WORKING GROUP ON INTERNATIONAL DEEP PELAGIC ECOSYSTEM SURVEYS (WGIDEEPS)

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Contents

i Executive summary

The Working Group on International Deep Pelagic Ecosystem Surveys (WGIDEEPS) plans and reports on the international hydroacoustic-trawl surveys on pelagic redfish in the Irminger and Norwegian seas.

The detailed planning of the international trawl/acoustic survey on pelagic redfish in the Irminger Sea and adjacent waters in June/July 2021 has been agreed by all participating countries. Prior to the meeting, the Icelandic delegation informed group members that Iceland will not participate in the June/July 2021 IDEEEPS. To cover the whole distribution area of pelagic redfish in the Irminger Sea a minimum three vessels are needed. The scope of the survey therefore needed to be altered and will be carried out in a similar manner as in 2015 where the emphasis is on covering the main distribution area of redfish in the north and south-eastern area (subareas A and B) and part of the south-western area (subarea E). Two vessels from Germany and Russia will participate in the survey and operate within an area of around 270 000 square nautical miles (NM^2) in the Irminger Sea to estimate the abundance and biomass of pelagic redfish (*Sebastes mentella*). In the depth zone that can be surveyed by hydroacoustic measurements, i.e. shallower than the deep-scattering layer (DSL; down to about 350 m), hydroacoustic measurements and identification trawls will be carried out. Within and below the DSL (down to about 950 m), redfish abundance will be estimated by trawls. The trawl method applied is the same as in the 2009-2018 surveys and is in line with the recommendation from ICES to study separately the stocks shallower and deeper than 500 m. As in past surveys, biological data will be collected from the redfish caught in the pelagic trawls, and hydrographical measurements will be taken on regular stations on the survey tracks.

Work on a more direct approach to biomass and abundance estimation was presented and discussed at the meeting, but no decision was taken on applying the new method for the estimation of biomass and abundance of the deep pelagic stock. Additionally, two alternative methods of standardizing the biomass index were presented and discussed, but no decision was taken on applying an alternative method in the index estimation.

It was recognized that the methods presented to the group should best be presented, discussed and tested for their applicability at a future benchmark of redfish stocks.

ii Expert group information

Expert group name	Working Group on International Deep Pelagic Ecosystem Surveys (WGIDEEPS)
Expert group cycle	Multiannual fixed term
Year cycle started	2020
Reporting year in cycle	2/3
Chair(s)	Hannes Höffle, Norway
	Matthias Bernreuther, Germany
Meeting venue(s) and dates	25-27 August 2020, Virtual meeting (4 participants)
	16-19 February 2021, Virtual meeting (6 participants)

1 Cancellation of the Icelandic participation and future of the survey in the Irminger Sea and adjacent water

In December 2020, the Freshwater and Marine Research Institute (MFRI) in Iceland informed the group that Iceland will not participate in the survey in June/July 2021. No specific reasons were given for the withdrawal.

It is the view of the Group that the withdrawal of Iceland from the international redfish survey in the Irminger Sea and adjacent waters is very unfortunate. No alternatives that could be arranged for compensating the corresponding loss of survey coverage at the time being. For this reason, the group decided to focus mainly on surveying pelagic redfish in areas where in previous surveys it has been observed to be most abundant, which is in the north and south-eastern part of the research area (subareas A and B), but also to cover part of the south-western area (subarea E), where in the past a relative high abundance of the shallow pelagic *S. mentella* has been observed.

With only two vessels participating in the survey in 2021, the quality of the survey is seriously hampered and it may also undermine any scientific advice that ICES may provide to national and international bodies.

The future of the pelagic redfish survey in the Irminger Sea and adjacent waters was briefly discussed during the meeting. It is clear to the group that both management bodies and individual nations consider the pelagic redfish research not a high priority. Cancellation of participation of individual nations is often with short notice which means it is impossible to compensate the corresponding loss of survey coverage. The group encourages participant nations and relevant institutes to discuss the importance and priority of pelagic redfish surveys in the Irminger Sea and adjacent waters and decide whether the surveys should be carried out in the future.

2 Planning of the international trawl/acoustic survey on redfish in the Irminger Sea and adjacent waters in June/July 2021

The survey manual for the survey conducted in the Irminger Sea and adjacent waters is published under the Series of ICES Survey Protocols (SISP) and describes in detail the planning of the survey (ICES, 2015). Specific issues that are revised before the survey are described in this section.

2.1 Vessels, timing and survey area

The main objective of this survey is the trawl-acoustic assessment of the pelagic redfish stocks in the Irminger Sea and adjacent waters in June/July 2021. The group agreed to continue to cover the area from 55°00′N to 65°30′N and from the 25°W in the east till western boundary to 50°W.

Below is the list of research vessels which will participate in the IDEEP survey in the Irminger Sea and adjacent waters in June/July 2021, time period engaged to the survey and approximate time and number of days in the field:

Name of the vessel	Country	Period	Approx. working period in the field	Days in field
Atlantida	Russia	6 June – 27 July	15 June – 16 July	32
Walther Herwig III	Germany	7 June – 11 July	~14 June – 4 July	20

The vessels will communicate daily via e-mail or telex or telephone. Information on the communication between vessels is given in Annex 2.

In Figure 1 and Table 1 in Annex 3 the planned survey tracks are displayed for each participating vessel.

“Atlantida” will cover the northeastern area (subarea A) completely and part of subarea B. “Walther Herwig III” will cover part of the southeastern area (subarea B) and part of the southwestern area (subarea E). The total length of the planned survey tracks is about 6,309 nautical miles (NM), divided between the vessels as follows: “Atlantida” 3,700 NM and “Walther Herwig III” 2,609 NM.

The cruise leaders of these vessels will apply for entry into the relevant EEZs by notifications to Greenland and Iceland. The operations in the NAFO Convention Area will be notified to NAFO by the German cruise leader.

2.2 Data exchange

Daily reporting between the vessels is performed using the data sheet given in Annex 2 of the survey manual (ICES, 2015). A deviation from this reporting scheme is the reporting of roundnose grenadier (*Coriphaenoides rupestris*). Catches of roundnose grenadier will be reported between the research vessels in the data sheet in Annex 2 (ICES, 2015) as additional columns or as an additional work sheet. Length of each individual grenadier will be reported with a precision of 1 mm (below) and weight with a precision of 1 g because usually small juvenile individuals are expected to be present in the catches. Maturity stage and stomach fullness will be recorded and otoliths and scales will also be collected.

2.3 Trawling

Russia's position regarding the stock structure of redfish in the Irminger Sea remains unchanged, i.e. that there is a single stock of *S. mentella* in that area. With that in view, Russia does not agree with the ICES advice splitting the stock into two nor with the recommendation to conduct stratified surveys dividing the water column arbitrarily into 0-500 and 500-1000 m depth intervals, which generally does not contribute to better quality of stock assessment.

However, recognizing the need to obtain more accurate abundance and biomass estimates, in the light of possible underestimation of the stock by the 2009 international TAS results, the Russian Federation agrees to conduct sampling in the international trawl and acoustic survey of *S. mentella* as described in the ICES Survey Protocol (ICES, 2015). However, Russia will not be able to agree with separate estimates for the stock distributing above 500 m and below 500 m.

If possible, the inflow of redfish into the trawl at the depth intervals described above should be estimated by a probe device mounted to the net.

2.4 Further Issues

2.4.1 Exchange of experts

Germany and Russia invited other participants to join their part of the survey. Due to staff limitation, the German survey partner will not be able to send a guest scientist from its labs onto the other vessel. The Russian Federation has expressed interest in the offer and communications have started, whether a participation is practically feasible due to the various Covid-19 restrictions.

2.4.2 Participation of further countries

The Group is again facing the problem of covering the entire survey area with only two vessels, resulting in a large spacing of survey tracks and trawl hauls and the geographical area of redfish not being covered completely. To improve the precision of the survey by increasing the density of the tracks and trawl stations, additional vessels should take part in the survey. The Group recommended as in 2005 that "at least four vessels should participate to allow a sufficiently dense coverage of the survey area and to permit an improvement in the quality of the derived abundance and biomass estimates. Thus, the efforts directed at involving other nations in the survey should be continued."

Notwithstanding the disappointing outcome of earlier attempts, the group will continue its efforts in involving further countries in the survey. The group also notes that other non-EU countries involved in the fishery should consider their participation in the survey.

The group considered it appropriate to approach NEAFC to get nations involved in the commercial fishery to participate in the surveys. This should be done through the ICES Secretariat with an official letter to NEAFC.

2.4.3 Time schedule for the survey report

The final reporting will take place during the next virtual WGIDEEPS meeting from 17–19 August 2021. To finalize the work in three days, the following plan will be followed:

As soon as the vessel has finished scrutinizing the acoustic data, after the survey tracks are finished, the data must be sent to the other participant. Not later than 1 August 2021, all data shall be sent via e-mail to the cruise leaders and co-chairs. The data shall be sent in the format described in Annexes 3 and 4 in the SISP manual (ICES, 2015) and all participants shall have a copy in an electronic format.

Russia will calculate the abundance estimation of the redfish within and deeper than the DSL, including writing of the material and methods, results and discussion.

Russia will work up the environmental data, including the drawing of graphs, writing of the material and methods, results and discussion.

Russia will calculate and finalize the acoustic data, including writing of the material and methods, results and discussion. Russia will also draw the cruise tracks and information on stations.

Germany will be responsible for writing about biological results, including writing of the material and methods, results and discussion.

All drafts must be sent to the WGIDEEPS co-chairs before 19 August 2021.

3 Evaluation of the calculation of biomass and abundance indices derived from the trawl method in the Irminger Sea.

Summary of the proposal by Iceland for the calculation of the survey index of deep pelagic redfish (Working document 1, Annex 5).

The method currently used to calculate biomass indices within and deeper than the Deep Scattering Layer (DSL) from the trawl data are based on a combination of standardized survey catches and the hydroacoustic data. A proportional relationship is assumed between trawl catch and acoustic values (s_A) during trawling in the shallower layer (0–350 m) where redfish can be acoustically identified. This relationship is used to predict acoustic values (s_A) for trawl catch in the deeper layer. That is, trawl catch indices are transformed into acoustic values (s_A) and then biomass is estimated in similar manner as biomass estimates based on acoustic measurements.

It was recognized by the group in 2017 (ICES, 2017) that the current approach used to estimate biomass in deeper layers, that is to translate trawl catch indices into acoustic energy (s_A), should be replaced by a more direct approach to biomass and abundance estimation, using swept volume estimates.

In this Working Document the approach proposed in 2017 (see Annex 3 in the 2017 ICES WGIDEEPS report) was tested. Results indicate that in relative terms the results are similar to the results obtained with the current method. Results are presented in Working Document 1.

Summary of the proposal by Russia for a standardization of biomass indices of the beaked redfish stock in the Irminger Sea (Working document 2, Annex 6).

During the international trawl-acoustic survey of the beaked redfish in the Irminger Sea, a gradually decrease in the research area is noted. There has been a rapid decrease in the survey area since 2015. The area covered by the survey was reducing from 420 thousand square miles in 2001 to 200 thousand square miles in 2015, what means that the survey area was reduced more than two times. In 2018, the research area was decreased to 103 thousand square miles. The interannual differences in the research area has a negative impact on the assessment.

Currently, surveys can be carried out only in a small part of the initial survey area due decrease in the number of countries participating in the survey. It can lead to incorrect conclusions about the state of the stock. An analysis of the impact of decrease in the survey area on the stock assessment was presented at the NWWG (Khlivnoy, Astakhov, Gavrilik, Popov, 2019).

In 2019, following the submission of information on the difference in the survey area and impact of decrease in research area on stock assessment, the North-Western Working Group (NWWG) recommended that the compilation of the survey indices should be reviewed at WGIDEEPS.

In WD 2 (see Annex 6), two alternative derivations of a biomass index were presented and discussed at WGIDEEPS 2021. The aim of that work was a standardization of indices to exclude the effect of annual changes in the size of surveyed area. Two methods of deriving indices were presented in WD2:

1. Biomass index was estimated in similar fashion described as has been done since 1999 but restricted in the standard area, which was covered by all surveys (Subarea A). In the future, the standard area can be increased with including the part of Subareas B and E covered by all the surveys. Standardized indices were estimated for three layers: above the DSL, in the DSL above 500 m and in the layer deeper than 500 m. Biomass estimates in Subarea A are found in Tables 7 and 9 in the 2018 WGIDEEPS report (ICES, 2018) and in Tables 10.2.1, 10.2.2a and 10.2.2b the 2004 NWWG report (ICES, 2004).

2. Density index (t/nmi2) was derived from the total annual survey biomass divided by the total annual survey area covered. Data on the stock biomass and the survey area were taken from the reports of the 2018 WGIDEEPS (ICES, 2018) and 2014 NWWG (ICES, 2014).

The analysis showed that generally there is a similarity in the dynamics of the non-standardized indices (assessed the entire survey area) and standardized indices (assessed by both methods). However, an increase in the research area leads to an increase in the calculated biomass index and in value of differences between those indices. WD2 concludes that standardization of indices reduces the impact of interannual differences in the survey area and propose used that indices to stock assessment.

During the working group meeting this proposal for calculation of biomass indices was discussed. It was recognized that this method should best be discussed and tested for its applicability at a future benchmark of this stock.

NOTE: The methods presented here were discussed at the NWWG meeting in April 2019. There was and is no consensus within the NWWG group on how to derive survey biomass index used in the assessment. NWWG recommended that the compilation of the survey indices should be reviewed at WGIDEEPS. During the WGIDEEPS meeting in 2021, the methods presented above were introduced to the group, but no consensus was reached.

The effect of the survey area coverage in 2015 and 2018 surveys, and the appropriateness of the biomass indices, was investigated at the 2019 meeting. The most extensive coverage was in 2001 (440 000 nmi^2) which most likely comprise most of the stock distribution. In 2003–2013 the area covered by the survey was around 350 000 nmi^2 and covered the main part distribution of the stock. However, in the last two surveys the area covered was reduced. In the 2015 survey, when the survey area was reduced to 201 000 nmi^2, attempts were made to ensure that the distribution of the deep pelagic stock was covered by surveying areas A and B. Unfortunately, due to unforeseen circumstances in 2018 survey was unable to cover area B, reducing the survey area to area A with a coverage of 103 000 nmi^2. Therefore in 2018, the total area of coverage was reduced twofold compared with the previous survey area in 2015.

4 Extent of the deep scattering layer in the deep pelagic ecosystem survey 2019 in the Norwegian Sea

In the open Norwegian Sea, the Deep Scattering Layer (DSL), formed by a high density of mesopelagic organisms below 200 m depth, can be very pronounced. The DSL is part of the mesopelagic zone. Many of these organisms perform characteristic diurnal vertical migrations, rising to the epipelagic zone during the night. However, the long daylight length during the survey period (11 - 28 August in 2019) largely prevents to observe such migrations.

Like for earlier surveys, the acoustic energy reflected by organism in the two zones (meso- and epipelagic) was registered as an integrated abundance measure, following the method of Siegelman-Charbit and Planque (2016). Here, the biological signals in the two zones are categorized as separate acoustic categories. Whereas the lower boundary of the mesopelagic zone was specified as 800 m, the upper boundary varied between 400 m and 200 m depending on the extent of the DSL. The biological signal above this upper mesopelagic boundary was categorized as the epipelagic zone. As this is a deep sea pelagic survey, areas with a bottom depth of less than 400 m were not considered, which applies to small portions of the survey track above the shelf break.

In 2019, the calibration of the echosounder was problematic and the reflected acoustic energy, measured as surface backscattering strength (s_A), is therefore highly uncertain. However, for the ratio of the epi- and mesopelagic zones this is irrelevant, as the potential error is the same for both zones. For the mesopelagic zone the mean s_A is 105 $m^2 n.mi.^{-2}$ and for the epipelagic zone it is 25 $m^2 n.mi.^{-2}$, resulting in a ratio of mesopelagic: epipelagic = 4.2 : 1. The average s_A values are for both zones lower than in earlier surveys, but the trend of an increasing proportion of biomass in the mesopelagic zone continues (Table 4.1, Figure 4.1).

Table 4.1: s_A values in the epi- and mesopelagic zones ($m^2 n.mi.^{-2}$) and the ration between them. Data for 2013 was not available at the time of the meeting and will be added in the report for the next meeting.

	2008	2009	2013	2016	2019
Epipelagic	116	71	NA	53	25
Mesopelagic	133	140	NA	184	105
Meso:Epi	1.2	2.0	NA	3.5	4.2

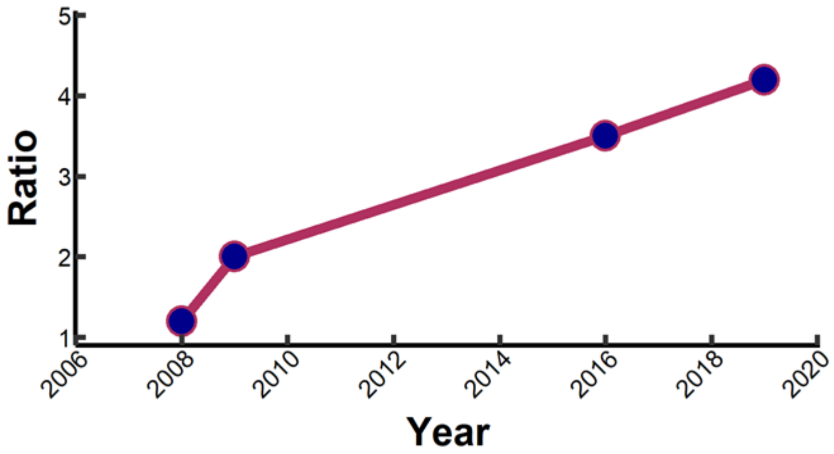

Figure 4.1: Development of the Meso:Epi proportion over the survey series. Data for 2013 was not available at the time of the meeting and will be added in the report for the next meeting.

5 ICES Acoustic Data Portal

One of the recurring ToRs of WGIDEEPS is the finalization of the transfer of trawl survey data from international deep pelagic ecosystem surveys coordinated by the group to ICES DATRAS databases. The group has so far not been successful in completing this task. At this year´s planning meeting, Hjalte Parner from ICES Data Centre presented the ICES Acoustic Data Portal. In the course of the presentation, the group recognized the possibilities of that portal in hosting not only the hydroacoustic data, but also the trawl and hydrographic data. The WG discussed the switch from uploading the trawl data to DATRAS to start uploading the hydroacoustic, trawl and hydrographic data to the Acoustic Data Portal. However, a decision has not been made and will be discussed in the upcoming working group meetings.

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Annex 1: List of participants

Name	Institute	Country (of institute)	Email
Alexey Astakhov	Atlantic Branch of the Russian Federal Research Institute of Fisheries and Oceanography (AtlantNIRO)	Russian Federation	astakhov@atlantniro.ru
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Hannes Höffle (co-chair)	Institute of Marine Research	Norway	hannes.hoffle@hi.no
Vladimir Khlivnoy	Polar Branch of the Russian Federal Research Institute of Fisheries and Oceanography (PINRO named after N.M. Knipovich)	Russian Federation	khlivn@pinro.ru
Kristján Kristinsson	Marine and Freshwater Research Institute	Iceland	kristjan.kristinsson@hafogvatn.is
Aleksei Rolskii	Polar Branch of the Russian Federal Research Institute of Fisheries and Oceanography (PINRO named after N.M. Knipovich)	Russian Federation	rolskiy@pinro.ru

Annex 2: Information on communication between vessels for the Irminger Sea survey

RV "Atlantida" (Russia) Call sign: UALU Inmarsat C IMN: 427301487 E-mail: atlantniro@marsatmail.com
RV "Walther Herwig III" (Germany) Call sign: DBFR Telephone: 00870 763936068 Telefax: 00870 763936070 or 00870 600365043 Data: 00870 600365042 Inmarsat C (Telex): +581 421121550 e-mail: matthias.bernreuther@thuenen.de

Annex 3: Cruise tracks

Table 1. Agreed preliminary cruise tracks for the international survey on redfish in June/July 2021 (Decimal positions).

RV Atlantida			RV Walther Herwig III		
Latitude (North)	**Longitude (West)**	**Distance**	**Latitude (North)**	**Longitude (West)**	**Distance**
64.33	28.75	Start	58.83	33.75	Start
64.33	35.00	162	58.83	48.50	457
63.58	35.58	48	57.83	48.50	60
63.58	28.00	202	57.83	42.00	208
63.08	27.20	37	58.25	41.50	30
63.08	38.00	293	58.25	34.00	237
62.58	39.00	41	57.75	34.67	37
62.58	27.00	331	57.75	40.50	187
62.08	27.50	33	57.25	40.50	30
62.08	39.58	339	57.25	35.33	168
61.58	40.17	34	56.50	36.25	54
61.58	29.25	311	56.50	41.50	174
61.08	28.50	37	56.83	42.00	26
61.08	41.00	362	56.83	48.50	213
60.58	41.25	31	55.83	48.00	62
60.58	35.42	172	55.83	42.00	202
62.25	33.50	114	55.83	42.00	0
59.67	26.25	262	55.50	41.58	24
60.58	28.00	76	55.50	35.50	207
60.58	33.00	147	58.75	31.50	234
60.08	33.58	35			
60.08	41.58	239			
59.58	41.83	31			
59.58	30.50	344			

Total sailing (NM):	**3700**	**2609**
Days in the field:	**32**	**20**
Average sailing per day (NM/day):	**116**	**130**

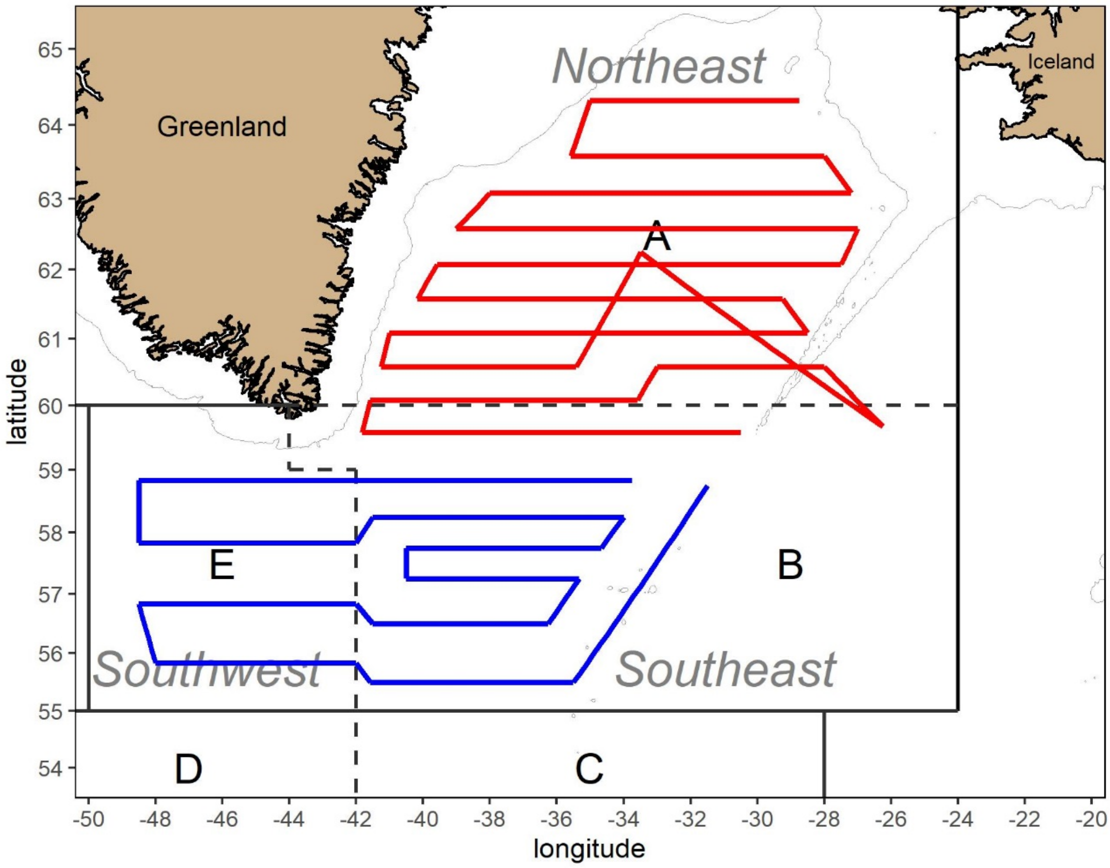

Figure 1. Preliminary cruise tracks of the international survey on redfish in June/July 2021. Red: RV "Atlantida". Blue: RV "Walther Herwig III".

Annex 4: Terms of Reference for next meeting.

The next meeting of the group will be from **17-19 August 2021**. It will be **virtual meeting (WebEx)**.

ToR	Description	Background	Science plan codes	Duration	Expected Deliverables
e	Report on the outcome of the Irminger Sea survey	a) Provide sound, credible, timely, peer-reviewed, and integrated scientific advice on fishery management and the protection of the marine environment. b) Redfish indices are being used by assessment working groups.	3.1, 3.2	Year 2 (August meeting)	WGIDEEPS 2021 – 2 report chapter 1 September 2021 SCICOM

Annex 5: Working Document 1

Proposed method for the calculation of biomass and abundance indices derived from the trawl method in the Irminger Sea

Kristján Kristinsson

The method currently used to calculate biomass indices within and deeper than Deep Scattering Layer (DSL) from the trawl data are based on a combination of standardized survey catches and the hydroacoustic data. A proportional relationship is assumed between trawl catch and acoustic values (s_A) during trawling in the shallower layer (0–350 m) where redfish can be acoustically identified. This relationship is used to predict acoustic values (s_A) for trawl catch in the deeper layer. That is, trawl catch indices are transformed into acoustic values (s_A) and then biomass is estimated in similar manner as biomass estimates based on acoustic measurements (Kristinsson, 2015).

It was recognized by the group that the current approach used to estimate biomass in deeper layers, that is to translate trawl catch indices into acoustic energy (s_A), should be replaced by a more direct approach to biomass and abundance estimation, using swept volume estimates.

The group recommends testing the following approach (see Annex 3 in the 2017 ICES WGIDEEP report):

1. Convert s_A from acoustic registrations of individual trawls into estimated biomass per trawl haul. This can be done as follows:

$$B_{ac} = \frac{s_A}{\overline{\delta}} \cdot \overline{W} \cdot A_{tr}$$

with

$$\overline{\delta} = 4\pi \cdot 10^{-k/10} \cdot \overline{L^2}$$ (mean acoustic cross section for individual redfish)

$$\overline{L^2} = \frac{1}{n}\sum_{j=1}^{n} L_j^2$$ (mean square length of redfish in cm^2)

$$\overline{W} = \frac{1}{n}\sum_{j=1}^{n} W_j$$ (mean redfish individual weight)

$A=D \times H$ (horizontal area covered by trawl)

where

L_j = length of redfish j in cm, j=1,2,…,n

W_j = weight of redfish j

n = number of redfish

D = trawl distance (in NM)

H = horizontal trawl opening (in NM)

K = parameter in TS equation TS = 20 log L−k

2. Compare the calculated acoustic estimates, $B_{ac,j}$, with the corresponding trawl catches, $B_{tr,j}$, and estimate the trawl-acoustic conversion factor, q:

$$\hat{q} = \frac{\sum_{j=1}^{n} B_{tr,j}}{\sum_{j=1}^{n} B_{ac,j}}$$

where n is the number of trawl hauls.

This can be performed for distinct strata, years, vessels, etc. Alternatively, q could be estimated using linear mixed effect models to derive stratum-, year-, or vessel- effects from the whole dataset.

3. For the deeper layer with only trawl estimates, calculate the trawl based biomass density of redfish (e.g. tonne/NM^3), ρ_j , for each trawl haul:

$$\rho_j = \sum_{j=1}^{n} \frac{B_j}{V_j}$$

with

$$V_j = D_j \times H_j \times \Delta Z_j$$

where D_j is trawled distance, H_j is horizontal opening and ΔZ_j is vertical opening in NM-units (1m = 1/1852 NM), and B_j is the total redfish biomass in the trawl catch. The total trawl based biomass in a stratum, s, is then estimated as

$$\hat{B}_{tr,s} = \left(\frac{1}{n_s} \sum_{j=1}^{n_s} \rho_j \right) \cdot \frac{V_s}{q_s}, \quad s = 1, 2, \ldots, m$$

with

$$V_s = A_s \times \Delta Z_s$$

where A_s[NM2] is the area and ΔZ_s[NM²] is the vertical extension of stratum s and m is the total number of distinct strata. Assuming independent density estimates and stationary conditions within the stratum, the variance of $\hat{B}_{tr,s}$ can be estimated as follows:

$$\hat{\sigma}_s^2 = \hat{\text{var}}(\rho_j) \cdot \frac{V_s^2}{n_j \cdot \hat{q}_s^2}$$

The total biomass, B, and its variance, Vs, are estimated by accumulating over the m strata:

$$\hat{B} = \sum_{s=1}^{m} \hat{B}_{tr,s}$$

$$\hat{V}_{\hat{B}} = \hat{\text{var}}\left(\hat{B}\right) = \sum_{s=1}^{m} \hat{\sigma}_s^2$$

with estimated cv

$$\hat{cv} = \frac{\sqrt{\hat{V}_{\hat{B}}}}{\hat{B}}$$

The utility of the above approach is critically dependent on the appropriateness of the approach to estimate the trawl-acoustic conversion factor q. This factor can be defined as the expected ratio between the number of fish caught by the trawl and the number of fish acoustically observed in the same volume at the time of acoustic registration. This is in general different from the trawl catchability defined as the expected ratio of trawl catch to the number of fish that would have been present in the covered volume at the same time as trawling, if the fish was not disturbed by any trawling activity. The trawl-acoustic conversion factor as well as the trawl catchability may depend on several factors such as fish length, fish age, light and vibrations induced by the vessel or fishing gear.

In the present case, the echosounder is mounted on the hull, and fish are typically detected by acoustics about 1 km ahead of the trawl and in the order of 10 min before the trawl covers the same volume as the acoustics which gives enough time between registration and trawling for the fish density to change. This will easily cause a trawl-acoustic conversion factor to be different from one, even in the case when the trawl catchability equals one. In addition, it is difficult to be sure that the trawl-acoustic conversion factor (as well as the trawl catchability) is not substantially different below and above the mesopelagic layer.

Ideally the estimated trawl-acoustic conversation factors should not vary too much between trawl hauls. A way to examine this is to bootstrap trawl hauls many times, with the number of bootstraps draw equal to the number of trawl hauls in each simulation. For each simulation, a new value of q is estimated, and if the cv of these simulated values is considerably lower than one, this is a good sign of strong proportionality between acoustic and trawl-based estimates. If one assumes the acoustic estimate to be close to real fish density in the ocean, and that the fish density is close to stationary on a time-scale equal to the time-lag of the trawl compared to the acoustics, the trawl-acoustic conversion coefficient q will be a reasonable proxy for trawl catchability. In this case a value considerably larger than one will indicate a strong herding effect, while a value close to zero will indicate a strong escaping behaviour. Both outcomes may indicate that the trawl is too small to provide reliable abundance and biomass estimates.

Applying the method with current data

Calculating q, the catchability. Linear mixed effect model is used to derive stratum-, year-, or vessel- effects from the whole dataset.

1. Convert s_A from acoustic registrations of individual trawls into estimated biomass per trawl haul

   - Mean square length of redfish in cm^2 per station
   - Mean individual weight in kg per station:

2. Compare the calculated acoustic estimates, $B_{ac,j}$, with the corresponding trawl catches, $B_{tr,j}$, and estimate the trawl-acoustic conversion factor, q

   Calculate q. Robust linear regression used:

```
### RLS
library(MASS)

y <- rlm(q ~  as.factor(Year) + as.factor(Country) + Subarea, data=st2,
na.action = na.omit)

summary(y)

##

## Call: rlm(formula = q ~ as.factor(Year) + as.factor(Country) +
Subarea,

##     data = st2, na.action = na.omit)

## Residuals:

##      Min       1Q    Median       3Q      Max

## -0.39760 -0.12991 -0.01117  0.12865  1.56754

##

## Coefficients:

##                       Value   Std. Error t value

## (Intercept)            0.1899  0.0757     2.5103

## as.factor(Year)2005    0.1192  0.0617     1.9327

## as.factor(Year)2007    0.1558  0.0670     2.3255

## as.factor(Year)2009    0.1567  0.0880     1.7809
```

```
## as.factor(Year)2011   0.0592  0.0632     0.9368
## as.factor(Year)2013   0.0680  0.0749     0.9074
## as.factor(Year)2015  -0.0559  0.1074    -0.5203
## as.factor(Year)2018   0.1658  0.0897     1.8474
## as.factor(Country)46 -0.0713  0.0561    -1.2703
## as.factor(Country)90 -0.1698  0.0606    -2.8045
## SubareaB              0.0550  0.0545     1.0107
## SubareaC             -0.0018  0.1399    -0.0128
## SubareaD              0.1005  0.0808     1.2437
## SubareaE              0.1462  0.0606     2.4107
## SubareaF             -0.0870  0.1668    -0.5216
##
## Residual standard error: 0.1914 on 128 degrees of freedom
```

From `rls`, estimated $\hat{q} = 0.1899$.

In this exercise all Type 1 tows are included, except the tows conducted in 1999 (relationship between s_A and kg/nm is assumed to be linear) and 2003 (not scrutinized). Robust linear regression is used since it is a compromise between excluding points (outliers or extreme values) entirely from the analysis (which has been done in the current method) and including all the data points and treating all of them equally in OLS regression (outliers which can influence the results). The idea of robust regression is to weigh the observations differently based on how well behaved these observations are. Roughly speaking, it is a form of weighted and re-weighted least squares regression.

For the deeper layer with only trawl estimates, calculate the trawl-based biomass density of redfish (e.g. tonne/NM3) for each trawl haul

Here, the 2005 and 2007 surveys are included. However, depth range of the trawling in these surveys were different. Here, the depth range is adjusted to 550-900 m (depth range was 350-950 m conducted in four steps), similar depth range as in other years. This is just an arbitrary way to include the 2005 and 2007 surveys.

Table 2.1: Biomass estimates (tonnes) of deep pelagic beaked redfish (500-950 m depth) by sub-areas in the Irminger Sea and adjacent waters 1999-2018.							
Year	**A**	**B**	**C**	**D**	**E**	**F**	**Total**
1999	257577	188301	14361	13043	18210	NA	491493
2001	213558	117693	5464	21987	19591	8057	386350
2003	97517	53022	18099	23403	19275	96	211411
2005	72374	58670	570	18440	47525	1515	199094
2007	83186	69964	330	4628	35162	3027	196298
2009	98675	57093	NA	4820	27969	NA	188557
2011	101498	31281	0	589	14780	48	148198
2013	61359	23948	NA	1271	5000	0	91578
2015	64170	21093	NA	NA	NA	NA	85264
2018	41744	NA	NA	NA	NA	NA	41744

The results show, large biomass declines over the period, both total biomass and biomass in Subarea A, the main distribution area of the stock.

3. Comparison of results with current method and kg/nm (scaled with area size covered)

- **All areas combined**

The problem here is that not all areas have been covered in some years. In 2018, only Subarea A was covered. The 2018 estimate was scaled to the area of the 2015 survey by the proportion of biomass found outside the 2018 survey area.

Table 2.2: Current biomass estimates (tonnes) of deep pelagic beaked redfish (500-950 m depth) by sub-areas in the Irminger Sea and adjacent waters 1999-2018. Zero values indicate that the area was not covered.							
Year	**A**	**B**	**C**	**D**	**E**	**F**	**Total**
1999	277000	568000	12000	27000	52000	0	935000
2001	497000	316000	28000	79000	64000	18000	1001000
2003	476000	142000	20000	13000	27000	0	678000
2005	221000	95000	0	8000	65000	3000	392000
2007	276000	166000	1000	5000	62000	11000	522000
2009	291000	121000	0	8000	37000	1000	458000
2011	342000	112000	0	1000	18000	0	474000

2013	193000	75000	0	2000	10000	0	280000
2015	153000	43000	0	0	0	0	196000
2018	130000	0	0	0	0	0	130000

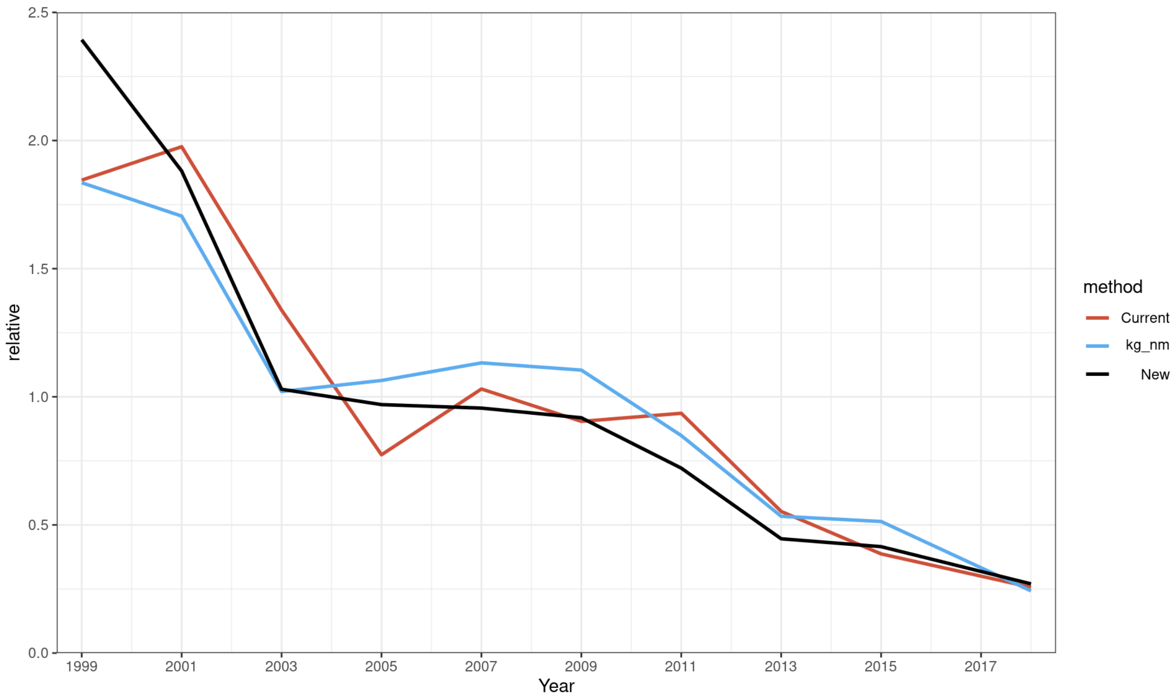

Figure 2.1: Comparison of results in relative term. Value for 2018 raised by 24.7%.

- **Only Subareas A and B**

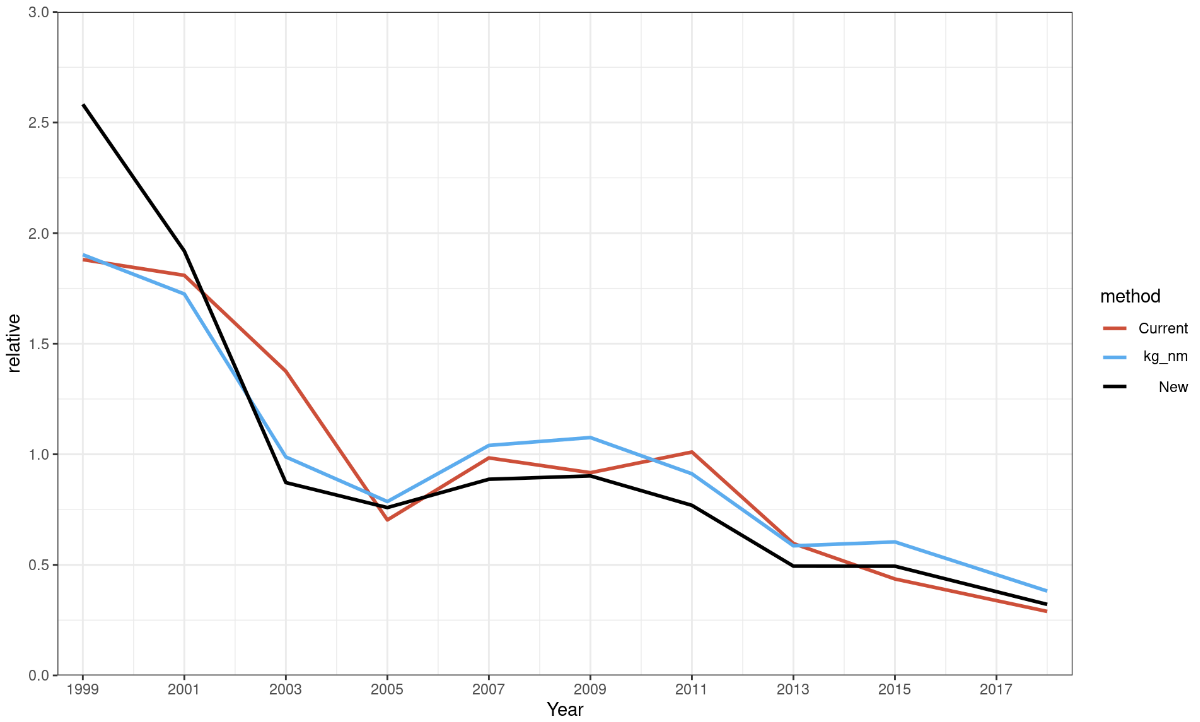

Figure 2.2: Comparison of results in relative term for subareas A and B. Value for 2018 raised by 24.7%.

In relative terms, there is little difference in the results and the perception of the stock. The main difference is that the 1999 estimate is higher in the new method compared to the current method.

Variance

To be done.

Next Step

The next step is to apply these estimates to the GADGET model. It is, however, highly likely that the new method will not change anything regarding the stock assessment.

To include any new methods in calculation of the survey index, the stock needs to be benchmarked. The proposed method is though much simpler than current method used to derive abundance and biomass estimates of the deep pelagic stock.

Annex 6: Working Document 2

The Working Group on International Deep Pelagic Ecosystem Surveys (WGIDEEPS)

Working Document 2

V.N. Khlivnoy, A.Yu. Astakhov

Standardization of biomass indices of the beaked redfish stock in the Irminger Sea

Substantiation of the need to refine the assessment

During the international trawl-acoustic survey of the beaked redfish in the Irminger Sea, a decrease in the research area is noted. The survey area was gradually reducing from 420 thousand square miles in 2001 to 200 thousand square miles in 2015, what means that the survey area was reduced more than two times (Figure 1). In 2018, the survey area was also reduced twofold compared with the previous survey in 2015 and amounted to 103 thousand square miles (Figure 1).

The situation has worsened in recent years when the number of vessels involved in the International Trawl-Acoustic Survey decreased as a result of a decrease in the number of countries participating in the survey. Currently, surveys can be carried out only in a small part of the initial survey area, leading to incorrect conclusions about the state of the stock.

Data, obtained in surveys of maximum coverage, indicated that a significant part of the stock was distributed in areas, where no surveys were conducted in recent years (Figure 1). In 2021 (survey area is 420 thousand square miles) and in 2005 (survey area is 386 thousand square miles), about 19% of the total part of the stock, distributed in the layer deeper than 500 m, were estimated at survey sites located outside A and B areas. Subsequently, as the water area of the International Trawl-Acoustic Survey decreased, the share of the stock, estimated outside these areas, decreased and amounted to less than 5% in 2011 (survey area is 343 thousand square miles) and in 2013 (survey area is 340 thousand square miles) (ICES, 2018a , ICES, 2019). In 2015 and 2018, these Subareas accounted for 100 % of the estimated biomass, as surveys were carried out only in Subareas A and B. At the same time, even in the years with the maximum water area covered by the survey, the stock was not fully estimated, since the stock distribution limit was not reached. As a result of the reduction in the survey area, the stock of pelagic redfish *S. mentella* in the Irminger Sea is currently estimated within only a small part of the original study area, leading to incorrect conclusions about the state of the stock. An increase in the research area leads to an increase in the calculated biomass index and a decrease in the water area leads to its decrease. There is a high probability that the indices, used in the assessment, reflect the change in the survey area to a greater extent than the dynamics of the stock.

Under these conditions it becomes impossible to use the old method of calculating the indices based on the comparison of data obtained in the area covered by the survey in each separate year. The indices, calculated for survey areas of different coverage, are not comparable and do not reflect the real change in biomass. Indexes are used to set up an analytical model for assessing the state of the stock and this cause erroneous calculation. Therefore, the use of these indices for stock status assessing is incorrect. Analysis of impact of decrease in the survey area on the stock assessment was presented at the NWWG (Khlivnoy, Astakhov, Gavrilik, Popov, 2019).

In 2019, following the submission of information on the difference in the survey area and impact of decrease in research area on stock assessment, the North-Western Working Group recommended revising the calculation of the Irminger beaked redfish stock biomass indices by the ICES WG on International Deep Pelagic Ecosystem Surveys (WGIDEEPS).

Taking into account the above, in order to obtain a reliable assessment of the stock state, it seems appropriate to switch over to the methodology of assessing the biomass indices of the beaked redfish stock smoothing over the interannual changes in the survey area. To do this, you need to standardize the indexes.

Data and methods

To exclude the influence of interannual changes in the survey area, the indices were standardized by two methods:

a) Indices were determined by the biomass of the beaked redfish stock in the standard area, which was covered by the survey in all years (method A).

b) Indices were calculated by the biomass of the stock per unit area covered by the survey (method B).

This working document provides standardized indices derived from the International Trawl-Acoustic Survey of pelagic redfish conducted in the Irminger Sea in 1999-2018. Previously, the methodology of index standardization was presented at the ICES North-Western Working Group (Khlivnoy, Astakhov, Gavrilik, Popov, 2019).

Determination of indices by stock biomass in a standard area, which was covered by survey during all years of study (method A).

In order to remove the effect of interannual changes in the area covered by the survey, area-standardized indices of the beaked redfish stock biomass were used. For this purpose, a standard area was used, which was covered by survey in all years of survey. The survey area is divided into six geographic strata (Subareas): A, B, C, D, E and F. In 2015, due to participation of only two vessels in the survey, it was decided to cover only Subareas A and B. At the same time, the Subarea B was only partially covered by the survey (ICES, 2015). In 2018, only Subarea A was covered by the survey (Figure 1). Until 2015, the research area was also not permanent. During all the International Trawl-Acoustic Surveys, only Subarea A was fully covered, so it was chosen as the standard area.

Determination of the biomass indices in the standard area was conducted by analogy with the calculations previously performed by ICES, which were carried out with full coverage of the survey areas. Calculations were made in accordance with the adopted ICES guideline (Mamylov, 1999), which has been used for the International Trawl-Acoustic Survey since 1999, but the data obtained in the area selected as standard (Subarea A) were used (Figure 1).

In the future, the standard area can be increased by obtaining a representative data for other areas. For example, the standard area can include the part of Subareas B and E that was covered by all the surveys.

During the survey, the stock assessment is performed separately in three layers: above the deep-scattering layer (DSL), in the deep-scattering layer above 500 m and deeper than 500 m. This is due to the differences in the sound transmitting properties of these layers. Subsequently, these data are combined depending on the interpretation. For the layer above the DSL, an acoustic estimation of the beaked redfish biomass indices is used. For deeper layers, calculations are performed using trawl data. For 2005 and 2007, within the WG on summarizing the results of International Trawl-Acoustic Survey, the indices were initially evaluated for only two layers: above 350 m and below 350 m. In 2014, the data from these two surveys were recalculated with the allocation of three layers and presented in the report of the North-West Working Group (ICES, 2014). However, this report provided information for a range of depths covering the deep-scattering layer up to 500 m (Layer 2) without division by area. In this regard, data on this layer for Subarea A for 2005 and 2007 are not available. To clarify the index estimates, the data for 2005 and 2007, divided by areas, should be presented and included in the report of the North-West Working Group.

Currently, in ICES, the biomass for two layers: in the DSL up to 500 m and above the DSL is combined into the shallow-water component of the beaked redfish stock. Biomass, estimated in the layer below DSL, is considered to correspond to the deep sea component. Combining of data, obtained from all layers, can show the overall biomass index of pelagic redfish in the Irminger Sea.

The indices were standardized using data on stock biomass in layers given in the reports of ICES WG on summarizing the results of International Trawl-Acoustic Survey WGIDEEPS (ICES, 2018) and North-West Working Group (NWWG) 2018 (ICES. 2018a). To obtain detailed information for Subarea A for the period up to 2005, the data provided in the 2004 NWWG report (ICES. 2004) were used.

Calculation of indices per unit area covered by the survey (method B). In practice, for many trawl surveys, average catch per trawl or per unit area covered by the survey is used to calculate the indices of biomass and stock abundance. Similarly, to remove the influence of differences in the area covered by the International Trawl-Acoustic Survey of redfish in the Irminger Sea, the biomass indices can also be recalculated per unit area covered by the survey.

Area normalization was performed for all three layers: above the deep-scattering layer, in the deep-scattering layer above 500 m and in the layer deeper than 500 m. Standardized indices are obtained in accordance with formula (1) by dividing the biomass of the stock, estimated over the entire survey area, by its area.

$$I(y) = \frac{\mathbf{B(y)}}{\mathbf{S(y)}}$$, where (1)

I(y) - area-standardized biomass index in year y;

B(y) - biomass of the stock estimated over the entire survey area in year y;

S(y) - the entire survey area in year y.

In the calculations, data on stock biomass and survey area were taken from the report of ICES WG on summarizing the results of International Trawl-Acoustic Survey WGIDEEPS (ICES, 2018). Data on trawl estimate of the stock in the deep-scattering layer above 500 m for 2005 and 2007, which are not available in the WGIDEEPS report, are taken from the NWWG reports of 2014 and 2018 (ICES. 2014; ICES. 2018a).

The results

The biomass indices of the pelagic redfish stock, obtained for the standard water area, are presented in Table 1. Subarea A, which was covered by surveys in all years, was used as the standard area. The calculations are given for all three layers and the total indices are also determined. For the layer above the deep-scattering layer, the data are presented for all years, except for 2015, because for this year the survey participants did not carry out calculations to estimate the biomass of the stock in this layer. For a layer deeper than 500 m, information is available in all years. There are gaps in the stock estimation for the deep-scattering layer located above 500 m. This is explained by the fact that after the recalculation of the results of the 2005 and 2007 surveys, performed in 2014, the data for the depth range, covering the deep-scattering layer above 500 m, were presented to ICES without division by areas. In this regard, data on this layer for Subarea A, as well as for other Subareas, are not available in 2005 and 2007. For complete information, it is necessary to provide information with a division by Subareas.

The biomass value estimated in the standard water area is less than its value obtained for the entire survey area (Figure 2). Standardized indices are not indicator of the absolute biomass of the stock. They characterize trends in the state of the stock.

The analysis showed that in recent years there has been a decrease in the differences between the indices of the redfish stock biomass, calculated for the entire survey area, and the indices estimated for the area selected as a standard area (Subarea A), which may be due to a decrease in the area covered by surveys outside Subarea A (Figure 2). The stock valuation in recent years has been reduced to the definition of it in the Subarea A or Subareas A and B. This allows us to conclude that standardized indices smooth over the impact of interannual differences in the research area on the assessment.

In general, there is a similarity between the trends of changes in the indices of the redfish stock biomass, assessed for the standard and for the entire survey area (Figure 3). However, the indices, determined by biomass for the entire area, do not take into account the effect of changes in the research area on the stock biomass estimation. For example, they did not reflect that in 2018, with a threefold reduction in the research area in relation to 2013, from 340 to 103 square miles, the stock in the layer above the deep-scattering layer was estimated at almost equal levels of 91 and 82 thousand tons, respectively. At the same time, in previous years, a significant part of the stock was distributed outside the area assessed in 2018. All this indicates an increase in biomass in the layer above the deep-scattering layer in 2018, which is reflected by the indices estimated in the standard area.

Normalized to unit area indices, which were obtained by dividing the stock biomass, in the entire area covered by the survey, by its area are presented in Table 2. The trends in the temporal dynamics of indices estimated by the biomass of the redfish stock throughout the survey area (unstandardized indices) and by its value per unit area (standardized indices) are similar. However, in the years with the maximum research area, a relative increase in the non-standardized indices in relation to the standardized ones was reflected. This can probably be a consequence of an increase in the estimated biomass due to an increase in the research area (Figure 4). Conversely, as the area covered by the survey decreased, the estimated biomass decreased. Also, in contrast to the unstandardized indices, the standardized ones reflect the growth of the biomass of the redfish stock in the layer above the deep-scattering layer in 2018. This allows us to conclude that the standardized indices smooth over the impact of interannual differences in the research area on the assessment (Figure 3).

The conclusion

Interannual changes in the area, covered by the trawl survey, influence significantly the value of assessed biomass indices. As a result of the reduction in the study area, the share of Subareas A and B in the stock, estimated throughout the survey area, increased. This is a consequence of the reduction of survey area outside these subareas. The stock valuation in recent years has been reduced to the definition of it in the Subarea A or Subareas A and B. In 2011 and 2013, the share of Subareas A and B in the total biomass indices in the layer deeper than 500 m was 96 % compared to 81 % in 2001 and 2005 and 84 % in 2008 (ICES, 2019). In 2015 and 2018, these Subareas accounted for 100 % of the estimated biomass, as surveys were carried out only in Subareas A and B. This means that there was an increase in the undervalued biomass by at least 15-20 % due to a reduction in the research area. There is a high probability that the indices, calculated using different areas, reflect the change in the survey area to a greater extent than the dynamics of the stock.

Currently, surveys can be carried out only in a small part of the initial survey area, leading to incorrect conclusions about the state of the stock.

Taking into account the above, in order to obtain a reliable assessment of the stock state, it seems appropriate to switch over to the methodology of assessing the biomass indices of the beaked redfish stock smoothing over the interannual changes in the survey area. To this end, it seems appropriate to all years, including 2018, to estimate the indices for the standard area, covered by the survey in all years, or recalculate them per unit area covered by the survey.

Standardized indices are not an indicator of the absolute biomass of the stock, since they are determined in the part of the area of the beaked redfish distribution. They characterize trends in the state of the stock. However, the biomass of the stock, estimated for the entire area covered by the International Trawl-Acoustic Survey, is also not complete, as when the surveys were carried out, part of the stock remained outside it.

In general, there is a similarity in the dynamics of the biomass indices of the beaked redfish stock, assessed for the standard and for the entire survey area. The same tendencies are observed for the indices calculated by the stock biomass per unit area. At the same time, the indices, determined by the biomass for the entire area, do not take into account the impact of the research area reduction on them. Thus, in 2018, with a threefold reduction in the research area compared to 2013, the biomass of the stock in the layer above the DSL practically did not change. Taking into account the fact that in previous years a significant part of redfish accumulations in this layer was distributed outside the area covered by the survey, this indicates an increase in the biomass of redfish in the layer above the DSL. In 2018, the abundance of redfish individuals with a length of less than 35 cm, estimated in the survey area, was the highest in the entire history of the survey, which may indicate the appearance of large number of recruits (ICES, 2018). These facts confirm the information on the growth of biomass in this layer in 2018. The indices, determined by the biomass estimated over the entire survey area, do not reflect this increase. Standardized indices record the growth of the stock in this layer. The standardization of indices by area makes it possible to smooth over the interannual changes in the research area and gives a more accurate idea of the dynamics of the stock.

In 2015, the survey area decreased by more than two times compared to the initial period, which calls into question the possibility of using the data obtained during the survey. Standardization of indices by area allows us to use the data of all surveys conducted in 1999-2018.

To improve the quality of information on the state of the stock of redfish in the Irminger Sea, it is necessary to strive to collect data for full survey coverage of its distribution area. In the future, due to accumulation of data from number of surveys carried out over the entire area of redfish distribution, it will be possible to use these data to assess the state of the stock.

There are gaps in the data for the deep-scattering layer located above 500 m. This is explained by the fact that after the recalculation of the results of the 2005 and 2007 surveys, performed in 2014, the data for the depth range, covering the deep-scattering layer above 500 m, were presented to ICES without division by areas. In this regard, data on this layer for standard Subarea A, as well as for other areas, are not available in 2005 and 2007. For complete information, it is necessary to provide information with a divide by Subareas.

The indices, given in this Working Document, allow us to remove the impact of interannual changes in the study area, since they were determined in the area covered by the survey in all years, which makes them more reliable compared with the indices estimated from surveys that differ in area.

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Tables and Figures

Table 1. Biomass indices of redfish stock by layers that were calculated for standard survey Subarea A (method A)

Year		1999	2001	2003	2005*	2007*	2009	2011	2013	2015**	2018
Survey biomass in '000 t	Layer 1*	72	88	32	121	80	39	5	9	-	82
	Layer 2	-	23	25	-	-	136	69	71	31	171
	Layer 3	277	497	476	221	276	291	342	193	153	130
	Total	349	608	533	-	-	466	416	273	-	383
	Layer 1 + Layer 2	-	111	57	-	-	175	74	80	-	253

Layer 1 –Layer shallower than the DSL
Layer 2– Layer within DSL and shallower than the 500 m
Layer 3 – Layer deeper than 500 m
* The NWWG 2018 report provides information in general for Layer 2 without division by Subarea
** Not information on Layer shallower than the DSL

Table 2. Biomass, square of survey area calculated by results of the international redfish surveys and the indexes standardized per unit area (method B)

Year		1999	2001	2003	2005	2007	2009	2011	2013	2015**	2018
Survey area, mile^2 *		296	422	405	386	349	360	343	341	201	103
Survey biomass in '000 t*	Layer 1	614	716	89	551	372	108	123	91	-	82
	Layer 2	-	565	92	392	283	278	309	201	69	171
	Layer 3	935	1001	678	392	522	458	474	280	196	130
	Total	1549	2282	859	1335	1177	844	906	572	265	383
	Layer 1 + Layer 2	614	1281	181	943	655	386	432	292	69	253
Stand. Indixes in 1000t/mile^2	Layer 1	2.07	1.70	0.22	1.43	1.07	0.30	0.36	0.27	-	0.80
	Layer 2	-	1.34	0.23	1.02	0.81	0.77	0.90	0,59	0,34	1,66
	Layer 3	3.16	2.37	1.67	1.02	1.50	1.27	1.38	0.82	0.98	1.26
	Total	5.23	5.41	2.12	3.46	3.37	2.34	2.64	1.68	1.32	3.72
	Layer 1 + Layer 2	2.07	3.04	0.45	2.44	1.88	1.07	1.26	0.86	0.34	2.46

Layer 1 –Layer shallower than the DSL
Layer 2 – Layer whithin DSL and shallower than the 500 m
Layer 3 – Layer deeper than 500 m
* data NWWG 2018 (ICES, 2018a)
** there is data only for layer whithin DSL and shallower than the 500 m. Not information on – Layer shallower than the DSL

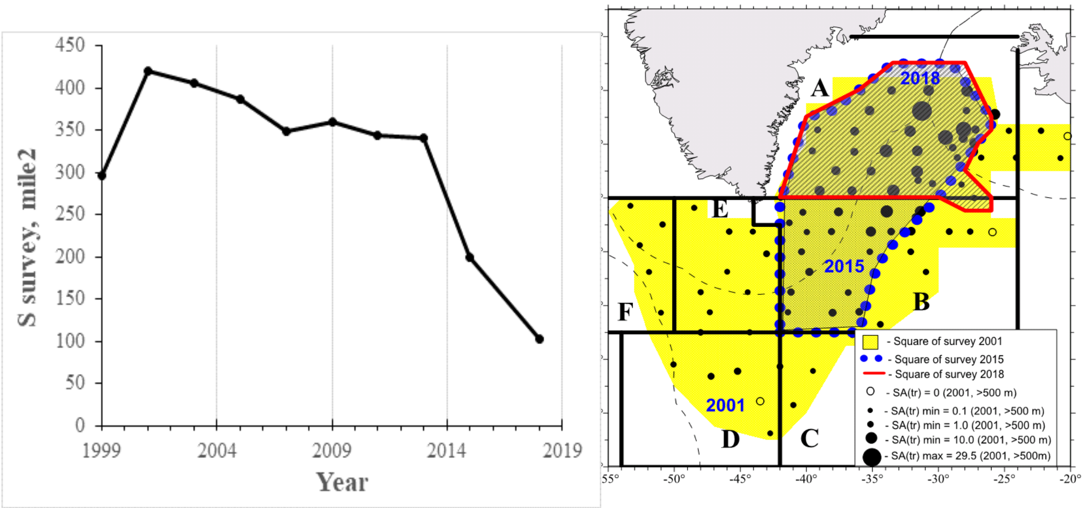

Figure 1. Changes in the area of the international trawl-acoustic survey in 1999-2018.

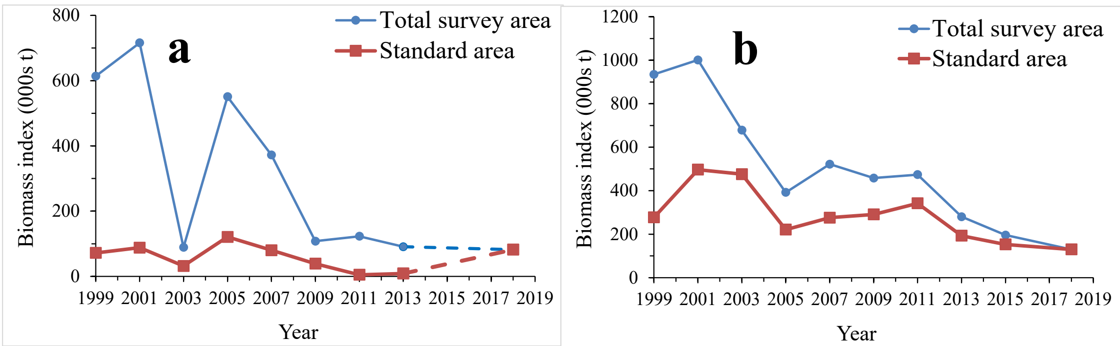

Figure 2. Comparison of the values of biomass indices of beaked redfish in the layer above the DSL (a) and in the layer deeper than 500 m, estimated for the entire areas of each survey in 1999-2018, which had a different area, and for the standard area (Subarea A; method A).

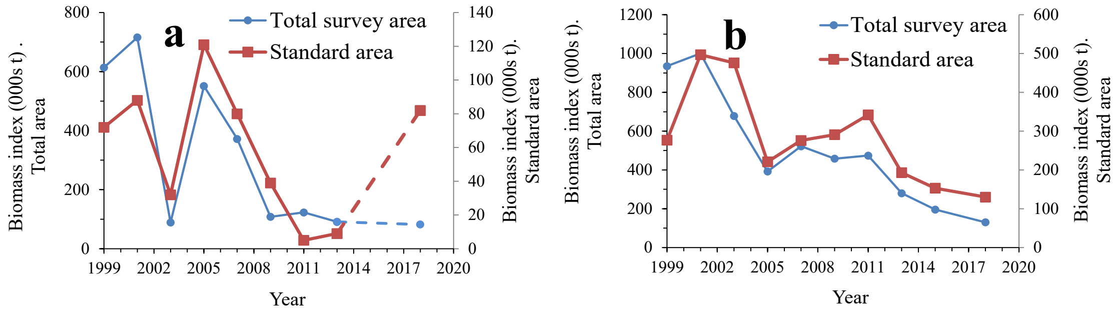

Figure 3. Dynamics of beaked redfish biomass indices in the layer above the DSL (a) and in the layer deeper than 500 m, estimated for the entire area of each survey in 1999-2018, which had different area, and for the standard area (Subarea A; the same indicators are given as in Figure 2, but with an additional scale for the standard area; method A).

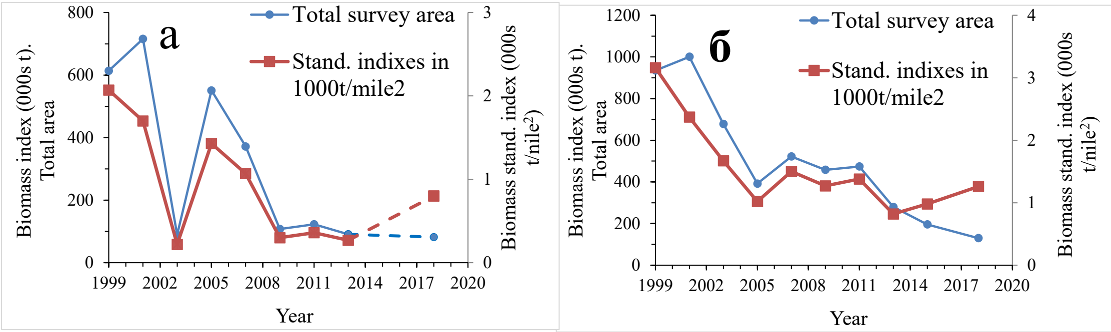

Figure 3. Beaked redfish biomass indices in the layer above the DSL (a) and in the layer deeper than 500 m, estimated by the biomass for the entire area of each survey in 1999-2018, which had different area, and standardized indices calculated by the biomass per unit area of the survey (method B).