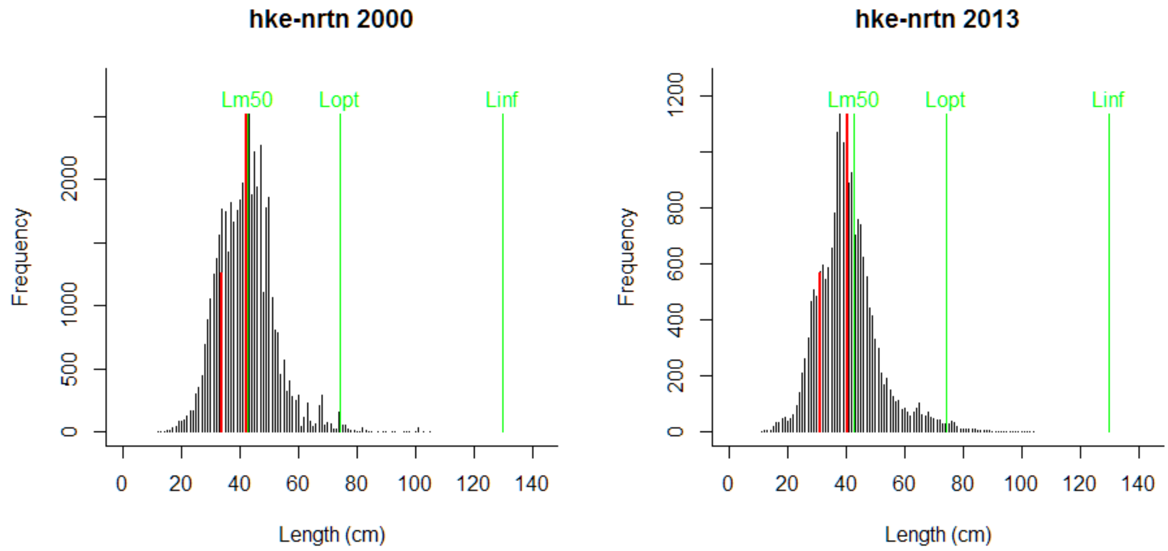
Mean length at first capture Lc = 31 cm

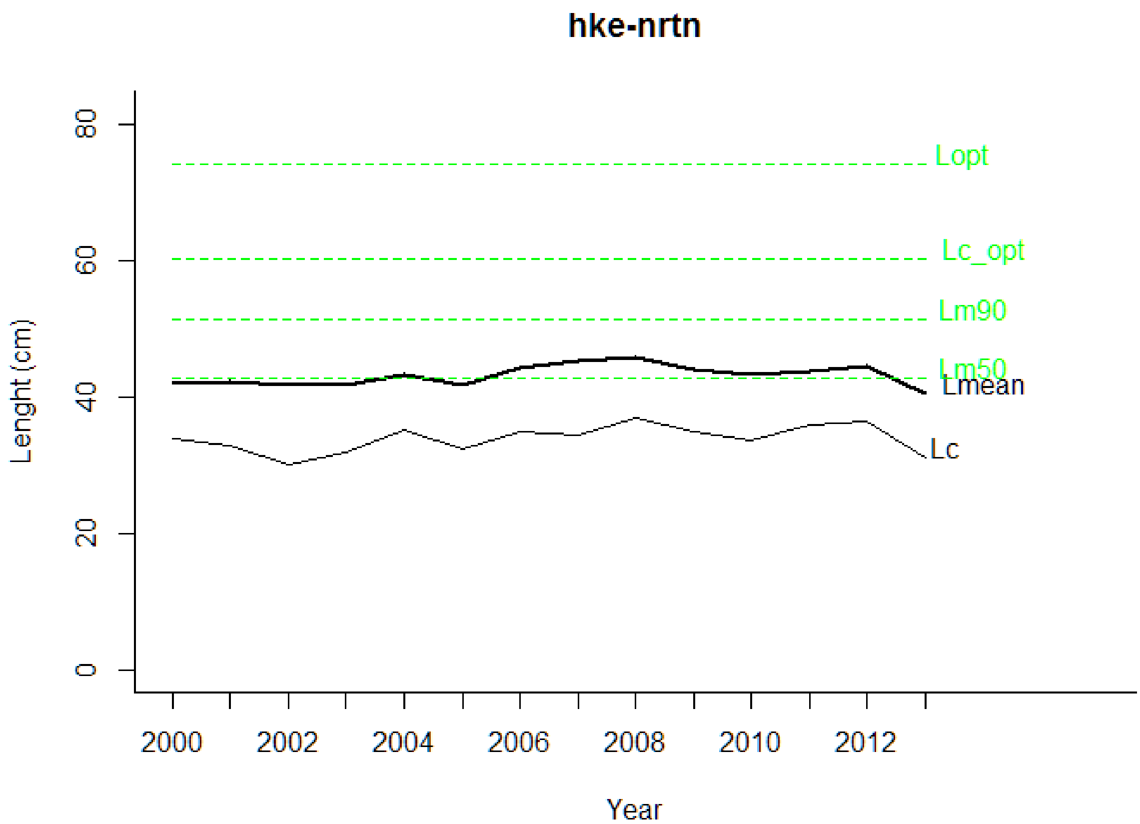
Mean length in catch Lmean = 40.6 cm

Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	hke-nrtn	2000	34.0	42.1	45.0	105
2	hke-nrtn	2001	33.0	42.2	42.0	125
3	hke-nrtn	2002	30.0	41.8	40.7	115
4	hke-nrtn	2003	32.0	41.8	40.0	113
5	hke-nrtn	2004	35.2	43.2	40.7	116
6	hke-nrtn	2005	32.5	41.9	37.0	118
7	hke-nrtn	2006	35.0	44.3	43.0	110
8	hke-nrtn	2007	34.5	45.2	42.7	113
9	hke-nrtn	2008	37.0	45.9	42.0	117
10	hke-nrtn	2009	35.0	44.0	42.7	119
11	hke-nrtn	2010	33.7	43.2	43.0	122
12	hke-nrtn	2011	35.9	43.7	45.0	122
13	hke-nrtn	2012	36.5	44.7	44.0	119
14	hke-nrtn	2013	31.0	40.6	38.0	104

NORTHERN HAKE (II)





WESTERN MEDITERRANEAN HAKE (I)

Results of LFCOM analysis, Fri Mar 18 16:07:59 2016

Species = *Merluccius merluccius*, stock = hke-med

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 96.8 cm

Growth parameter K = 0.08 1/year

Length at 50% maturity Lm50 = 32.5 cm

Length at 90% maturity Lm90 = 39 cm

Natural mortality of adults M = NA 1/y

Commercial fishing mortality F = NA 1/y

M/K (expected 1.0-2.0) M/K = NA

Comment: It is unclear whether this length–frequency is representative of the whole stock

----

Lopt, Lc_opt and L(F=M) based on Linf

Length at max cohort biomass Lopt = 64.5 cm, assuming b ~ 3 and M/K ~ 1.5

Lc resulting in Lopt Lc_opt = 48.4 cm, if F ~ M

Lc resulting in Lopt Lc_opt = 53.2 cm, if F ~ 2 M

Mean length in catch if F=M L(F=M) = 28.4 cm

Observed Lc and Lmean in 2014

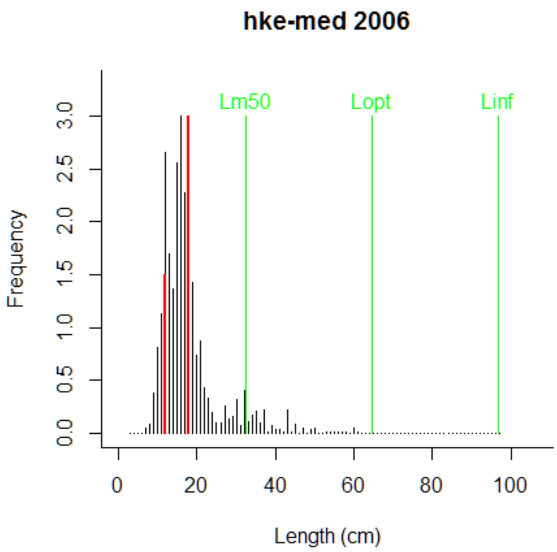
Mean length at first capture Lc = 5.67 cm

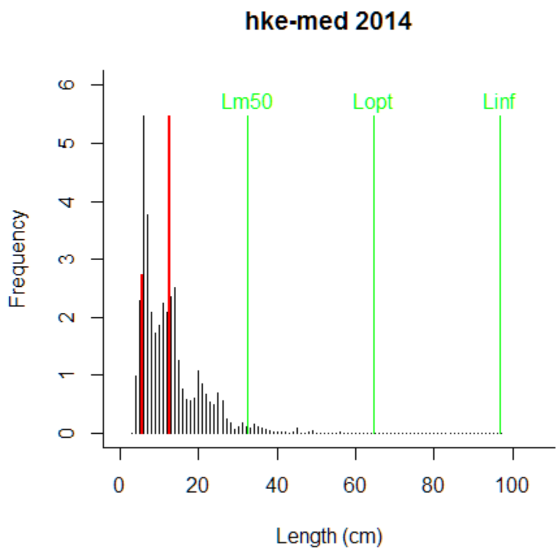
Mean length in catch Lmean = 12.5 cm

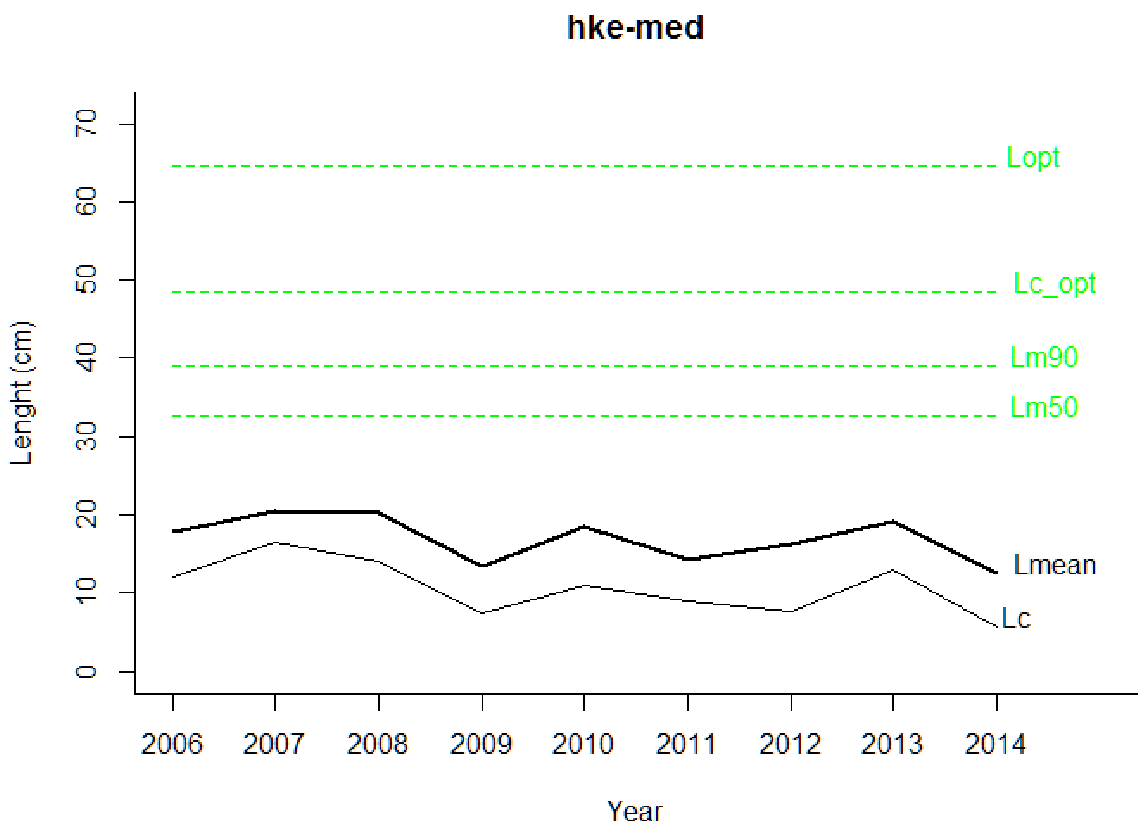
Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	hke-med	2006	12.00	17.8	14.3	73
2	hke-med	2007	16.50	20.4	19.0	86
3	hke-med	2008	14.00	20.1	16.7	81
4	hke-med	2009	7.50	13.4	13.0	81
5	hke-med	2010	11.00	18.5	17.0	97
6	hke-med	2011	9.00	14.2	14.0	85
7	hke-med	2012	7.71	16.4	11.3	80
8	hke-med	2013	13.00	19.2	17.0	80
9	hke-med	2014	5.67	12.5	9.0	80

WESTERN MEDITERRANEAN HAKE (II)







ADRIATIC ANCHOVY (I)

Results of LFCOM analysis, Fri Mar 18 16:14:11 2016

Species = *Engraulis encrasicolus*, stock = anc-GSA1718

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 20 cm

Growth parameter K = 0.4 1/year

Length at 50% maturity Lm50 = 10.5 cm

Length at 90% maturity Lm90 = 14 cm

Natural mortality of adults M = NA 1/y

Commercial fishing mortality F = NA 1/y

M/K (expected 1.0-2.0) M/K = NA

Comment:

Lopt, Lc_opt and L(F=M) based on Linf

Length at max cohort biomass Lopt = 13.3 cm, assuming b ~ 3 and M/K ~ 1.5

Lc resulting in Lopt Lc_opt = 10 cm, if F ~ M

Lc resulting in Lopt Lc_opt = 11 cm, if F ~ 2 M

Mean length in catch if F=M L(F=M) = 13.1 cm

Observed Lc and Lmean in 2014

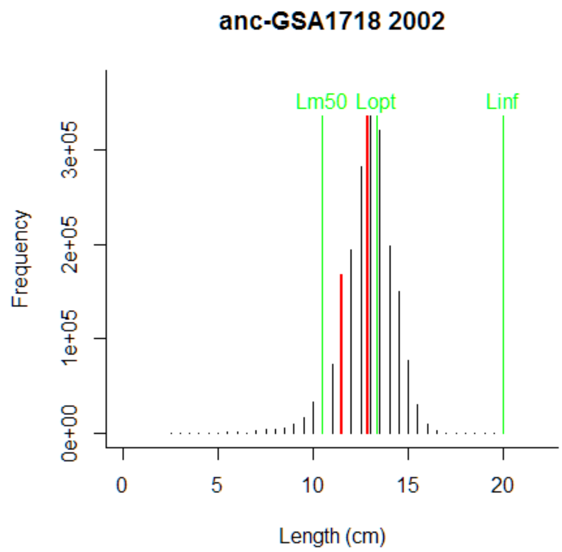
Mean length at first capture Lc = 10.8 cm

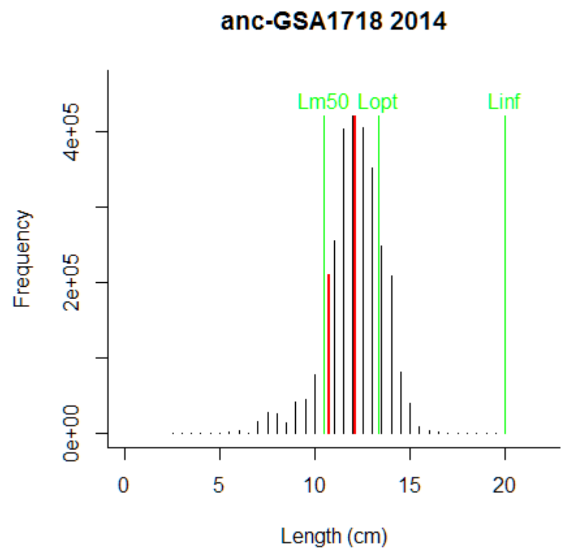
Mean length in catch Lmean = 12.1 cm

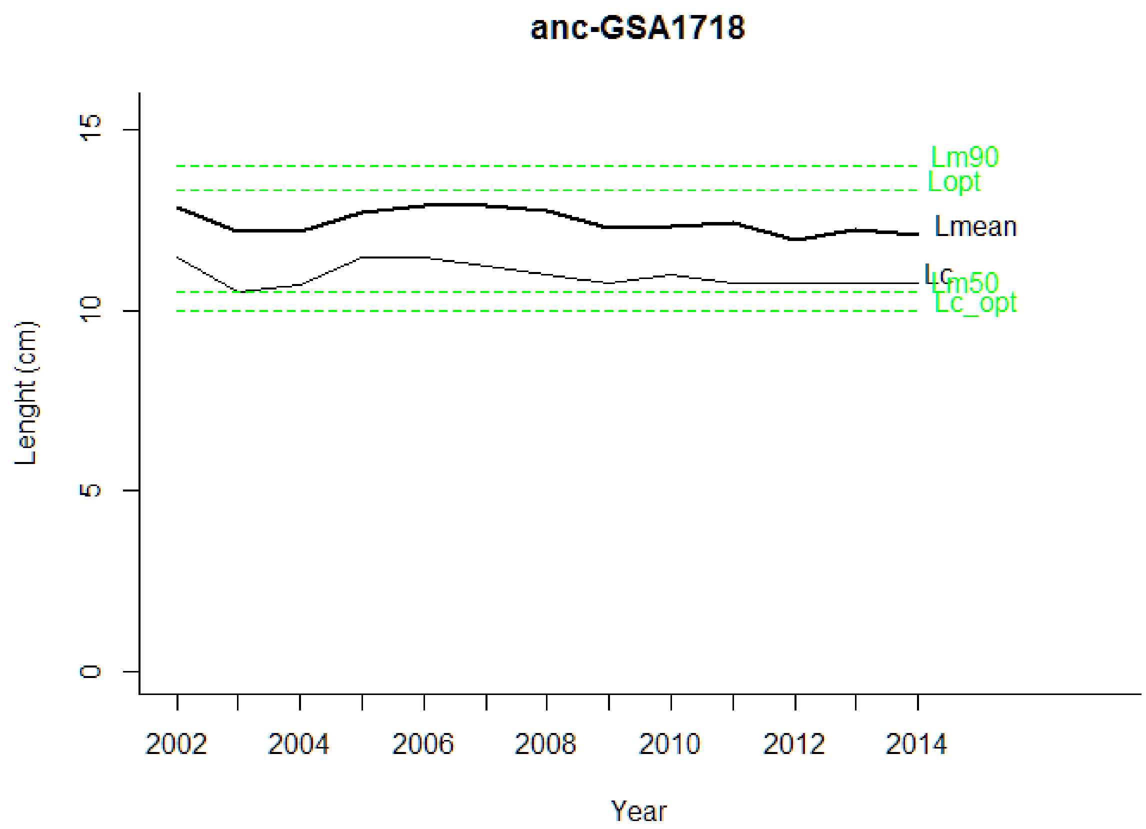
Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	anc-GSA1718	2002	11.5	12.9	13.0	17.0
2	anc-GSA1718	2003	10.5	12.2	12.5	18.0
3	anc-GSA1718	2004	10.7	12.2	13.0	18.0
4	anc-GSA1718	2005	11.5	12.7	13.0	16.5
5	anc-GSA1718	2006	11.5	12.9	13.0	18.0
6	anc-GSA1718	2007	11.2	12.9	13.0	18.5
7	anc-GSA1718	2008	11.0	12.8	12.5	18.0
8	anc-GSA1718	2009	10.8	12.3	13.0	17.5
9	anc-GSA1718	2010	11.0	12.3	12.5	18.0
10	anc-GSA1718	2011	10.8	12.4	12.7	18.0
11	anc-GSA1718	2012	10.8	11.9	12.0	18.0
12	anc-GSA1718	2013	10.8	12.2	12.5	17.0
13	anc-GSA1718	2014	10.8	12.1	12.0	17.0

ADRIATIC ANCHOVY (II)







GIANT RED SHRIMP (I)

Results of LFCOM analysis, Fri Mar 18 16:20:11 2016

Species = *Aristaeomorpha foliacea*, stock = GRShrimp11

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 7 cm

Growth parameter K = 0.45 1/year

Length at 50% maturity Lm50 = 3.05 cm

Length at 90% maturity Lm90 = 3.66 cm

Natural mortality of adults M = NA 1/y

Commercial fishing mortality F = NA 1/y

M/K (expected 1.0-2.0) M/K = NA

Comment: Carapace length

Lopt, Lc_opt and L(F=M) based on Linf

Length at max cohort biomass Lopt = 4.67 cm, assuming b ~ 3 and M/K ~ 1.5

Lc resulting in Lopt Lc_opt = 3.5 cm, if F ~ M

Lc resulting in Lopt Lc_opt = 3.85 cm, if F ~ 2 M

Mean length in catch if F=M L(F=M) = 3.78 cm

Observed Lc and Lmean in 2014

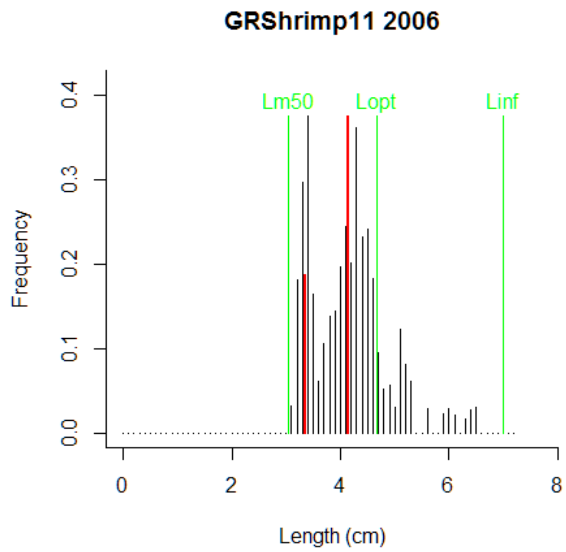
Mean length at first capture Lc = 2.7 cm

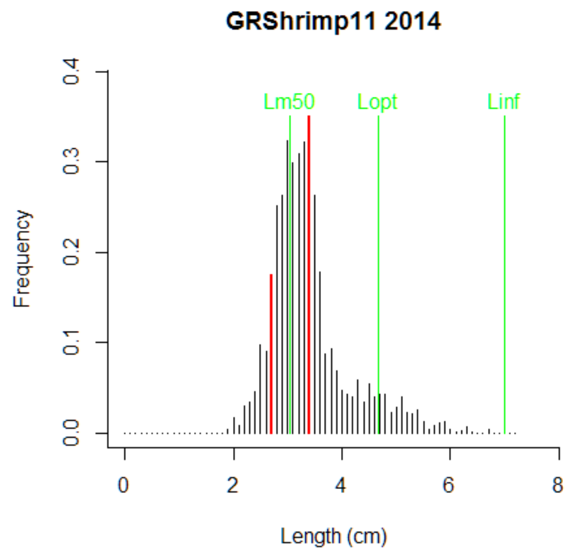
Mean length in catch Lmean = 3.4 cm

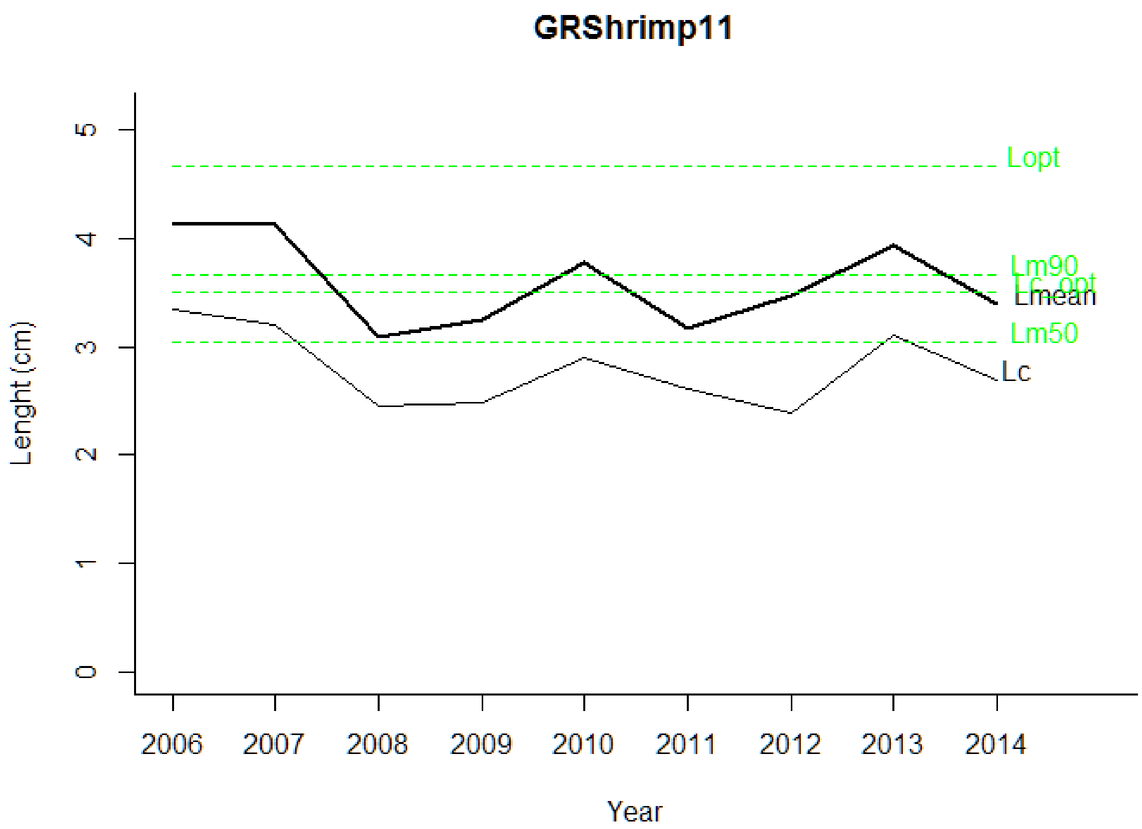
Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	GRShrimp11	2006	3.35	4.15	3.67	6.5
2	GRShrimp11	2007	3.20	4.13	3.73	6.6
3	GRShrimp11	2008	2.45	3.10	2.75	5.5
4	GRShrimp11	2009	2.48	3.25	3.03	6.8
5	GRShrimp11	2010	2.90	3.78	3.30	6.6
6	GRShrimp11	2011	2.62	3.17	3.13	6.5
7	GRShrimp11	2012	2.38	3.47	2.90	6.6
8	GRShrimp11	2013	3.10	3.93	3.40	6.9
9	GRShrimp11	2014	2.70	3.40	3.23	6.7

GIANT RED SHRIMP (II)



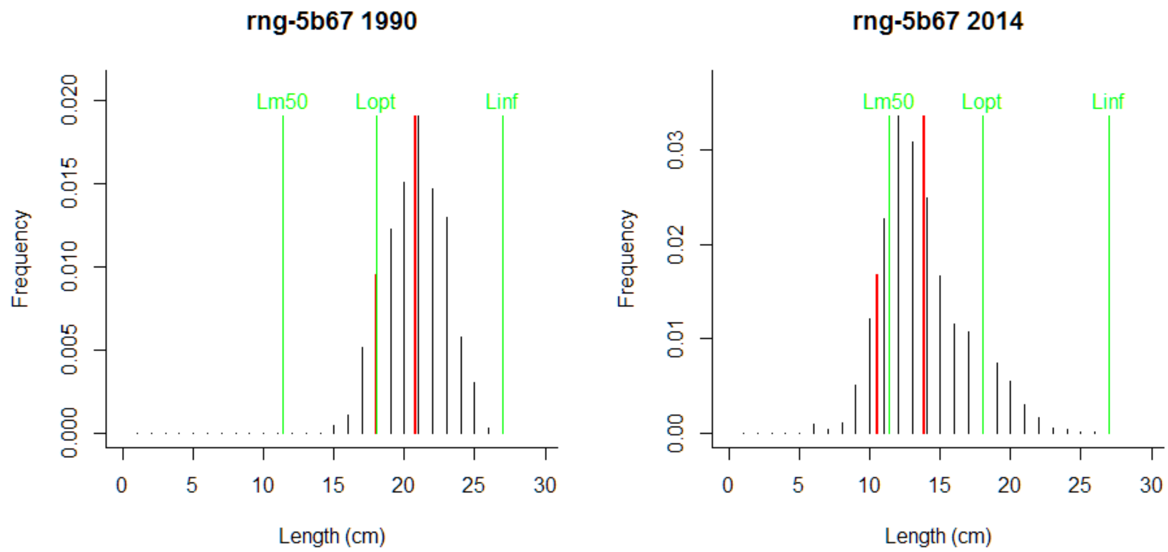


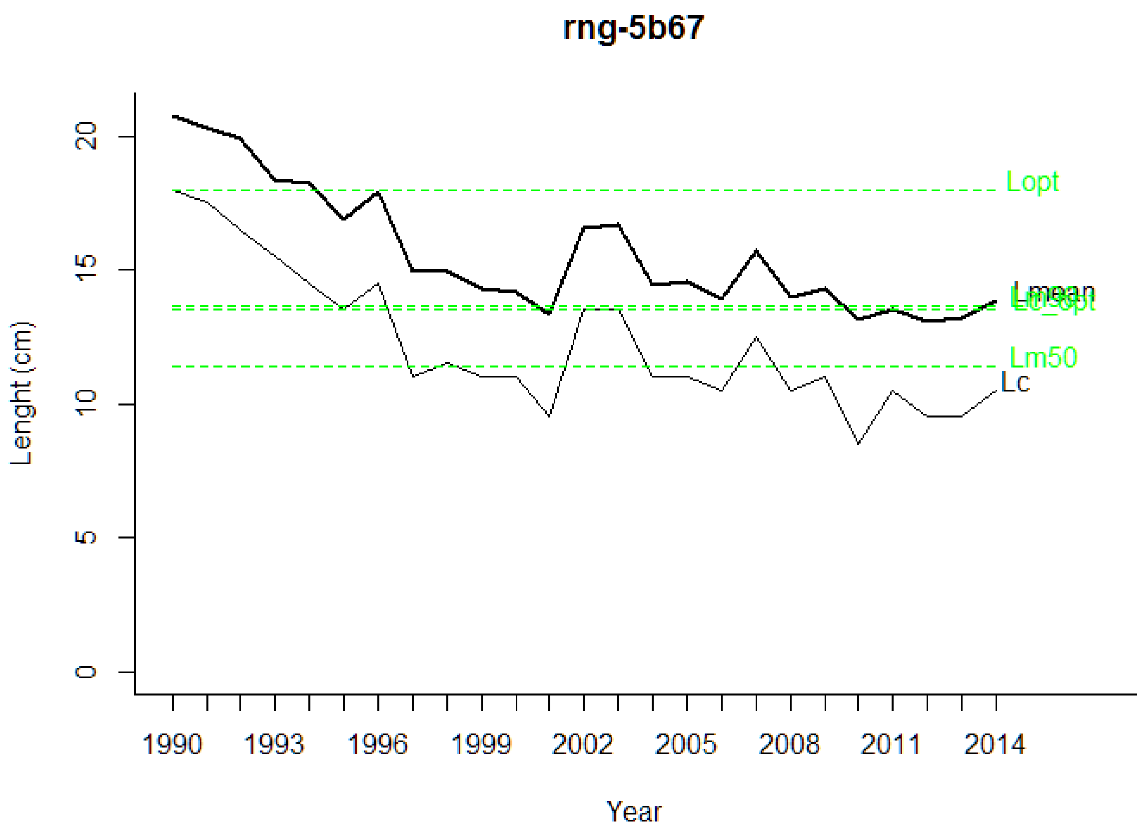


ROUNDNOSE GRENADIER (I)

```
---------------------------------------------
Results of LFCOM analysis, Fri Mar 18 16:47:39 2016
Species = Coyphaenoides rupestris, stock = rng-5b67

External estimates of Linf, K, Lm50, Lm90, M, F
---------------------------------------------
Asymptotic length            Linf = 27 cm
Growth parameter                K = 0.06 1/year
Length at 50% maturity       Lm50 = 11.4 cm
Length at 90% maturity       Lm90 = 13.7 cm
Natural mortality of adults     M = NA 1/y
Commercial fishing mortality    F = 0.037 1/y
M/K (expected 1.0-2.0)        M/K = NA
Comment: Length type is preanal fin length, with PAFL = 0.196*TL+2.29; ref points were adjusted

----------------------------------------------
Lopt, Lc_opt and L(F=M) based on Linf
----------------------------------------------
Length at max cohort biomass Lopt   = 18 cm, assuming b ~ 3 and M/K ~ 1.5
Lc resulting in Lopt        Lc_opt = 13.5 cm, if F ~ M
Lc resulting in Lopt        Lc_opt = 14.9 cm, if F ~ 2 M
Mean length in catch if F=M  L(F=M) = 14.6 cm

---------------------------------------------
Observed Lc and Lmean in 2014
---------------------------------------------
Mean length at first capture   Lc = 10.5 cm
Mean length in catch        Lmean = 13.9 cm

Time-series
---------------------------------------------
      Stock Year   Lc Lmean Lpeak Lmax
1  rng-5b67 1990 18.0  20.7  21.0   27
2  rng-5b67 1991 17.5  20.3  21.0   26
3  rng-5b67 1992 16.5  19.9  19.0   27
4  rng-5b67 1993 15.5  18.3  18.0   26
5  rng-5b67 1994 14.5  18.2  18.0   27
6  rng-5b67 1995 13.5  16.9  16.3   24
7  rng-5b67 1996 14.5  17.9  17.0   25
8  rng-5b67 1997 11.0  15.0  14.0   25
9  rng-5b67 1998 11.5  15.0  15.0   24
10 rng-5b67 1999 11.0  14.3  15.0   24
11 rng-5b67 2000 11.0  14.2  14.0   25
12 rng-5b67 2001  9.5  13.3  12.0   23
13 rng-5b67 2002 13.5  16.6  16.0   25
14 rng-5b67 2003 13.5  16.7  16.0   24
15 rng-5b67 2004 11.0  14.4  15.0   25
16 rng-5b67 2005 11.0  14.6  14.0   25
17 rng-5b67 2006 10.5  13.9  14.0   25
18 rng-5b67 2007 12.5  15.7  15.0   24
19 rng-5b67 2008 10.5  14.0  13.0   25
20 rng-5b67 2009 11.0  14.3  14.0   26
21 rng-5b67 2010  8.5  13.2  13.0   25
22 rng-5b67 2011 10.5  13.5  13.0   24
23 rng-5b67 2012  9.5  13.1  12.0   25
24 rng-5b67 2013  9.5  13.2  12.0   25
25 rng-5b67 2014 10.5  13.9  13.0   26
```

ROUNDNOSE GRENADIER (II)





SPURDOG, MALES (I)

Results of LFCOM analysis, Fri Mar 18 16:27:07 2016
Species = *Squalus acanthias*, stock = dgs_nea

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 116 cm
Growth parameter K = 0.1 1/year
Length at 50% maturity Lm50 = 64 cm
Length at 90% maturity Lm90 = 76.8 cm
Natural mortality of adults M = 0.1 1/y
Commercial fishing mortality F = 0.014 1/y
M/K (expected 1.0-2.0) M/K = 1
Comment: Data for males

Lopt, Lc_opt and L(F=M) based on Linf, M, K, F

Length at max cohort biomass Lopt = 87.2
Lc resulting in Lopt Lc_opt = 61.7
Mean length in catch if F=M L(F=M) = 84.2 cm

Lopt, Lc_opt and L(F=M) based on Linf

Length at max cohort biomass Lopt = 77.5 cm, assuming b ~ 3 and M/K ~ 1.5
Lc resulting in Lopt Lc_opt = 58.1 cm, if F ~ M
Lc resulting in Lopt Lc_opt = 64 cm, if F ~ 2 M
Mean length in catch if F=M L(F=M) = 80.2 cm

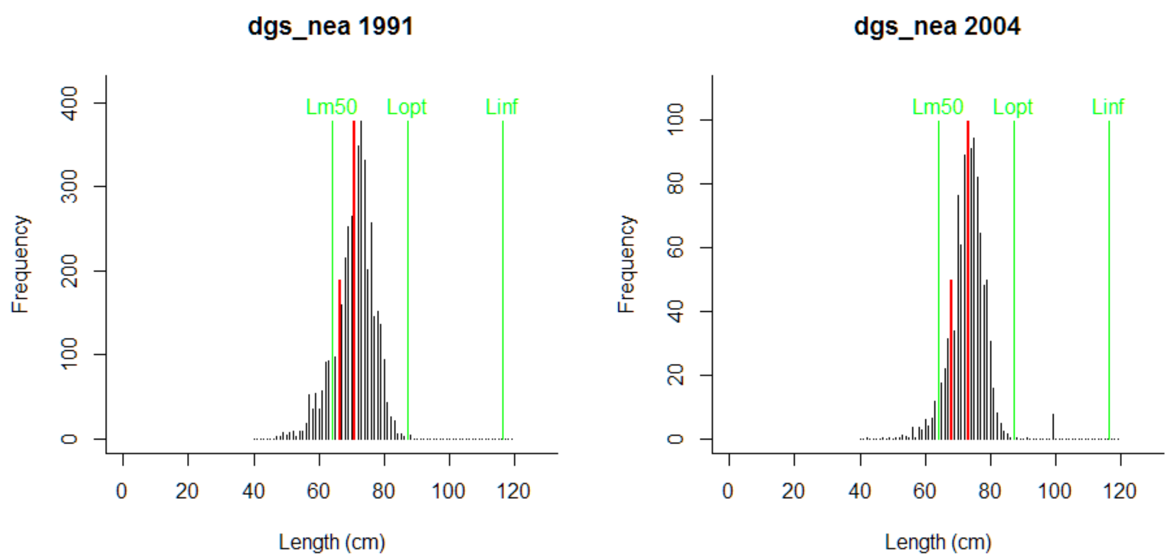
Observed Lc and Lmean in 2004

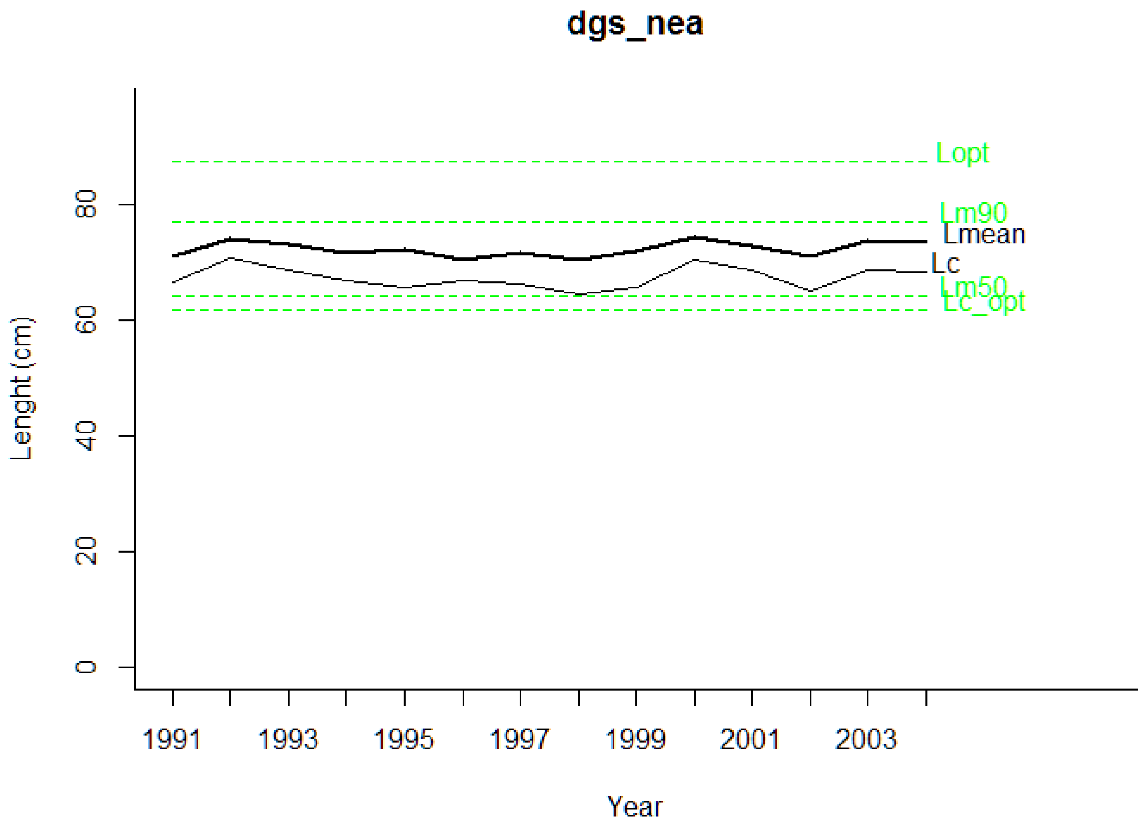
Mean length at first capture Lc = 68.2 cm
Mean length in catch Lmean = 73.2 cm

Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	dgs_nea	1991	66.5	70.9	73.0	88
2	dgs_nea	1992	70.5	74.0	74.7	92
3	dgs_nea	1993	68.5	73.0	73.0	88
4	dgs_nea	1994	66.9	71.6	73.0	96
5	dgs_nea	1995	65.4	72.1	73.3	87
6	dgs_nea	1996	66.8	70.5	72.7	88
7	dgs_nea	1997	66.0	71.6	72.3	91
8	dgs_nea	1998	64.3	70.2	73.0	100
9	dgs_nea	1999	65.7	71.7	73.0	108
10	dgs_nea	2000	70.3	74.1	75.0	100
11	dgs_nea	2001	68.5	72.8	74.0	94
12	dgs_nea	2002	65.0	70.8	74.0	94
13	dgs_nea	2003	68.4	73.6	73.3	97
14	dgs_nea	2004	68.2	73.2	74.0	99

SPURDOG, MALES (II)





SPURDOG, FEMALES (I)

Results of LFCOM analysis, Fri Mar 18 16:31:01 2016

Species = *Squalus acanthias*, stock = dgs-nea

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 116 cm

Growth parameter K = 0.1 1/year

Length at 50% maturity Lm50 = 80 cm

Length at 90% maturity Lm90 = 96 cm

Natural mortality of adults M = 0.1 1/y

Commercial fishing mortality F = 0.014 1/y

M/K (expected 1.0-2.0) M/K = 1

Comment: Data for females, Lm50 from assessment

Lopt, Lc_opt and L(F=M) based on Linf, M, K, F

Length at max cohort biomass Lopt = 87.2

Lc resulting in Lopt Lc_opt = 61.7

Mean length in catch if F=M L(F=M) = 83.3 cm

Lopt, Lc_opt and L(F=M) based on Linf

Length at max cohort biomass Lopt = 77.5 cm, assuming b ~ 3 and M/K ~ 1.5

Lc resulting in Lopt Lc_opt = 58.1 cm, if F ~ M

Lc resulting in Lopt Lc_opt = 64 cm, if F ~ 2 M

Mean length in catch if F=M L(F=M) = 79.2 cm

Observed Lc and Lmean in 2004

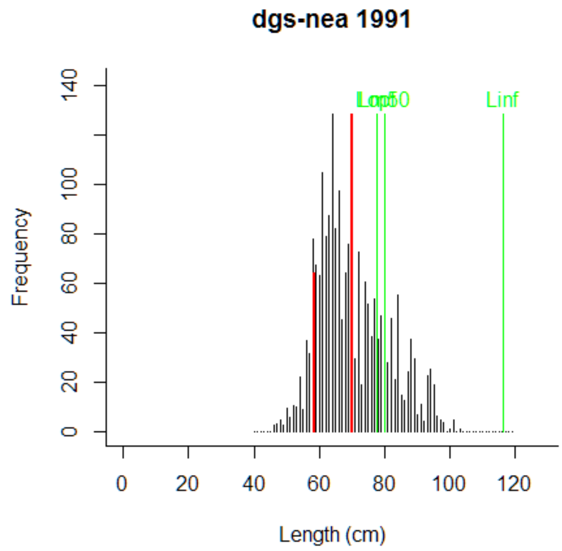
Mean length at first capture Lc = 66.8 cm

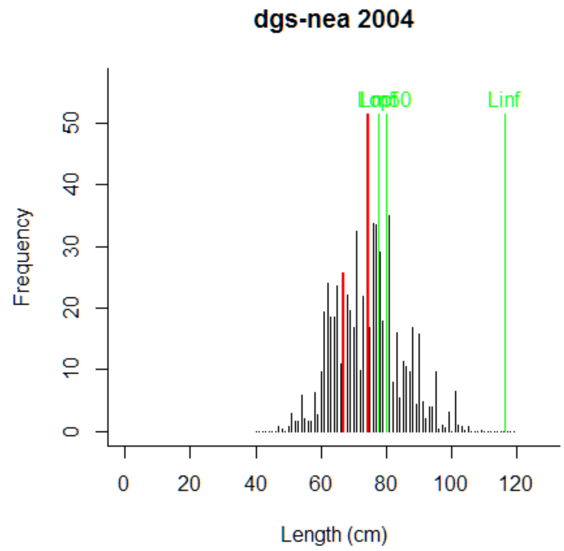
Mean length in catch Lmean = 74.5 cm

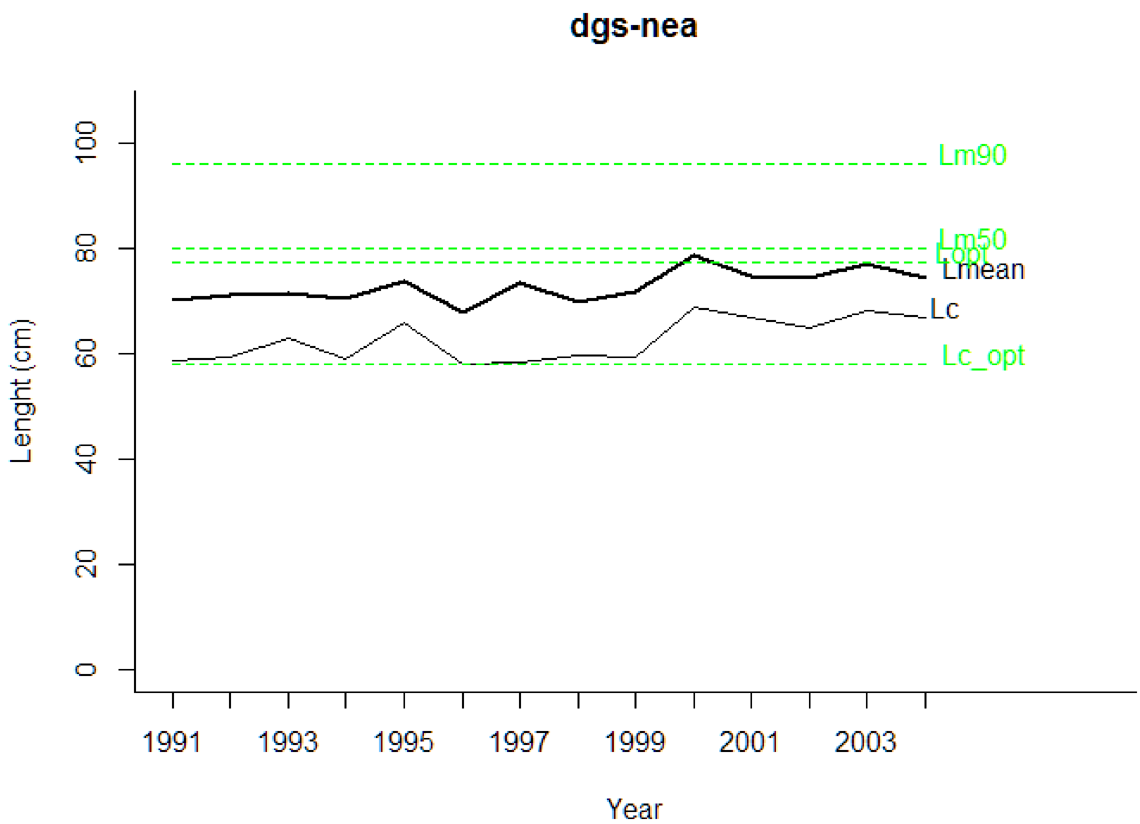
Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	dgs-nea	1991	58.6	70.2	63.7	105
2	dgs-nea	1992	59.3	71.1	67.7	109
3	dgs-nea	1993	62.9	71.4	69.3	108
4	dgs-nea	1994	59.0	70.6	68.0	107
5	dgs-nea	1995	65.9	73.8	78.3	107
6	dgs-nea	1996	58.0	67.9	62.0	103
7	dgs-nea	1997	58.5	73.4	64.7	105
8	dgs-nea	1998	59.6	69.9	66.3	108
9	dgs-nea	1999	59.2	71.8	66.7	110
10	dgs-nea	2000	69.0	78.9	78.3	107
11	dgs-nea	2001	66.9	74.9	74.3	107
12	dgs-nea	2002	65.0	74.4	80.0	107
13	dgs-nea	2003	68.1	77.0	75.7	107
14	dgs-nea	2004	66.8	74.5	77.0	111

SPURDOG, FEMALES (II)







ATLANTIC SWORDFISH (I)

Results of LFCOM analysis, Fri Mar 18 16:35:17 2016

Species = *Xiphias gladius*, stock = SWO_AS

External estimates of Linf, K, Lm50, Lm90, M, F

Asymptotic length Linf = 264 cm

Growth parameter K = 0.12 1/year

Length at 50% maturity Lm50 = 156 cm

Length at 90% maturity Lm90 = 187 cm

Natural mortality of adults M = 0.2 1/y

Commercial fishing mortality F = NA 1/y

M/K (expected 1.0-2.0) M/K = 1.67

Comment: M and Lm50 from assessment; Linf from lit.

Lopt, Lc_opt and L(F=M) based on Linf

Length at max cohort biomass Lopt = 176 cm, assuming b ~ 3 and M/K ~ 1.5

Lc resulting in Lopt Lc_opt = 132 cm, if F ~ M

Lc resulting in Lopt Lc_opt = 145 cm, if F ~ 2 M

Mean length in catch if F=M L(F=M) = 160 cm

Observed Lc and Lmean in 2003

Mean length at first capture Lc = 125 cm

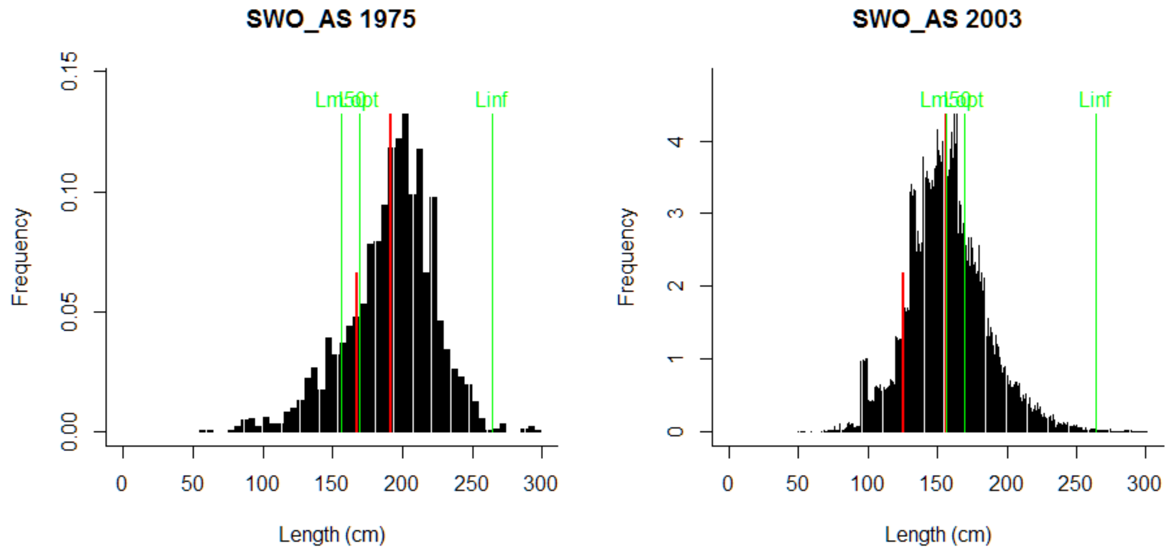
Mean length in catch Lmean = 157 cm

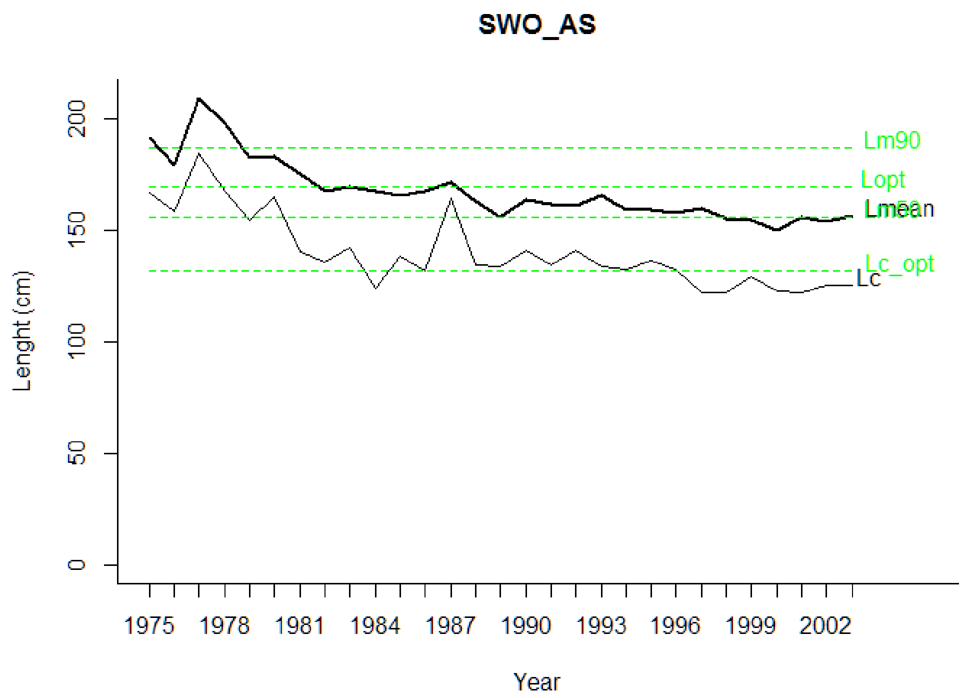
Time-series

	Stock	Year	Lc	Lmean	Lpeak	Lmax
1	SWO_AS	1975	167	192	202	299
2	SWO_AS	1976	159	179	182	259
3	SWO_AS	1977	184	209	212	269
4	SWO_AS	1978	167	198	195	299
5	SWO_AS	1979	155	183	177	293

6	SWO_AS	1980	165	183	196	295
7	SWO_AS	1981	140	175	183	295
8	SWO_AS	1982	136	167	157	295
9	SWO_AS	1983	142	170	152	284
10	SWO_AS	1984	124	168	148	290
11	SWO_AS	1985	138	166	168	301
12	SWO_AS	1986	132	168	166	301
13	SWO_AS	1987	164	172	189	295
14	SWO_AS	1988	134	163	167	295
15	SWO_AS	1989	134	156	165	301
16	SWO_AS	1990	141	164	171	301
17	SWO_AS	1991	134	161	163	301
18	SWO_AS	1992	141	161	158	301
19	SWO_AS	1993	134	166	157	301
20	SWO_AS	1994	133	159	157	301
21	SWO_AS	1995	136	159	158	301
22	SWO_AS	1996	132	158	156	301
23	SWO_AS	1997	122	160	162	299
24	SWO_AS	1998	122	155	158	301
25	SWO_AS	1999	129	155	148	301
26	SWO_AS	2000	122	150	144	299
27	SWO_AS	2001	122	156	149	301
28	SWO_AS	2002	125	154	144	299
29	SWO_AS	2003	125	157	159	301

ATLANTIC SWORDFISH (II)





Annex 7: Technical minutes from the Review Group of Practical methodology for delivering and MSFD GES assessment on D3

- RGIND3.3i
- Deadline: 14 April 2016
- Participants: Alain Biseau (Chair), José De Oliveira, Samuel Shephard and Sasa Raicevich. Inigo Martinez and Michala Ovens for ICES Secretariat.
- Review of WKIND3.3i

The report reads as a concise and sound piece of work. However the structure of the report is a bit uneven. Having a more consistent organization of the chapters (and presentation of indicator evaluation) would increase clarity.

It is not always clear if some parts are endorsed by the whole group or only presented the conclusion of the subgroup (named SG or SGSS or SG1...) who dealt with the concerned issue. On the other hand, in other parts (i.e. selectivity indicator) it is very clear that there were no consensus and both the pros and cons arguments are presented, which is found suitable. However, the executive summary did not provide the final conclusion of the group regarding the use of the selectivity indicators only for surveillance purposes.

The RG notes that the notation is sometimes rather poor or not consistent everywhere (e.g. L_{inf} vs. L_{∞}). Furthermore some indicators are not fully defined (e.g. L_{max_n} for which the value of n is not given), and some definitions are missing (e.g. mega-spawners). Some errors in results shown have been found (see in the detailed comments).

The report has met its terms of reference on the whole. However, the ToRs did ask for the drafting of a guidance document: although guidance is scattered throughout the report, it may have been usefully collated in one place (e.g. in an appendix). It must also be highlighted that the process did not include a proper "validation" of the indicators, but rather the calculation, evaluation and selection. Moreover, the relationship between state and pressure have been carried out only for a small set of indicators (i.e. relationship between indicators of genetic pressure and fishing mortality, par 5.2.3) while for other groups of indicators (SBI and Selectivity pattern) no assessment was carried out. Finally, correlation between indicators was not explored a part from those related to genetic effects.

All methods presented appear to be scientifically sound. However, there are some issues that are not fully developed / taken into account that should have been considered or mentioned. In particular, while the assessment of genetic effects considered both correlation between L_{m50} and L_{p50} indicators and between them and F, this assessment was lacking in the analysis of SBI and Selectivity pattern indicators. These analyses might have provided further rationale on the selection of indicators. The scoring of each indicator (at least the SBI) is welcomed. Although somewhat subjective, it is considered suitable to discard some low rated indicators.

The RG stressed that cautious should be taken while interpreting trends: if an increasing trend (or a higher level from TSBA) is better than a decreasing one, it does not necessarily mean a 'good' state (the reciprocal is also true).

The RG agrees on the choice of the selected indicators:

i) Size distribution in the stock: L_{95}, P_{mega} and $cpue_{mega}$. The RG notes that the group considered that only one (the best) should be chosen for GES assessment, without giving the answer. Furthermore, reference points still need to be investigated; TSBA is considered to be promising to provide the current state of the stock, although, sometimes only on a relative terms.

ii) Selectivity pattern of the fishery exploiting the stock: L_c and L_{mean}, used together but as surveillance indicator only.

iii) Genetic effects of exploitation on the species: L_{p50} (when enough data are available) or L_{50}. However, realistic reference points / targets are proved to be difficult to set. Furthermore, the RG shares the concern that the positive response to management actions may be very slow. Consequently and in the absence of targets, the RG felts that these type of indicators may not be used for GES assessment.

Finally, the RG shared WKIND's concern that assess C3.3 should not be considered for the 2018 GES assessment, since further development and validation are necessary.