WORKING GROUP ON MACKEREL AND HORSE MACKEREL EGG SURVEYS (WGMEGS)

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i Executive summary

The ICES Working Group on Mackerel and Horse Mackerel Egg Surveys (WGMEGS) coordi-nates the mackerel and horse mackerel egg surveys in the Northeast Atlantic (NEA) and the mackerel egg survey in the North Sea. This report focuses on the execution, and results, of the surveys (MEGS) conducted during 2022.

In 2022, the survey once again faced significant challenges with regards to its ability to provide adequate geographical and temporal coverage, given the limited vessel resources at its disposal. In 2022, Portugal, Spain (IEO and AZTI), Ireland, UK/Scotland, the Netherlands, Germany, the Faroe Islands, and Norway participated in the egg survey in the western and southern areas. Denmark and UK/England, with some additional assistance from Norway, surveyed the North Sea as a single-pass DEPM survey. This is the first time in many years that both the Atlantic and North Sea surveys have been conducted in the same year.

WGMEGS notes that the expansion of recent surveys during periods 5 and 6 occurred again in 2022. While the northern and western boundary was not contained, the number of eggs being missed in this area would not contribute significantly to the overall SSB calculation. Due to difficulties encountered by the Irish survey in period 6 this area was not surveyed.

Mackerel daily egg production was highest in period 5 for the western component, while for the southern component the maximum spawning intensity was observed in period 3. Total mackerel egg production for southern and western components combined was $2.093 * 10^{15}$ eggs. The realised fecundity estimate was 1268 egg per gram female, resulting in an SSB index of $3.565 * 10^{6}$ tonnes. The total 2022 Daily egg production (P0tot) for mackerel in the North Sea was $0.691*10^{13}$ eggs/day, a 50% decrease in egg numbers reported during the 2021 survey.

For the Western stock of horse mackerel highest mean daily egg production was estimated during period 6. Spawning was very low throughout all survey periods, with an obvious peak occurring in period 6. Total annual egg production for western Horse mackerel was $5.51 * 10^{14}$, a 310% increase on 2019. In addition, P0tot and SSB was calculated using DEPM for western horse mackerel. The total Daily egg production for 2022 was $0.186*10^{13}$ eggs/day resulting in an SSB index of $891 * 10^{6}$ tonnes.

For the Southern stock of horse mackerel, the peak spawning period was estimated to be in January- February. The Total Egg Production estimated for the 2022 survey was 5.18×10^{11} eggs/day, 37% lower than the estimate for the survey in 2019. Adult parameters to estimate SSB couldn't be obtained for the present report.

ii Expert group information

Expert group name	Working Group on Mackerel and Horse Mackerel Egg Surveys (WGMEGS)
Expert group cycle	Multiannual fixed term
Year cycle started	2021
Reporting year in cycle	3/3
Chair(s)	Gersom Costas, Spain
	Brendan O' Hea, Ireland
Meeting venue(s) and dates	26 – 29 April 2021, online meeting, (29 participants)
	26 – 27 August 2022, Copenhagen, Denmark, (14 participants)
	17 – 21 April 2023, Madrid, Spain, (32 participants)

1 Summary of work plan

Year 1	Planning of the egg survey in 2022 and reporting on the North Sea egg survey of 2021.
Year 2	Survey year, the Atlantic and North Sea surveys are conducted in 2022. A two-day hybrid meeting was held in Copenhagen to finalise the preliminary results to be presented to WGWIDE.
Year 3	Reporting and finalizing of the results of the 2022 egg survey.

2 Summary of achievements of the WG during 3-year term

- Planning, execution and reporting on the 2022 Atlantic and North Sea mackerel and horse mackerel egg surveys.
- Total Annual Egg Production of western and southern mackerel and western horse mackerel and SSB estimate of western and southern mackerel for the assessment of these stocks to WGWIDE.
- Daily Egg Production and SSB estimate of southern horse mackerel.
- Report on the 2021 mackerel egg survey in the North Sea.
- Planning, execution and reporting of the results from the 2021 exploratory mackerel egg survey along the Norwegian shelf.
- Total Annual Egg Production estimate of North Sea mackerel for the assessment of this stock to WGWIDE.
- Daily Egg Production and SSB estimate of North Sea mackerel.
- Review results from egg staging and fecundity workshops as reported in the 2021 WKMACHIS and WKAEPM Reports (ICES, 2022b and c).
- Publish three papers on mackerel fecundity and spawning dynamics.

  - Alvarez, P., D., Garcia and U. Cotano (2023). Investigating the Applicability of Ichthyoplanktonic Indices in Better Understanding the Dynamics of the Northern Stock of the Population of Atlantic Hake Merluccius merluccius (L.). Fishes, 8, 50. https://doi.org/10.3390/fishes8010050
  - Chust, G., F. González, P. Alvarez, and L. Ibaibarriaga (2022). Species acclimatization pathways: Latitudinal shifts and timing adjustments to track ocean warming. Ecological Indicators 146. https://doi.org/10.1016/j.ecolind.2022.109752
  - I. Núñez-Riboni, G. Costas, R. Diekmann, J. Ulleweit and M. Kloppmann. Reviewing and improving spatiotemporal modelling approaches for mackerel's total annual egg production. Reviewing Fish Biology and Fisheries. Under review

- Four posters on MEGS surveys at the International Symposium on Small Pelagic Fish: New Frontiers in Science for Sustainable Management. November 2022. Lisbon, Portugal:

  - The implementation of the DEPM in Western Horse mackerel during the Triennial mackerel and horse mackerel surveys (MEGS): Pros and cons. P. Alvarez, M. Korta, C. van Damme, D. Garabana, A. Thorsen, B. O'Hea, F. Burns, G. Costas.
  - Challenges in DEPM implementation for NE Atlantic mackerel. D. Garabana, C. van Damme, C. Nunes, A. Solla, P. Sampedro, M. Korta, P. Álvarez, A. Thorsen, I. Riveiro, B. O'Hea, M. Kloppmann, F. Burns, P. Sampedro, and G. Costas.
  - Drivers of the short-term changes of reproductive potential in Scomber scombrus and Sardina pilchardus in the North Iberian Peninsula waters. I. Riveiro, P. Díaz-Conde, G. Costas, D. Garabana, M. G. Pennino, A.Solla, M. González and R. Domínguez-Petit.

DEPM surveys and spawning behaviour of horse mackerel (*Trachurus trachurus*) from the Atlantic Iberian-southern stock (ICES 9a). C. Nunes, K. Ganias, F. Mouchlianitis, E. Henriques, H. Mendes and M. M. Angélico

3 Final report on ToRs, workplan and Science Implementation Plan

3.1 Activities in 2021, 2022 and 2023

The Working Group on Mackerel and Horse Mackerel Egg Survey (WGMEGS) held an online meeting in April 2021 to plan the ICES Triennial Mackerel and Horse Mackerel Egg Survey scheduled for 2022 (ICES 2021). It was decided that the survey would continue as an AEPM (Annual Egg Production Method) survey, but with an additional intensive DEPM (Daily Egg Production Method) sampling during the expected peak spawning periods of both species. This approach aimed to calculate a DEPM SSB estimate, as was done in previous surveys in 2013, 2016, and 2019.

In 2021, the Mackerel Egg Survey in the North Sea was conducted using the DEPM method, with participation from the Netherlands and Denmark.

In order to ensure standardised methods and analyses between survey participants and to provide training for new participants, two online workshops, the Workshop on Identification and Staging of Mackerel, Horse Mackerel and Hake Eggs (WKMACHIS) and the Workshop on Estimation of Adult Egg Production Parameters in Mackerel and Horse Mackerel (WKAEPM), were held in October and November 2021. These workshops covered mackerel and horse mackerel egg staging and identification, as well as fecundity and atresia sampling and estimation (ICES 2022a; ICES 2022b). An updated survey plan for the 2022 surveys was presented during these workshops, and the final planning for the 2022 survey was included in the latest version of the WGMEGS Manual for the Mackerel and Horse Mackerel Egg Surveys (ICES, 2019a).

In 2021, WGMEGS proposed moving the timing of the North Sea survey to the same year as the western/southern surveys. As a result, the North Sea survey was carried out by Denmark and England in 2022.

The results and recommendations of the 2021 WKMACHIS and WKAEPM workshops had been taken into account and were incorporated into the 2022 survey.

Since 2004, WGMEGS has aimed to provide a preliminary estimate of NEA mackerel biomass and western horse mackerel egg production in time for the assessment meetings within the same calendar year as the survey. Calculating the preliminary results for WGWIDE required a comprehensive data analysis of the egg survey and mackerel fecundity and atresia samples. Because of the limited timeframe between the survey completion and the submission of preliminary results, only fecundity samples from periods 2 and 3 were available for calculating the potential fecundity.

The details and final results of the MEGS survey in the western and southern areas, together with the North Sea mackerel egg survey in 2022, are published in the 2023 report.

Members of this working group have been actively involved in various scientific activities in recent years. The result of this activity is a number of publications. One paper published in 2022 by Chust et al. on the spawning dynamics of horse mackerel and Atlantic mackerel in the Northeast Atlantic. This study analyses the drivers of observed changes in the spawning of horse mackerel and Atlantic mackerel in Northeast Atlantic. Another publication by Alvarez et al. in 2023, explores the utility of ichthyoplankton indices derived from egg surveys for spawning biomass estimation.

In addition, four informative posters on Mackerel and Horse Mackerel Egg Surveys were presented at the International Symposium on Small Pelagic Fish: New Frontiers in Science for Sustainable Management in 2022. These posters are a presentation of the latest research, results, and challenges of the group.

A major focus of the WGMEGS in recent years has been to address the increasing discrepancies between its survey-based estimates of mackerel SSB and the results obtained from assessments and other survey-based indices of mackerel. This challenge led the group to undertake a comprehensive review of the key assumptions and methodologies underlying the estimation of mackerel SSB indices. This included assessing the representativeness of the spatial and temporal coverage of spawning activity, refining the methods used to estimate daily and total egg production, and reviewing the assumptions and methods used.

Collaboration with the ICES Working Group on Improving the use of Survey Data for Assessment and Advice (WGISDAA) is an important part of this effort. Through this collaboration, both groups are sharing knowledge and insights, to strengthen the scientific basis for fish stock assessment. This work is still a work in progress.

3.2 Western and Southern egg surveys in 2022

3.2.1 Countries and Ships Participating

The 2022 survey plan, designed at the WGMEGS meeting in April 2021, was modified and updated during the WKMACHIS meeting in October 2021. Eleven Institutes from ten countries participated: Portugal, Spain (AZTI), Spain (IEO), Netherlands, Germany, Denmark, UK (Scotland), UK (England), Norway, Faroes and Ireland. Survey dates, as well as vessel details, for cruises can be found below in Table 3.1. In 2022 the North Sea survey was undertaken in the same year as the Atlantic surveys. This was facilitated by the participation of Denmark and UK (England).

The survey coordinator for the 2022 survey was Brendan O' Hea, Marine Institute, Galway, Ireland.

Table 3.1 Countries, vessels, areas assigned, dates and sampling periods for the 2022 surveys.

Country	Vessel	Area	Dates	Period
Portugal	Vizconde de Eza	Portugal	Jan 23rd – Feb 20th	2
Ireland	Celtic Explorer	West of Ireland, Celtic Sea, Biscay,	March 2nd – 22nd	2
	Prince Madog	West of Ireland, west of Scotland	June 11th – 18th	6
Scotland	Altaire	West of Scotland	April 12th – 27th	4
	Scotia	West of Scotland, west of Ireland	May 13th – June 2nd	5
	Altaire	West of Scotland, west of Ireland, Celtic Sea, Biscay	July 4th – 26th	7
Spain (IEO)	Miguel Oliver	Cantabrian sea, Galicia, southern Biscay	March 14th – April 3rd	3
	Miguel Oliver	Cantabrian sea, Galicia, Biscay	April 4th – April 30th	4

Spain (AZTI)	Ramon Margalef	Northern Biscay	March 10th – 30th	3
	Vizconde de Eza Emma Bardan	Biscay, Cantabrian Sea	April 30th – May 19th	5
Germany	Walther Herwig	Celtic sea, west of Ireland	March 31st – April 8th	3
	Walther Herwig	Celtic sea, west of Ireland, west of Scotland	April 10th – 22nd	4
Netherlands	Tridens	Northern Biscay, Celtic Sea	May 8th – 26th	5
	Tridens	Biscay, Celtic Sea	June 5th – 24th	6
Norway	Brennholm	North Sea, Faroes & Norway	June 7th – 20th	6
Faroes	Jakup Sverri	Faroes, Iceland	May 19th – June 1st	5
Denmark	Dana	North Sea	June 7th – 19th	6
England	Cefas Endeavour	North Sea	June 4th - 25th	6

3.2.2 Sampling Areas and Sampling Effort in the Western and Southern Areas

The AEPM survey design for mackerel and horse mackerel (Western and Southern stocks) for 2022 was not changed, however another attempt was made to estimate DEPM adult parameters for both species. This required additional sampling during the perceived peak spawning periods for these stocks, as identified from the 2010 surveys during WKMSPA (ICES 2012b). For the 2022 survey, this sampling was planned to take place during periods 2 and 3 for mackerel, periods 6 and 7 for western horse mackerel, and during period 2 for southern horse mackerel.

The 2022 survey plan was split into 6 sampling periods (Table 3.2). In 2022 the survey effort in ICES division 9a was again targeted at a single extended DEPM survey.

Sampling continued in the southern area and commenced in the western area during period 3. During period 3 the survey concentrated on the Cantabrian Sea, Bay of Biscay, the Celtic Sea, West of Ireland and West of Scotland. No sampling took place in the Cantabrian Sea, and southern Biscay, after period 5. In periods 5 and 6 the survey area was extended into Faroese and Icelandic waters. In periods 6 and 7 the surveys were designed to identify a southern boundary of spawning and to survey all areas north of this. The deployment of vessels to all areas and periods is summarised in Table 3.2.

Maximum deployment of effort in the western area was during periods 3, 4, 5 and 6. Historically these periods would have coincided with the expected peak spawning of both mackerel and horse mackerel. Recent years have seen peak spawning taking place during periods 3 to 5 for mackerel and periods 6 and 7 for western horse mackerel.

Due to the expansion of the spawning area which has been observed since 2007 the emphasis was even more focused on full area coverage and delineation of the spawning boundaries. Cruise leaders had been asked to cover their entire assigned area using alternate transects and then use any remaining time to fill in the missed transects (Figure 3.1).

In 2013 the peak of mackerel spawning occurred in period 2 in the Bay of Biscay, in 2016 it occurred in May, to the west of Scotland and in 2019 occurred in April, close to the Shetland Islands. Therefore, and due to the expansion of the spawning area that has been taking place since 2007, the emphasis in 2022 was once again focussed on maximising area coverage If time was short this should be concentrated in those areas identified as having the highest densities of egg abundance.

Table 3.2 Periods and area assignments for vessels by week for the 2022 survey

		Area							
week	**Starts**	**Portugal, Cadiz & Galicia**	**Cantabrian Sea**	**Biscay**	**Celtic Sea**	**Northwest Ireland**	**West of Scotland**	**Northern Area**	**Period**
4	23-Jan-22	PO1 (DEPM)							2
5	30-Jan-22	PO1 (DEPM)							2
6	6-Feb-22	PO1 (DEPM)							2
7	13-Feb-22	PO1 (DEPM)							2
8	20-Feb-22	PO1 (DEPM)							2
9	27-Feb - 22				IRL1	IRL1	IRL1		3
10	6-Mar-22				IRL1	IRL1	IRL1		3
11	13-Mar-22	IEO1	IEO1	AZTI1	IRL1	IRL1	IRL1		3
12	20-Mar-22		IEO1	IEO1 / AZTI1					3
13	27-Mar-22	IEO1	IEO1	IEO1 / AZTI1	GER1				3
14	3-Apr-22	IEO1	IEO2	IEO2	GER1				3
15	10-Apr-22		IEO2	IEO2	GER2	GER2	SCO1	SCO1	4
16	17-Apr-22		IEO2	IEO2	GER2	GER2	SCO1	SCO1	4
17	24-Apr-22	IEO2	IEO2		GER2	GER2	SCO1	SCO1	4
18	1-May - 22		AZTI2 (DEPM)	AZTI2 (DEPM)					5
19	8-May-22		AZTI2 (DEPM)	AZTI2 (DEPM)	NED1	SCO2	SCO2		5

20	15-May-22		AZTI2 (DEPM)	AZTI2 (DEPM)	NED1	SCO2	SCO2	FAR	5
21	22-May-22				NED1	SCO2	SCO2	FAR	5
22	29-May-22					SCO2	SCO2	FAR	5
23	5-Jun-22			NED2	NED2		IRL2	NOR	6
24	12-Jun-22			NED2	NED2		IRL2	NOR	6
25	19-Jun-22			NED2	NED2			NOR	6
26	26-Jun-22								6
27	3-Jul-22			SCO3	SCO3	SCO3	SCO3		7
28	10-Jul-22			SCO3	SCO3	SCO3	SCO3		7
29	17–Jul-22			SCO3	SCO3	SCO3	SCO3		7
30	24-Jul-22			SCO3	SCO3	SCO3	SCO3		7

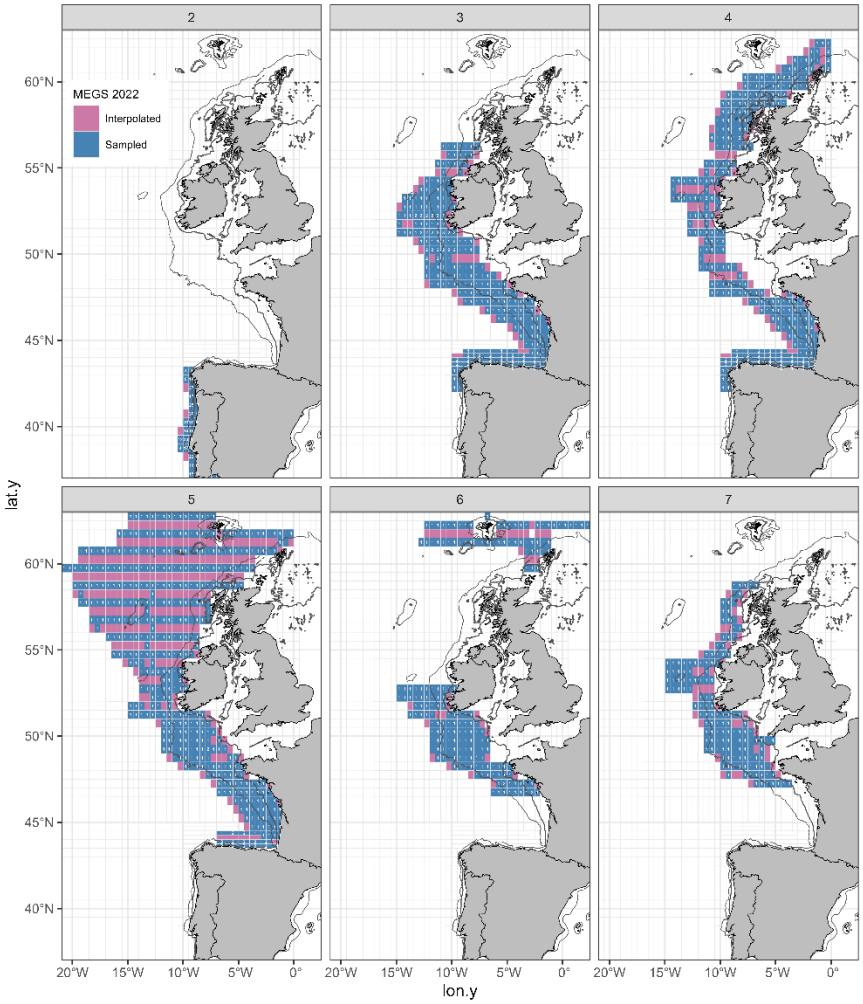

Figure 3.1: Survey coverage by period. Blue stations were sampled while purple were interpolated.

3.2.3 Sampling and Data Analysis

The triennial mackerel egg survey aims to determine annual egg production using the mean daily egg production rates per predefined sampling periods for the complete spawning area of the Northeast Atlantic mackerel and horse mackerel. The 2022 egg survey was designed to reach a broad spatial and temporal coverage in each of the sampling periods. To achieve this, plankton hauls per half degree longitude were conducted on mostly alternating transects covering the complete spawning area. In core spawning areas, sampling was intensified and all transects were covered (Figure 3. 1). Given the high variability of egg production by station this design ensures the smallest chances of under- and overestimation of the egg production (comp. ICES 2008).

A total of 1925 plankton samples were collected and sorted. Mackerel, horse mackerel, hake and ling eggs were identified and the egg development stages determined. Depending on the vessel facilities and the experience of the participants this was done either during the cruise or back in the institute laboratories.

Double micropipette samples and sections from 9300 ovaries of mackerel and horse mackerel were also taken on board. After finishing the individual surveys these samples were sent to seven

different European research institutes for the analysis and estimation of realized fecundity (potential fecundity minus atresia). For the mackerel atresia analysis only fish with atretic oocytes or spawning markers can be used. These markers can only be reliably detected histologically and these procedures and the resultant estimates are described in detail in section 3.4.3. WGMEGS decided that from the 2013 survey onwards, and in the period of peak of spawning, extra sampling effort would be dedicated to collect additional adult samples for the estimation of adult parameters to apply the DEPM.

The analysis of the plankton samples as well as of the fecundity samples were carried out according to the sampling protocols as described in SISP 5 and SISP 6 (ICES 2019a; ICES 2019b).

Horse mackerel is believed to be an indeterminate spawner and therefore since 2007 IPMA has adopted the DEPM methodology for southern horse mackerel (ICES Division 9a). The egg survey design in the western horse mackerel is directed at the AEP method for mackerel which produces an estimate of SSB. Fecundity samples for horse mackerel were taken during the expected peak spawning period in survey in order to develop a modified DEPM approach for estimating the biomass of the horse mackerel stock.

3.2.4 Sampling Strategy for Southern Horse Mackerel in ICES division 9a

In 2022 the DEPM survey directed at the southern horse mackerel was carried out in ICES division 9a (between Cape Trafalgar and Cape Finisterre) by Portugal (IPMA) onboard the RV "Vizconde de Eza" from 23 January - 20 February. A total of 46 out of a planned 48 transects, were surveyed, the two closest to the Gibraltar Strait were unable to be covered due to adverse sea conditions. Except for these two transects, the survey plan was achieved as expected.

Plankton surveying for egg density estimation and spawning area delimitation was conducted along transects perpendicular to the coast which were spaced 12 nautical miles apart. The sampler used was a modified CalVET structure with a CTDF probe (paired nets with 40 cm diameter mouth aperture and 150 µm mesh size). Plankton hauls (and CTDF casts) were conducted down to a maximum depth of 200 m, following a pre-defined grid of stations (every 3 or 6 nautical miles) along the transects. The plankton samples from each net were stored in separate containers, one preserved in 4% buffered formaldehyde solution in distilled water (for laboratory eggs identification, staging and counting) and the other in 96% ethanol (for *Trachurus spp*. and *Scomber spp*. genetic analyses). Concurrently, CUFES samples (335 µm mesh size) were collected (every 3 nmiles) along the path between the vertical plankton tows, as an auxiliary sampler for adaptive area surveying. Also surface temperature, salinity and fluorescence data were recorded continuously using a probe associated to the water pumped by the CUFES sampler. During the survey, a total of 559 CalVET and 731 CUFES samples were collected.

Surveying for adult horse mackerel took place simultaneously with the ichthyoplankton sampling, 1-2 fishing hauls were performed opportunistically during the survey using bottom trawl gear. In total, 33 fishing hauls were obtained on board the research vessel, with 20 hauls (61%) being positive for horse mackerel. Additional fish samples were collected from the bottom trawl and purse seine fleets at several harbours along the coast, from the same period when the research vessel was surveying each area. A total of 13 samples were obtained at the harbours of Matosinhos, Aveiro, Peniche, Sesimbra, and Portimão/Olhão. For each trawl, complete biological sampling of a random sample of 60 fish was undertaken: individual biological information was recorded, a minimum of 30 ovaries per trawl were preserved in 4% buffered formaldehyde for histology and fecundity estimation, and otoliths were collected for ageing. Extra effort was taken to obtain females with hydrated ovaries for the fecundity estimation (F), as well as to collect fish of smaller sizes to obtain a maturity ogive.

Mackerel sampling was also carried out whenever possible to support the estimations undertaken by WGMEGS. The biological data and sub-samples of the preserved ovaries were sent to all partner institutes for screening analysis and fecundity calculations (ICES 2022).

Details on the biological sampling, laboratory work and parameters calculation are described in the MEGS Manual for AEPM and DEPM fecundity (ICES 2019a, http://doi.org/10.17895/ices.pub.5139)

3.3 North Sea mackerel egg survey in 2022

In 2022 a coordinated survey was undertaken by the UK (England), Denmark and Norway between the 5th and 24th June 2022. The egg survey in the North Sea was set up to estimate the total annual egg production (TAEP) and spawning stock biomass (SSB) for mackerel using a single pass (DEPM) (Table 3.3.) similar to the survey undertaken in the North Sea in 2021. The survey was designed to cover the entire spawning area using half ICES rectangle samples (ICES 2014) as the standard sampling unit (Figure 3.2). There was a concern that as the North Sea is such a large area England and Denmark would not have sufficient survey days available to survey it all. As a result, Norway agreed to survey the four northernmost transects, before they began their survey in the western area.

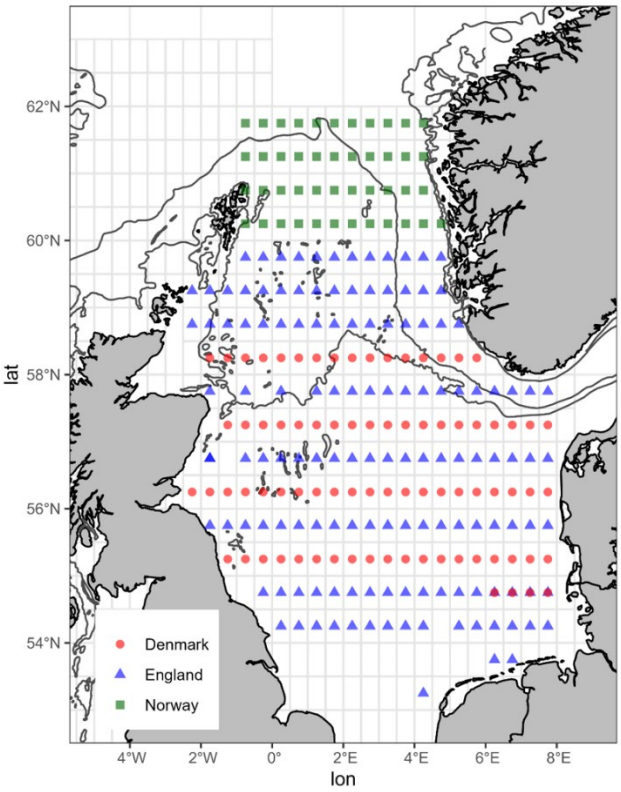

Figure 3.2 Ichthyoplankton stations for the North Sea, 2022.

On each of the Danish transects at least one pelagic trawl haul was performed for the collection of mackerel adult samples. Denmark conducted 33 hauls, from which they sampled 1180 mackerel and collected ovary samples from 364 females. Due to problems with their fishing gear Cefas (UK) carried out 20 rod and line fishing events of which 9 were positive, biologically sampling

225 mackerel and collecting ovary samples of 74 females. Norway collected 239 female mackerel samples from 5 fishing hauls (Table 3.3.).

Table 3.3 NSMEGS surveys cruise dates in 2022 (For Norway only stations used in the NSMEGS DEP calculation are shown). UK = UK England, DK = Denmark, NO = Norway.

Country	UK	DK	NO
Period	**6**	**6**	**6**
Dates (2022)	5.06-24.06	08.06-19.06	7.06-19.06
Plankton stations sampled	135	85	45
Pelagic trawl hauls		33	5
Positive rod and line events	9		

3.4 Hydrography 2023 report

3.4.1 Southern Horse Mackerel DEPM Survey

In 2022, and according to schedule, surveying during the PT-DEPM22-HOM started at its southern boundary, off Cape Trafalgar, in the Bay of Cadiz, on the 23rd of January and ended at its northern border, close to Cape Finisterre, on the 20th of February, with a short break (less than 24h), in Lisbon on the 6th February for team replacements.

The oceanographic conditions encountered during the period of late January – end of February were typical for the region in late winter – early spring (Figure 3.3). The surface temperature distribution, ranging from 12.5°C to 17°C approximately, showed the usual pattern of lower temperatures in the northern zone, increasing towards the south and reaching a maximum off the southern coast, particularly in the Cadiz area. In the northern areas, a nearshore water mass, with lower temperature and salinity, was apparent, indicating the prevalence of wintry conditions.

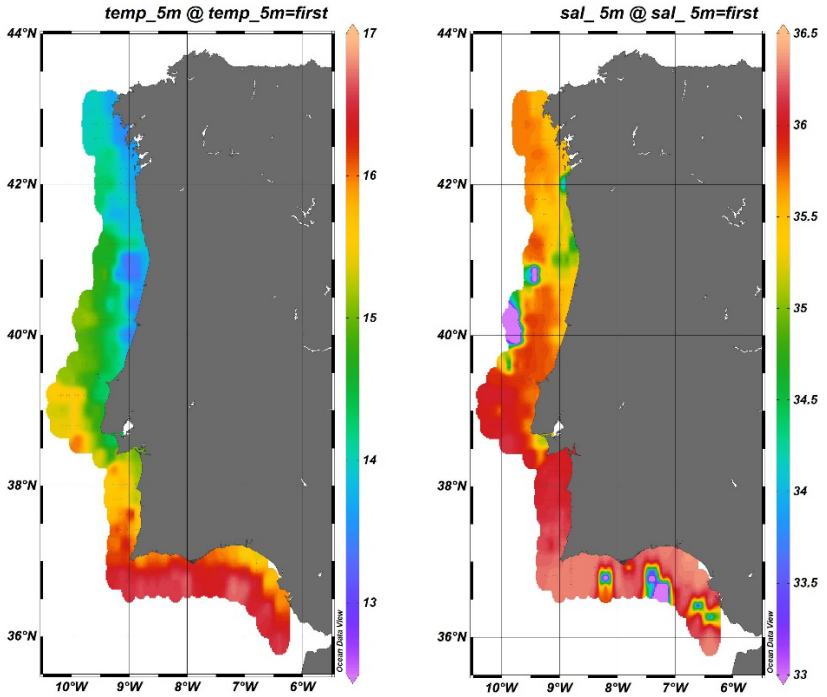

Figure 3.3 Sea surface distributions of temperature (left panel), salinity (right panel). The data were obtained by the sensors attached to the CUFES system.

3.4.2 Mackerel and Western Horse Mackerel Egg Surveys

For the Northeast Atlantic MEGS, the temperature values at 20m depth are used in the calculation of the daily egg production for mackerel and horse mackerel. Horizontal distribution of those temperatures during all sampling periods, except for period 2, are displayed in Figure 3.4. Overall, temperatures at 20 m depth ranged from values < 8.5°C to >18°C and were, though very similar in their distribution, about 0.5 – 1.0°C warmer than those observed during the 2019 MEGS for almost all survey periods. Only during period 4, temperatures were very similar to those observed in 2019 followed by a steep incline towards period 5. Lowest temperatures were always observed in the North increasing towards the South and also with the progression of the sampling periods. Temperatures everywhere were almost all the time higher than the supposed threshold minimum value of 8 °C, associated with an increased probability of mackerel egg occurrence.

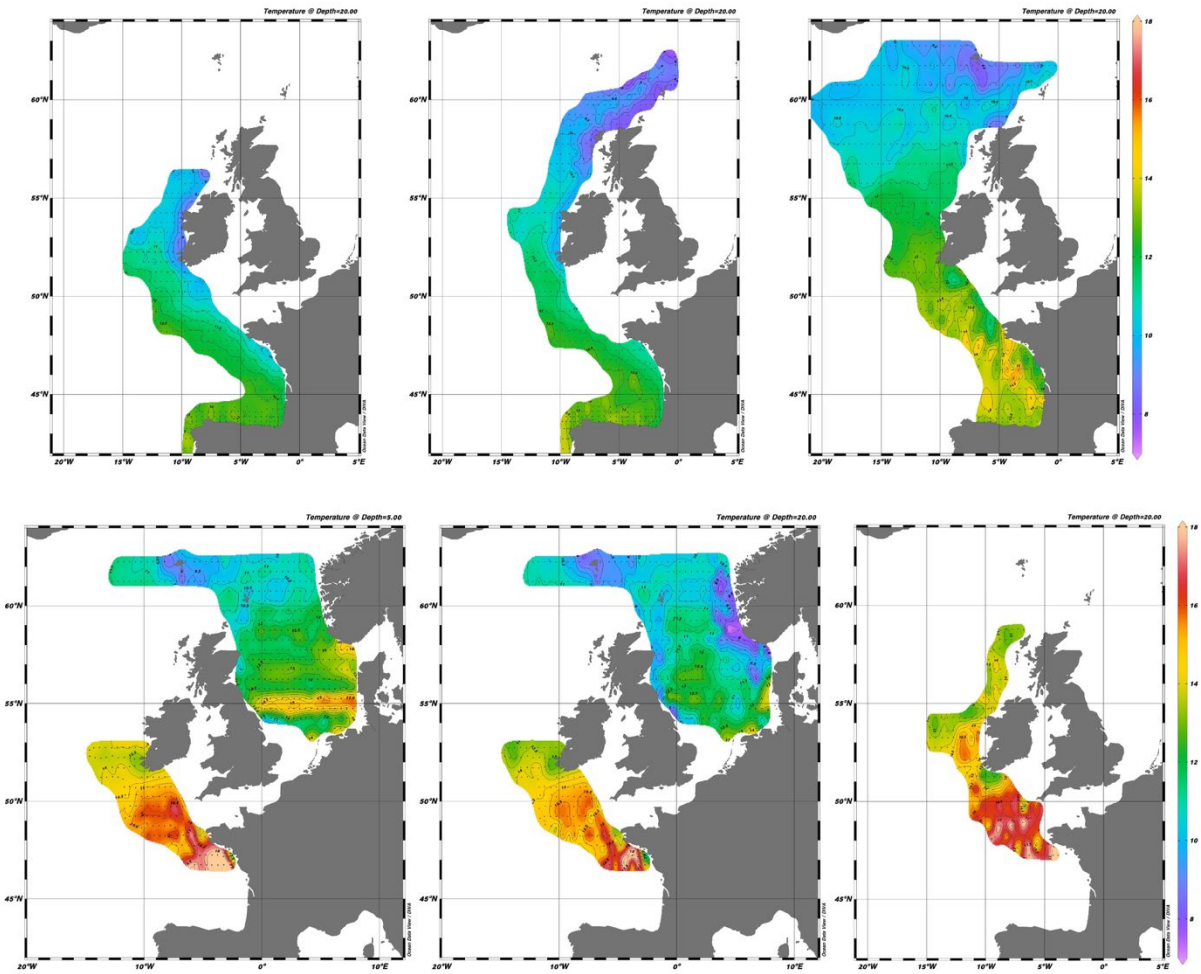

Figure 3.4. The 20 m depth temperature distribution for periods 3 – 5 (top row, left to right) and periods 6 including the North Sea, at depths 5 and 20 m, and 7 at 20 m (bottom row, left to right).

For North Sea mackerel egg production, temperatures 5 m depth are used. For period 6, therefore, temperatures at this depth are also displayed (Figure 3.4, lower left panels). Temperatures at that shallower depth were considerably warmer than at 20 m. Due to their stronger direct exposure to atmospheric forcing, (i.e., high daily and day to night variability of sun radiation), and in particular for the North Sea, the spatial distribution of temperatures reflects rather the progression of the survey than the seasonal dynamics of the hydrography.

3.5 Mackerel in the western and southern spawning areas: 2022 egg survey results

3.5.1 Spatial distribution of stage 1 mackerel eggs

As already described in section 3.2.1, the 2022 MEGS was split into 6 survey periods, the start and end dates of which can be found in Table 3.1. For each of the 6 sampling periods, particular points to note are:

Period 2 – Portugal started the 2022 survey series on January 23rd. This is a DEPM survey mainly targeting the southern horse mackerel stock and is designed for this purpose, however it also delivers mackerel egg abundance data. The survey is usually undertaken between Cadiz and Galicia and is confined to ICES division 9a (Figure 3.5.).

Period 3 – Period 3 marks the commencement of the western area surveys as well as a continuation of sampling in the southern area. Sampling was undertaken by Ireland (West of Scotland, west of Ireland, Celtic Sea), Germany (Celtic Sea) and AZTI (northern Biscay). Further south the Bay of Biscay, Cantabrian Sea and Galicia were covered by Spain (IEO).

No eggs were found by Ireland in northern waters so after a number of days the vessel turned south and sampled in the Celtic Sea. Due to issues with COVID cases among the crew, the German survey was delayed in starting, however it was successful in linking with the Irish vessel. Both IEO and AZTI experienced difficulties with their vessels, and lost a number of sampling days, however full coverage was achieved (Figure 3.6).

Egg numbers were relatively low to the west of Ireland. In contrast, further south large numbers of eggs were found close to the 200m contour line. In Biscay and the Cantabrian Sea AZTI and IEO recorded a number of stations with large numbers of mackerel eggs. 298 stations were sampled and there were only 13 interpolations. There were 52 replicate samples with the majority being completed in the Cantabrian Sea.

Period 4 – This period was covered by three surveys. Scotland sampled the area from the northwest of Ireland to the Shetland Islands. Germany surveyed west of Ireland, Celtic Sea and northern Biscay while IEO completed the survey coverage in southern Biscay and the Cantabrian Sea (Figure 3.7).

Due to difficulties in acquiring diplomatic clearance, the Scottish survey was unable to sample in Irish waters. As a result, Germany extended their survey area northwards to ensure continuity of survey coverage.

Once again moderate levels of eggs were recorded throughout the area, with the highest concentrations still being found close to the 200m contour line. Large numbers of mackerel eggs were once again recorded to the west of Scotland, however, they were lower within this area and time period than those reported in 2019. 327 stations were sampled and there were 46 interpolations. 52 replicate samples were taken and once again most of these were collected from the Cantabrian Sea.

Period 5 – In period 5, the entire spawning area from the Cantabrian Sea to the West of Scotland, and up to Faroese waters at around 61°N was surveyed by AZTI, the Netherlands, Scotland, and Faroes.

Spawning in the Cantabrian Sea was tailing off with only low egg numbers being found. Throughout Biscay and into the southern Celtic Sea numbers were generally low to moderate (Figure 3.8). This pattern continued west of Ireland, to around 54°N, with spawning remaining on and around the shelf edge. North of this, however, and similar to that noted in 2016 and 2019, spawning activity fanned out both west- and northwards. Due to the large area Scotland had to survey, their vessel was forced to restrict exploration of the western boundary around the SW of Rockall Bank. Egg counts recorded from the boundary stations within this area were lower than reported in 2019 so while the western boundary wasn't fully delineated, MEGS is happy that the survey has captured the majority of egg production in this area. North of this, the Faroese survey

completed stations North of Hatton Bank and up towards the Icelandic coast. Some egg production was found to the north of Rockall, however the largest number of eggs were encountered west of the Shetland Islands. In total 444 stations were sampled and there were 214 interpolations. One replicate sample was undertaken.

Period 6 – During period 6 northern Biscay, northwards from 46°N and also the Celtic Sea were covered by the Netherlands while Ireland was to cover west of Ireland and also west of Scotland. Norway surveyed the area north of 59°N from the south of Iceland to the Norwegian coast, as well as carrying out four transects in the northern North Sea to assist England and Denmark in providing full coverage for the DEPM survey.

Ireland had planned to charter a research vessel from Northern Ireland to conduct the period 6 survey. One week prior to departure the vessel had to go to dry dock for emergency repairs. After much searching, a smaller Welsh RV was contracted as a replacement. Once at sea however it quickly became clear that the replacement vessel was wholly unsuitable and not up to the task. With only two stations successfully completed the decision was made to abandon the survey leaving the area from 53N to 61N unsampled. Norway and Netherlands both completed their survey sampling successfully.

Low levels of spawning were observed in Biscay and to the south to the West of Ireland and Porcupine bank (Figure 3.9). Similarly, in the northern area, spawning was observed at low levels, with the exception once again of the area west of the Shetland Islands. Due to an unavoidable reduction in the number of survey days available, Norway was unable to secure either the northwestern or northern boundary within the northern area, while Netherlands secured the western boundary in their area. 184 stations were sampled with 36 interpolations. No replicate stations were completed.

Period 7 – This period was covered entirely by Scotland sampling on alternate transects in the area from 47°15N to north of the Hebrides and 59°N (Figure 3.10). Due to the lack of eggs encountered, the Scottish survey adhered very closely to the 200m contour and 144 stations were sampled with 24 interpolations. Two replicate stations were completed. Only very low levels of spawning were observed and these were confined to the continental shelf and shelf edge with all spawning boundaries being delineated successfully.

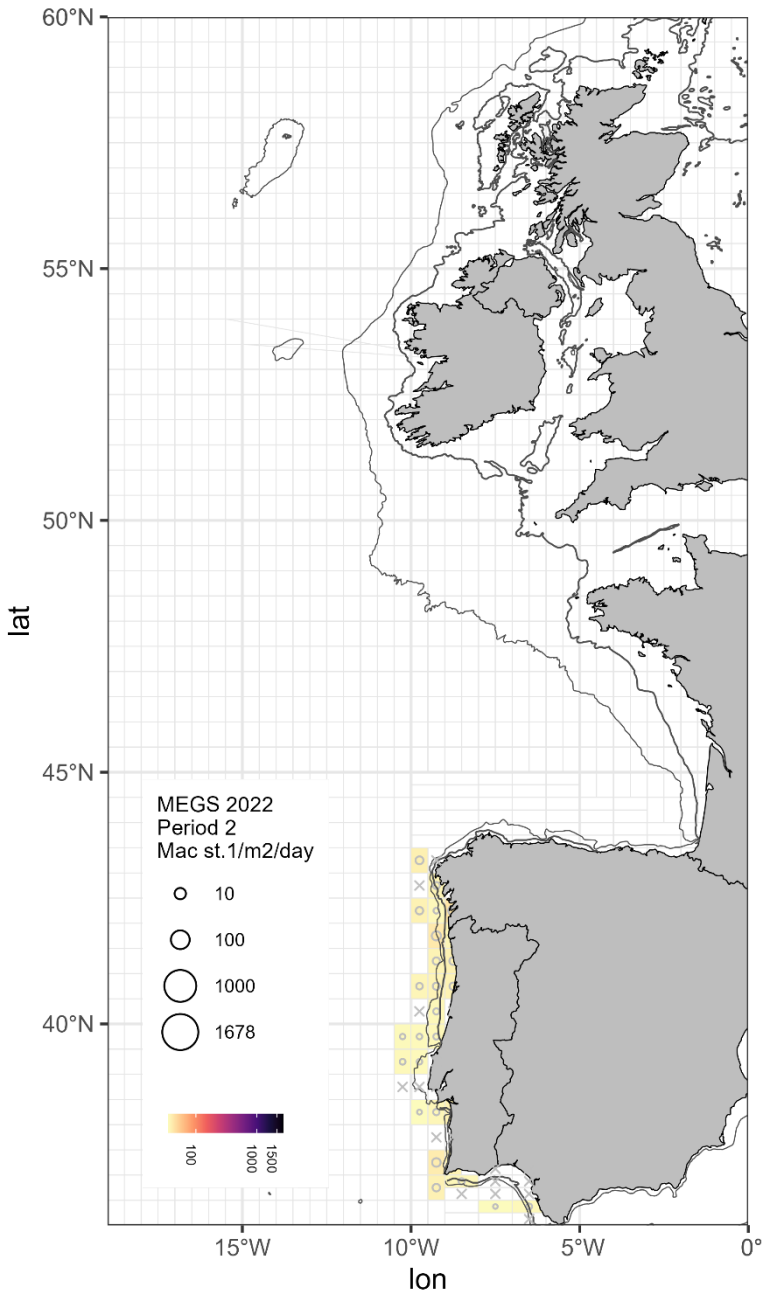

Figure 3.5 Mackerel egg production by half rectangle for period 2 (Jan 23rd – Feb 19th). Circle areas and colour scale represent mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

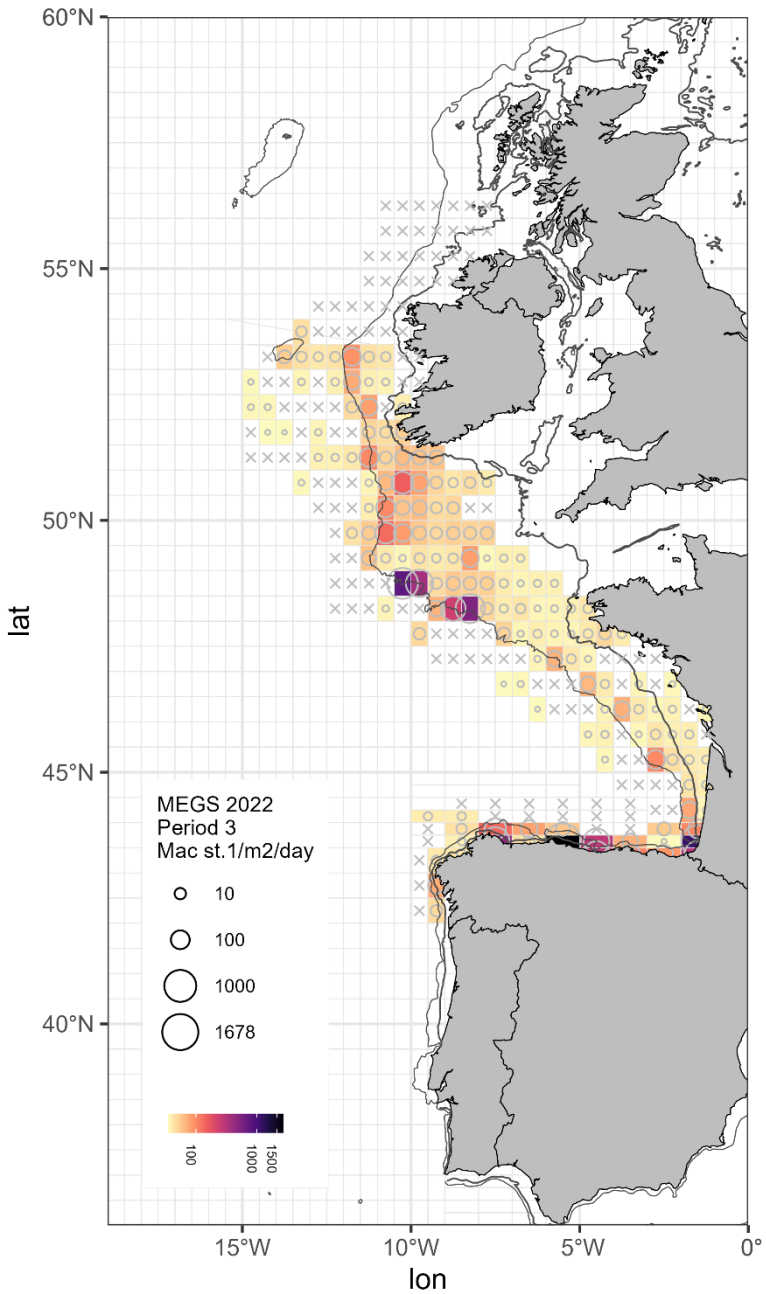

Figure 3.6 Mackerel egg production by half rectangle for period 3 (Mar 4th – Apr 8th). Circle areas and colour scale represent mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

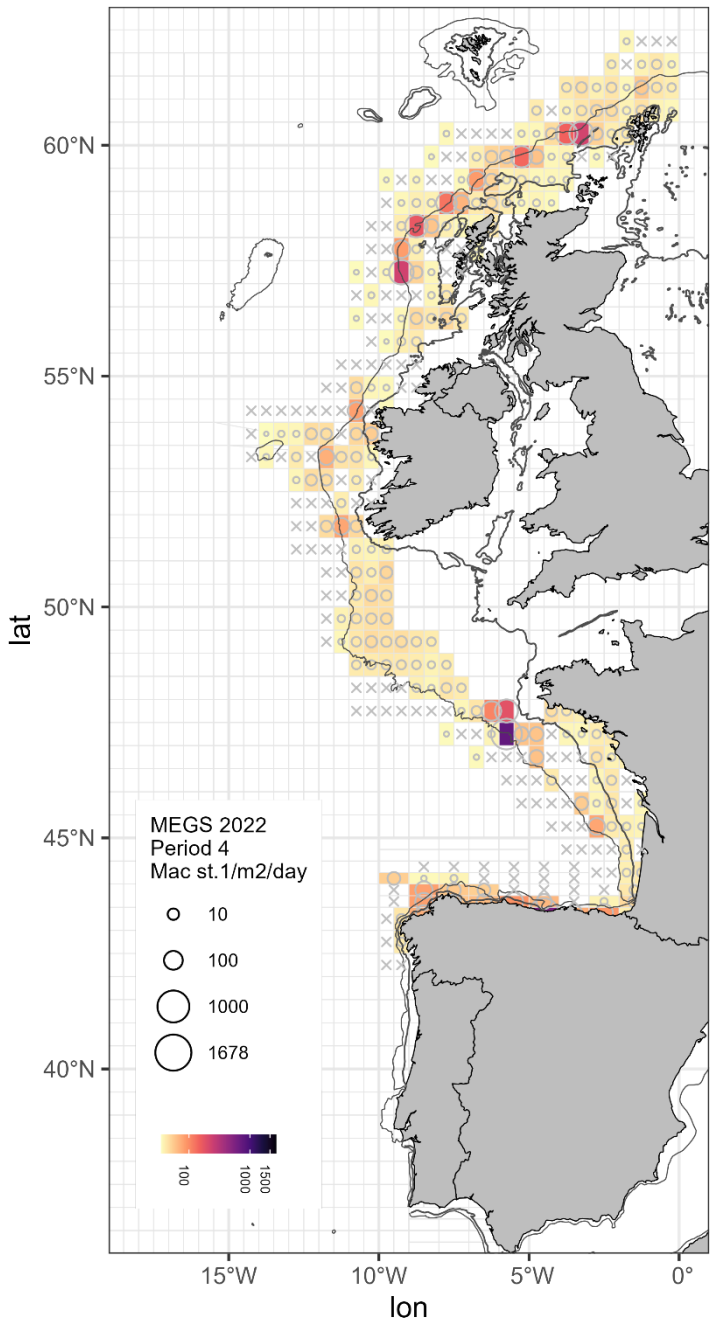

Figure 3.7 Mackerel egg production by half rectangle for period 4 (Apr 9th – 29th). Circle areas and colour scale represent mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

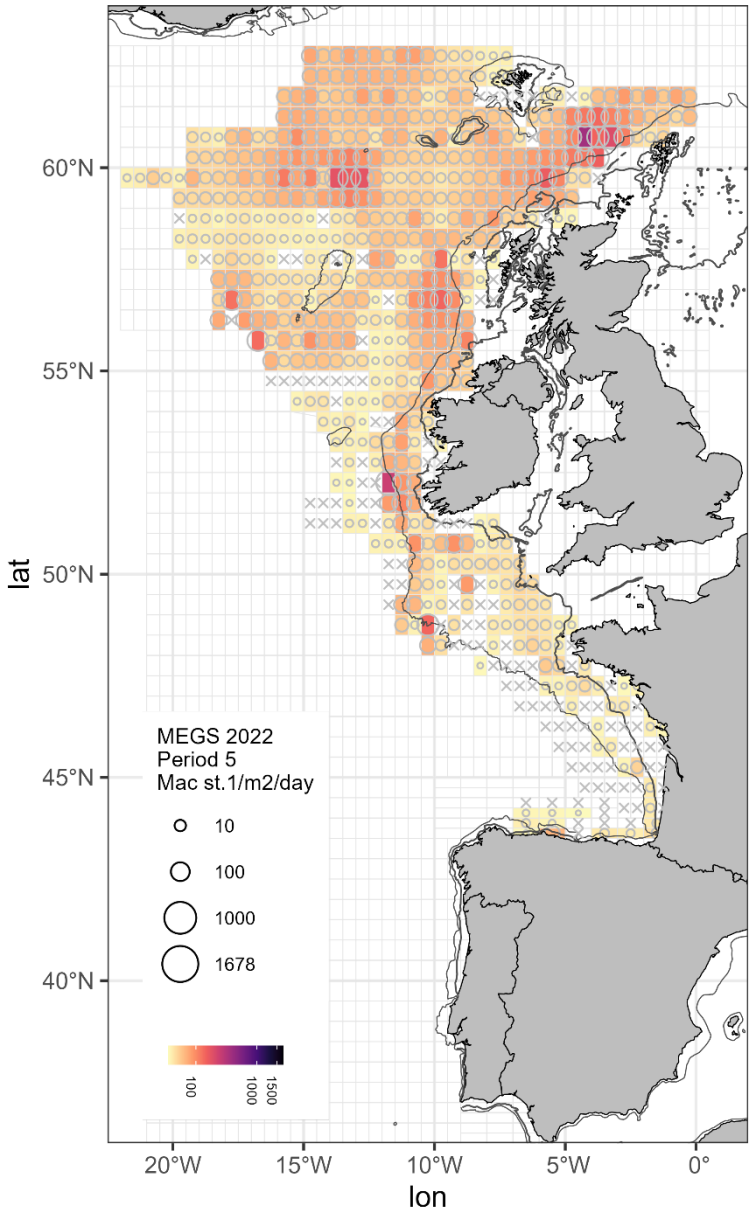

Figure 3.8 Mackerel egg production by half rectangle for period 5 (Apr 30th – May 31st). Circle areas and colour scale represent mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

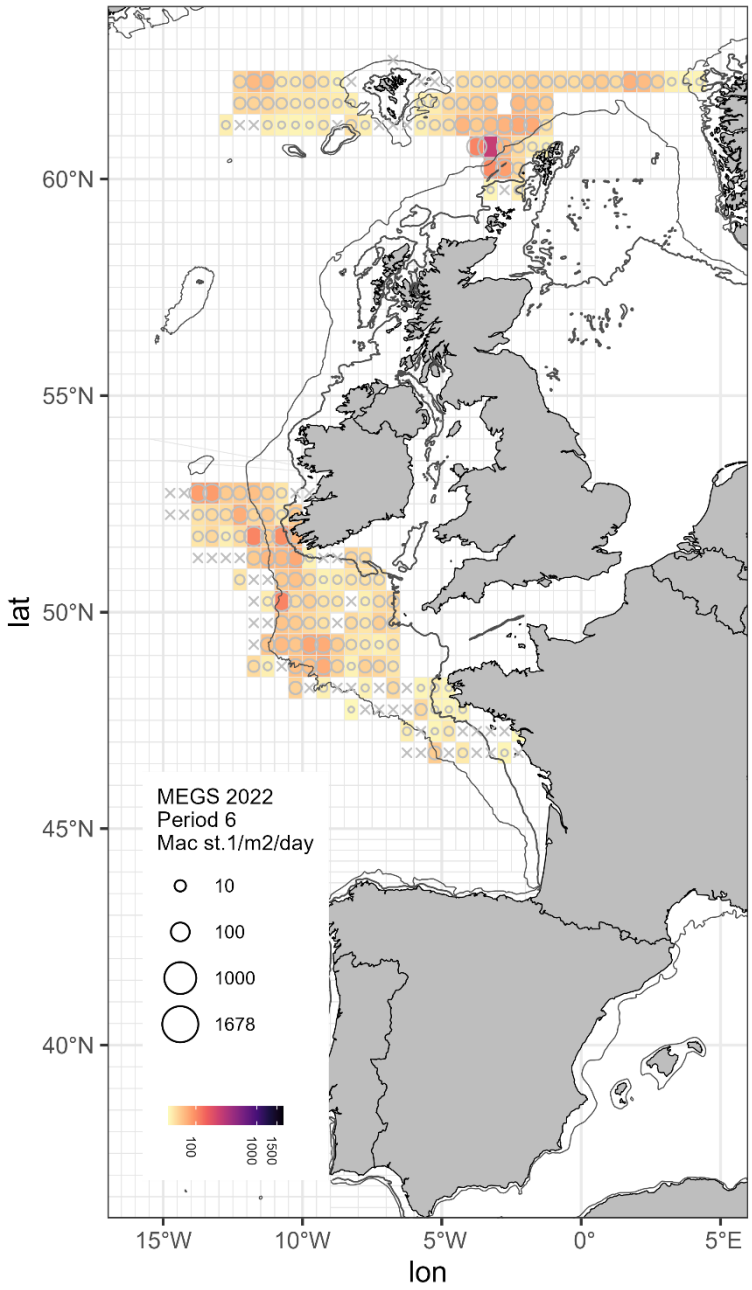

Figure 3.9 Mackerel egg production by half rectangle for period 6 (June 1st – 30th). Circle areas and colour scale represent mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

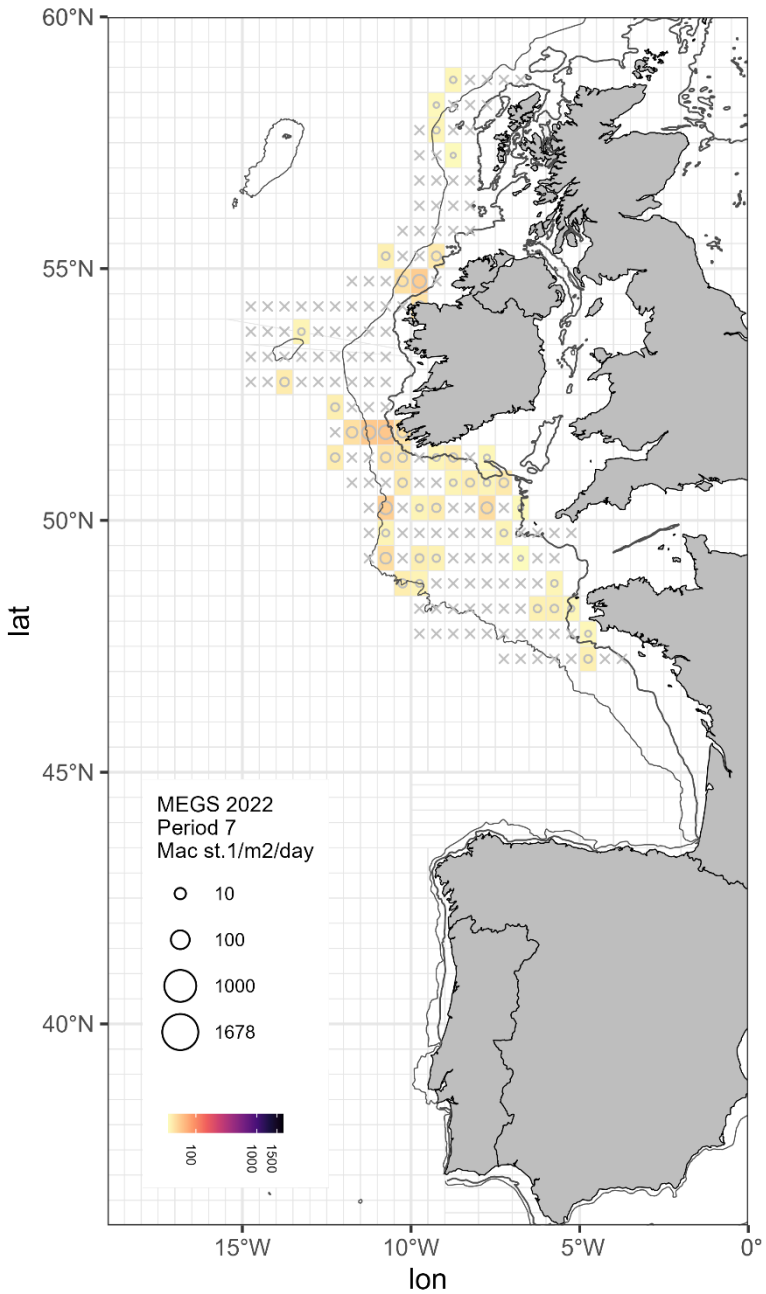

Figure 3.10 Mackerel egg production by half rectangle for period 7 (July 1st – 31st). Circle areas and colour scale represent mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

3.5.2 Egg production in Northeast Atlantic mackerel

3.5.2.1 Stage I egg production in the western area

The cancelling of the Irish survey in period 6 was addressed by WGMEGS. The group estimated the spawning area that was missed, and also estimated mean daily egg production for the period. The survey area from 53°N to 61°N, and 3.5°W to 21°W was looked at for the same time interval in the 2013 (period 5), 2016 (period 6) and 2019 (period 6) surveys. Positive stations were selected

where stage 1 eggs were found in a rectangle on at least two occasions over these three surveys (Figure 3.11, blue rectangles). WGMEGS estimated this amounted to 127 missed stations during the period. WGMEGS then calculated mean daily egg production from all the completed survey stations for period 6 in 2022 to be 19.58 stage 1 eggs/m^2/day, and applied this figure to the 127 stations. Figure 3.12 shows the spawning curve for 2022, with and without the correction for the Irish survey.

2010 provided an unusually large spawning event early in the spawning season, 2013 yielded an even larger spawning event indicating that spawning was probably taking place well before the nominal start date of 10th February (Figure 3.13). In 2016 the first survey commenced on February 5th which is five days prior to the nominal start date. That year however mackerel migration was later and slower than that recorded in the previous two surveys (Figure 3.13).

In 2016 concern was expressed that a non-sufficient survey coverage may have underestimated the total egg production estimate. The expansion observed in western and northwestern areas during periods 5 and 6 in 2016 was once again reported during 2022, however this year production in periods 5 and 6 was lower in these northwestern areas.

In 2017 and 2018 WGMEGS organized exploratory egg surveys in this region. These surveys provided significant evidence that while some spawning has been missed the loss of egg abundance is not sufficiently large to significantly impact the SSB estimate.

The 2022 spawning curve is very similar to that of 2016, with peak spawning again occurring during period 5. Annual egg production since 1992 is shown in Figure 3.14. Mackerel egg production by period since 2004 is shown in Figure 3.15.

Overall, the inclusion of the estimated egg abundance for the missing stations in period 6 has an impact of 10% on the annual egg production 2022.

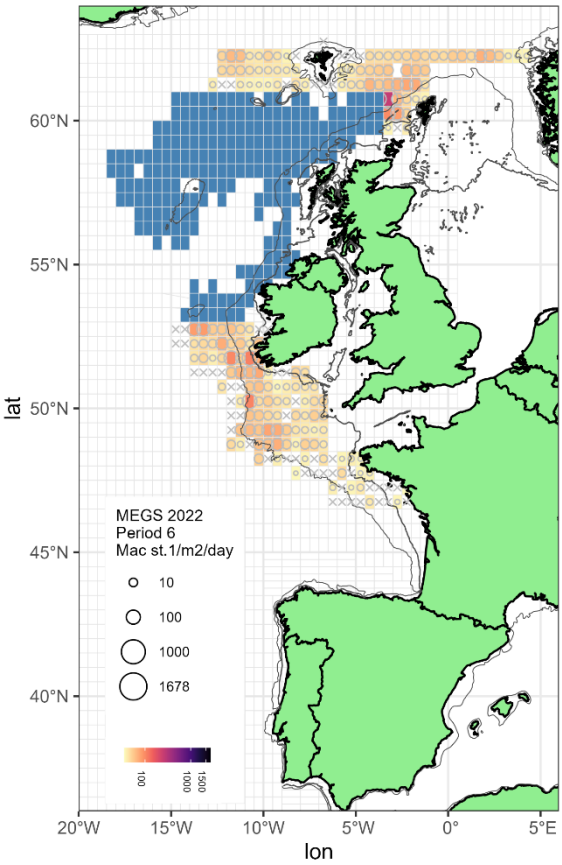

Figure 3.11 Area, blue colour, where it is estimated eggs would have been found during the Irish period 6 survey.

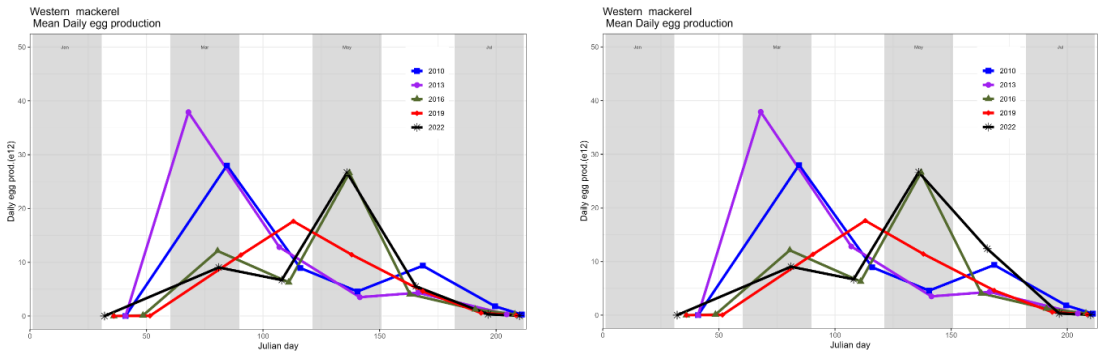

Figure 3.12 The daily mackerel egg production curves for 2010 – 2022 surveys with (right) and without (left) corrected estimates for period 6 of 2022 (black lines).

The nominal start and end dates of spawning are February 10th and July 31st respectively. These are the same dates that were used during previous survey years and the shape of the egg production curve for 2022 does not suggest that the chosen dates need to be altered. The total annual egg production (TAEP) for the western area in 2022 was calculated as $\mathbf{1.799 * 10^{15}}$ (Table 3.4). This is a 47% increase on the 2019 TAEP estimate which was $1.22 * 10^{15}$.

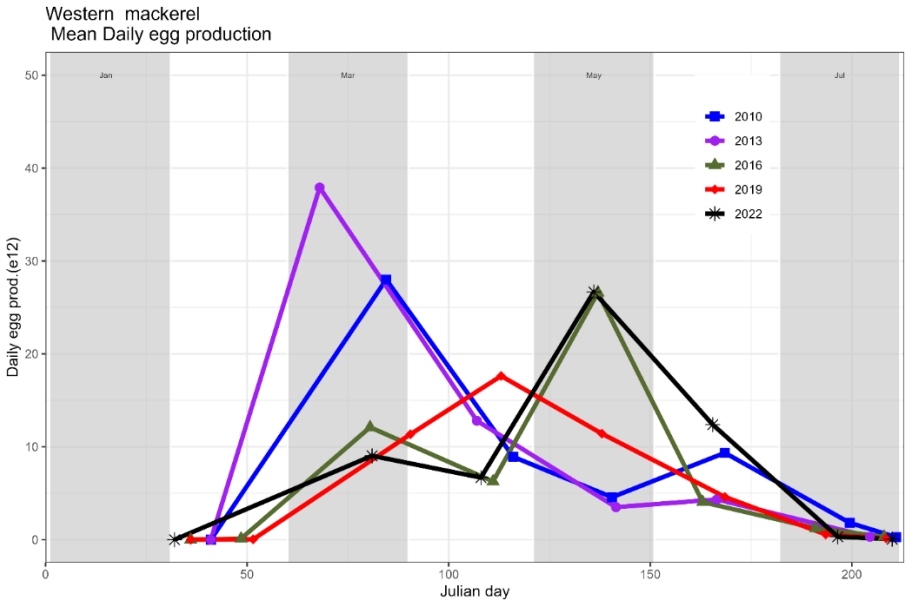

Figure 3.13 Annual egg production curve for mackerel in the western spawning component in 2022, (black line). The curves for 2010, 2013, 2016 and 2019 are included for comparison.

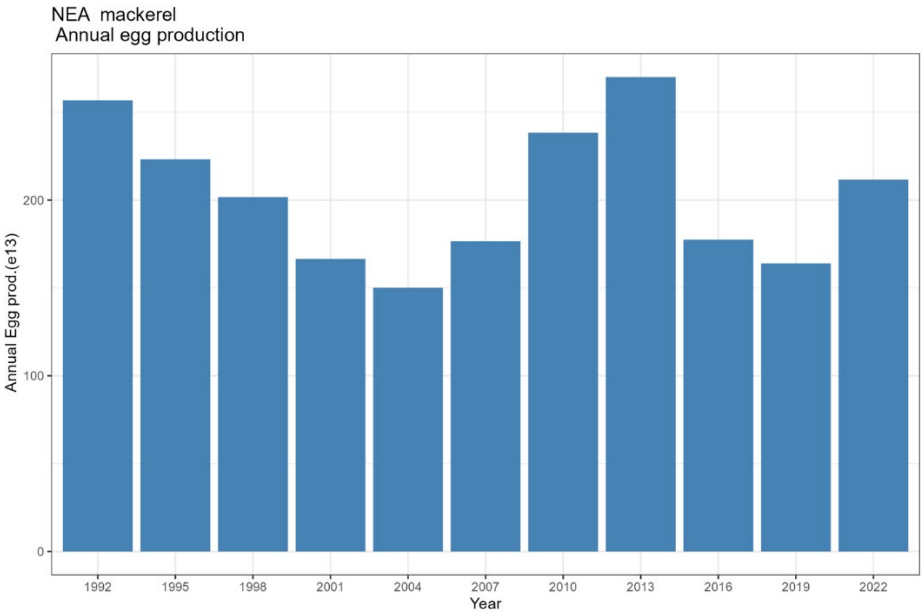

Figure 3.14 The total annual mackerel egg production for 1992 – 2022 for the western spawning component.

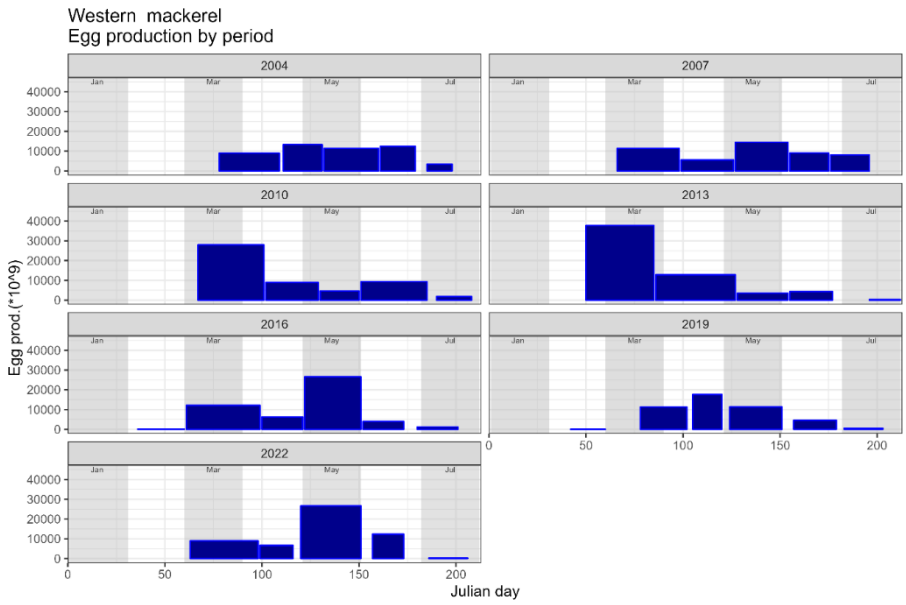

Figure 3.15 Egg production by period for the western spawning component since 2004.

Table 3.4 Estimate of the 2022 total mackerel stage I egg production by period for the western component using the histogram method.

Dates	Period	Days	Annual stage I egg production * 10^{15}
Feb 5th – Mar 3rd	Pre 3	31	0.087
Mar 4th – Apr 8th	3	36	0.319
Apr 9th – Apr 26th	4	18	0.120
Apr 27th – Apr 29th	4 - 5	3	0.043
Apr 30th – May 31st	5	32	0.863
Jun 1st – 5th	5 - 6	5	0.068
Jun 6th – Jun 22nd	6	17	0.211
Jun 23rd – Jul 4th	6 – 7	12	0.081
Jul 5th – Jul 25th	7	21	0.007
July 26th – July 31st	Post 7	6	0.0003
Total		1.7993	

3.5.2.2 Stage I egg production in the southern area

The start date for spawning in the southern area was the 23rd January (Table 3.5). Portugal surveyed in Period 2 in division 9a. Sampling in the Cantabrian Sea where the majority of spawning occurs within the Southern area commenced on the 18th March. The same end of spawning date of July 17th was used again this year and the spawning curve suggests that there is no reason for this to change (Figure 3.16). As in 2019 the survey periods were not completely contiguous and this has been accounted for (Table 3.5). The total annual egg production (TAEP) for the southern area in 2022 was calculated as **2.93 * 10^{14}** (Table 3.5). This is a 30% decrease on the 2019 TAEP estimate which was 4.23 * 10^{14} (Figure 3.17). The mackerel egg production by period since 2004 is shown in Figure 3.18.

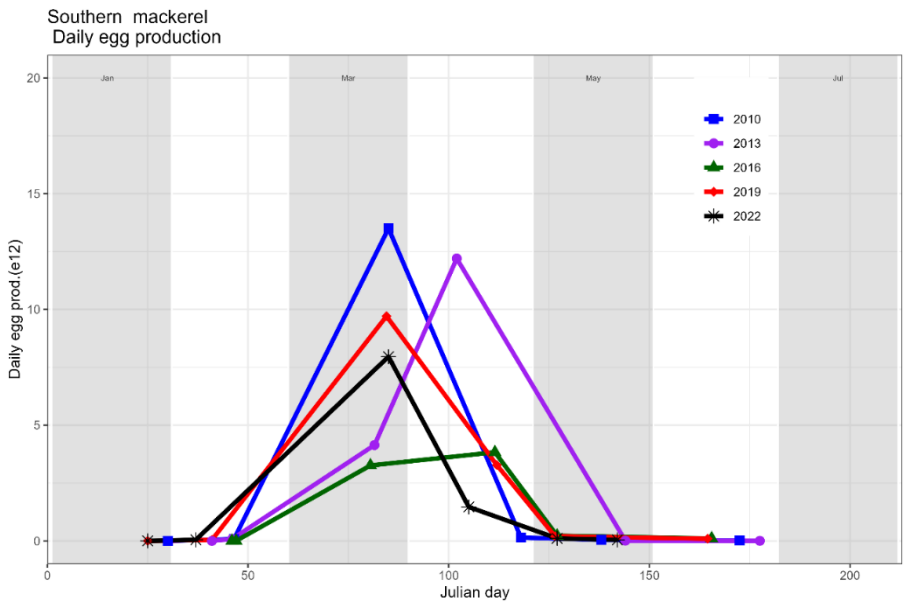

Figure 3.16 Annual egg production curve for mackerel in the southern spawning component for 2022, black line). The curves for 2010, 2013, 2016 and 2019 are included for comparison.

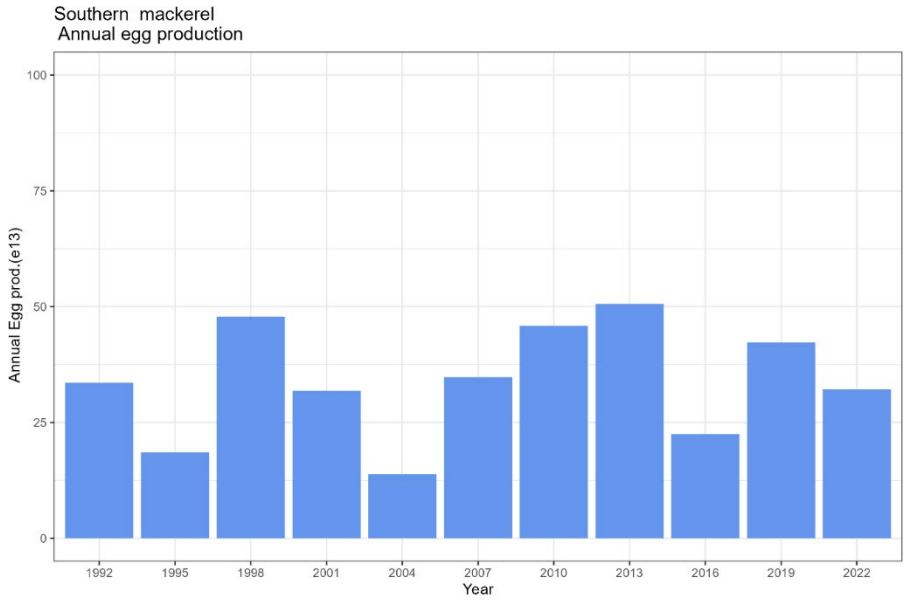

Figure 3.17 The total annual mackerel egg production for 1992 – 2022 for the southern spawning component.

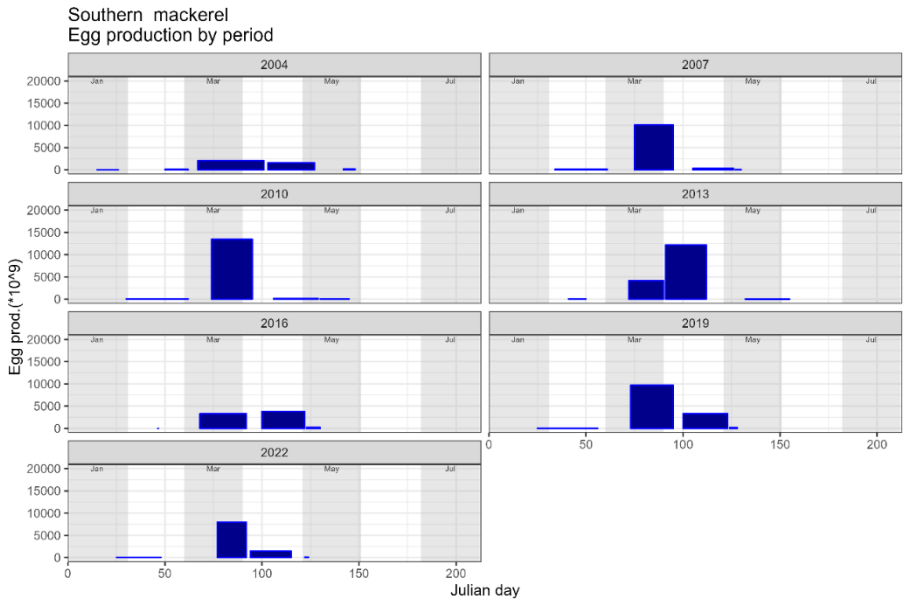

Figure 3.18 Egg production by period for the southern spawning component since 2004.

Table 3.5 Estimate of the 2022 total mackerel stage I egg production by period for the southern component using the histogram method.

Dates	Period	Days	Annual stage I egg production x 10^{14}
Jan 25th – Feb 17th	2	24	0.012
Feb 18th – Mar 17th	2 - 3	28	1.213
Mar 18th – Apr 2nd	3	16	1.274
Apr 3rd	3 - 4	1	0.052
Apr 4th – 25th	4	22	0.327
Apr 26th – May 1st	4 - 5	6	0.036
May 2nd – 11th	5	10	0.011
May 12th – May 31st	Post 5	20	0.009
Total	2.930		

3.5.2.3 Total Egg production (Western and Southern areas)

The total annual egg production (TAEP) for both the western and southern components combined in 2022 is **2.093x10^{15}** (Figure 3.19). This is an increase in production of **28%** compared to 2019, 1.64*10^{15} (Figure 3.19).

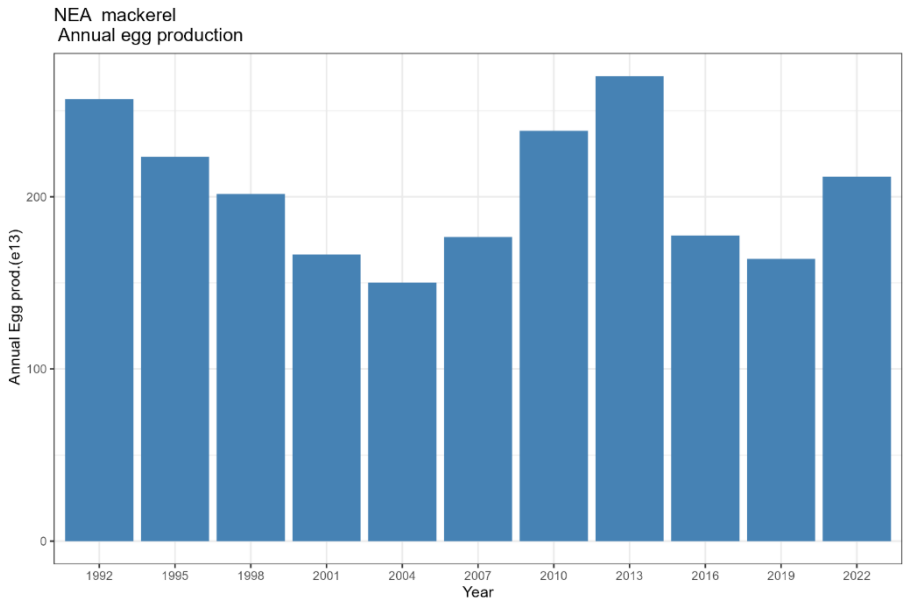

Figure 3.19 Combined mackerel TAEP estimates (*10^{13}) - 1992 – 2022.

3.5.3 Fecundity of Northeast Atlantic mackerel

3.5.3.1 Adult sampling

During the 2022 survey, 6784 adult mackerel were collected from 170 trawl hauls between 36.30°N and 61.75°N during periods 2–7. This year there has been a significant increase in the number of samples collected (2312) compared to previous surveys thanks to the valuable collaboration of the pelagic fishing industry (PFA). Only females were chosen for reproductive studies, so in this section, the results refer to mackerel females. In all, 1811 ovary samples (Figure 3.20 were used for AEPM (annual egg production method). Only 43% of the samples planned were collected (Table 3.6). Deviation from the initial plan was observed in all periods; the interannual variability in the mackerel migration as well as the probability of successful fishing effort makes it difficult to fit into the original sampling scheme.

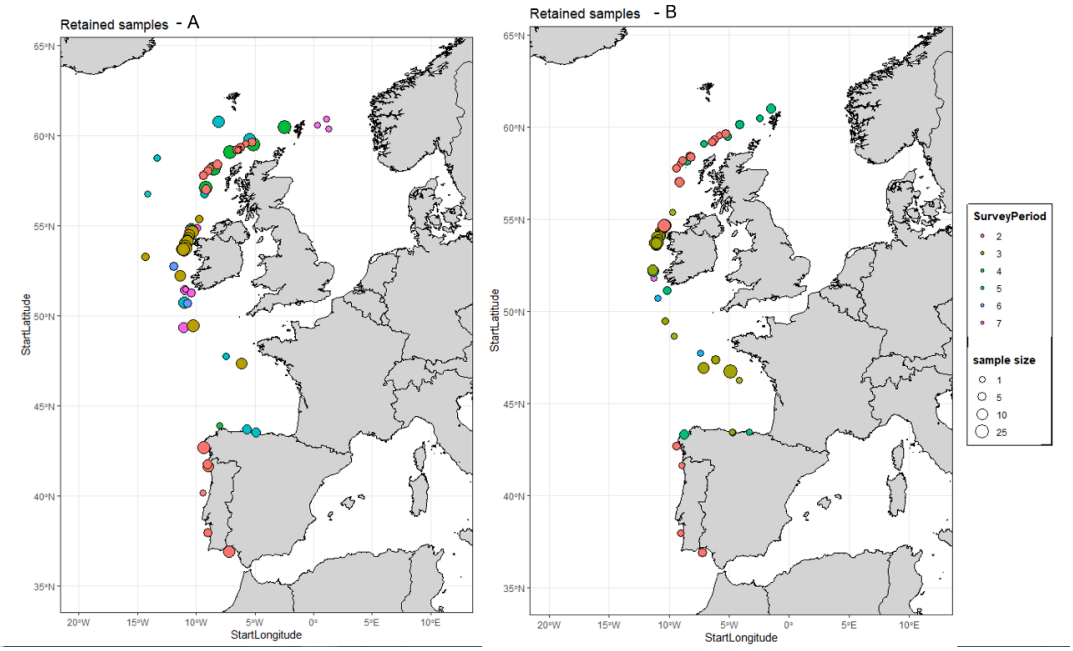

Figure 3.20 A: Mackerel ovary samples collected in 2022 for AEPM and DEPM by period. B: Mackerel ovary samples that were used for fecundity counting by period.

Table 3.6 Summary of fishing effort and the number of mackerel samples collected for AEPM and DEPM during the 2022 survey in Western and Southern components. Positive and negative hauls show the number of hauls where mackerel was present or absent, respectively. The number of collected and planned ovary samples are shown both in numbers and as percentages (number of collected samples compared to planned).

Period	2	3	4	5	6	7	Total
Positive hauls	27	55	16	16	9	10	133
Negative hauls	8	16	3	6	2	2	37
Ovary samples retained	74	891	602	145	75	26	1813
Planned	380	1830	1630	165	125	90	4220

Percentage (%)	19%	49%	37%	88%	60%	29%	43%

3.5.3.2 Histological screening

From the 1813 ovary samples, a total of 1717 samples were screened by histology and classified as described in the manual (ICES, 2019a; for DEPM samples see DEPM section). 1699 were valid for further analysing. From the 1699 samples analysed (Figure 3.21), 5% were assigned to stage 1 (previtellogenic oocytes), 11 % to stage 2, (early vitellogenic oocytes), 18 % to stage 3 (vitellogenic oocytes), 43% to stage 4 (migratory nucleus stage), 24% to stage 5 (hydrated oocytes). In total only 29% of the females were classified as pre-spawning or close to spawning, i.e., samples could be used for potential fecundity analyses, and 51% of the females were classified as spawning. Spawning females were only used for analyses of atresia. Migratory nucleus (4) was the most abundant stage in periods 2 to 5 and hydrated stages (5) in periods 3 to 6. Stage 1 increased significantly in period 7 (Figure 3.21).

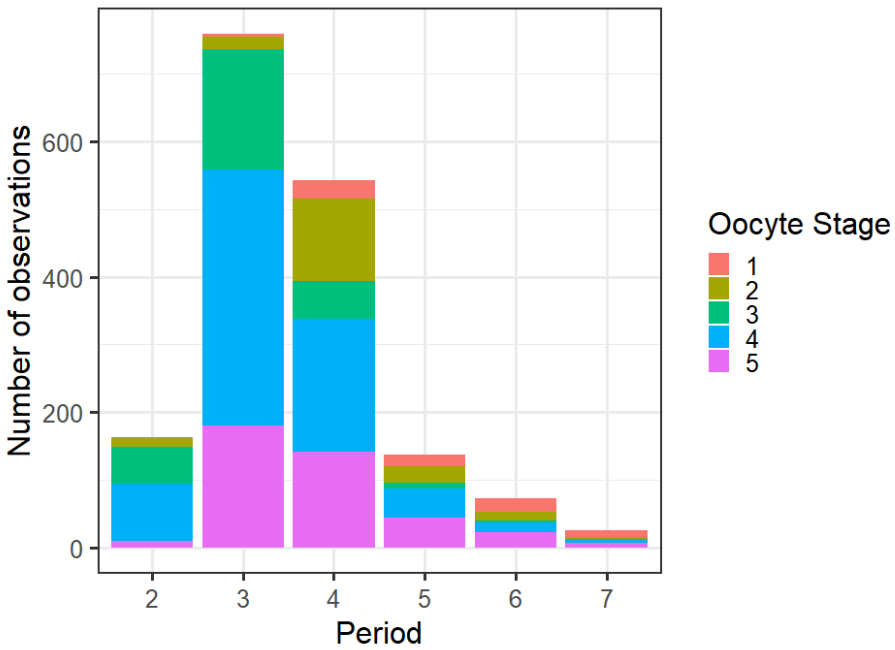

Figure 3.21 Frequencies of most advanced oocyte developmental stage in screened ovaries: 1-previtellogic oocyte stage; 2-early vitellogenic oocyte stage (< 400 µm); 3-vitellogenic oocytes; 4- nuclear migratory oocyte stage; 5-hydrated oocyte stage.

From the histological screening, a total of 492 samples qualified for potential fecundity analysis, which represents ~29% of the total samples screened by histology (N = 1699). After the whole mount screening, this number decreased to 396 samples. The reasons for disqualifications after the whole mount screening was mostly due to the detection of spent ovaries and the presence of hydrated oocytes. The number of samples used to estimate fecundity decreased further as 2 samples had an oocyte leading cohort diameter smaller than 400 µm. According to the manual (ICES 2019a, SISP 5), ovaries with a leading cohort smaller than 400 µm are considered to be not fully recruited yet; not all oocytes that are going to be spawned may have reached the 185 µm threshold that is used to classify oocytes as maturing.

Different to previous years WGMEGS decided for the fecundity analysis samples that had signs of stage 4 oocytes (migratory nucleus stage) should also be included. Stage 4 oocytes can be regarded as a marker for imminent spawning. For previous surveys these samples were disqualified even if the samples had no spawning marker (hydrated oocytes, eggs or post ovulatory follicles (POF´s)). This was an extra measure taken to assure that no spawning fish were included in the potential fecundity estimate. A Chi-squared statistical test was performed to check if ovaries with stage 4 oocytes were different with regards to fecundity than those without (see section 3.5.3.3).

POF´s are important spawning markers and were found in 54% of the samples (Figure 3.22). For all periods except period 2, the ovaries with POFs were more abundant than those without, particularly in periods 4 and 5.

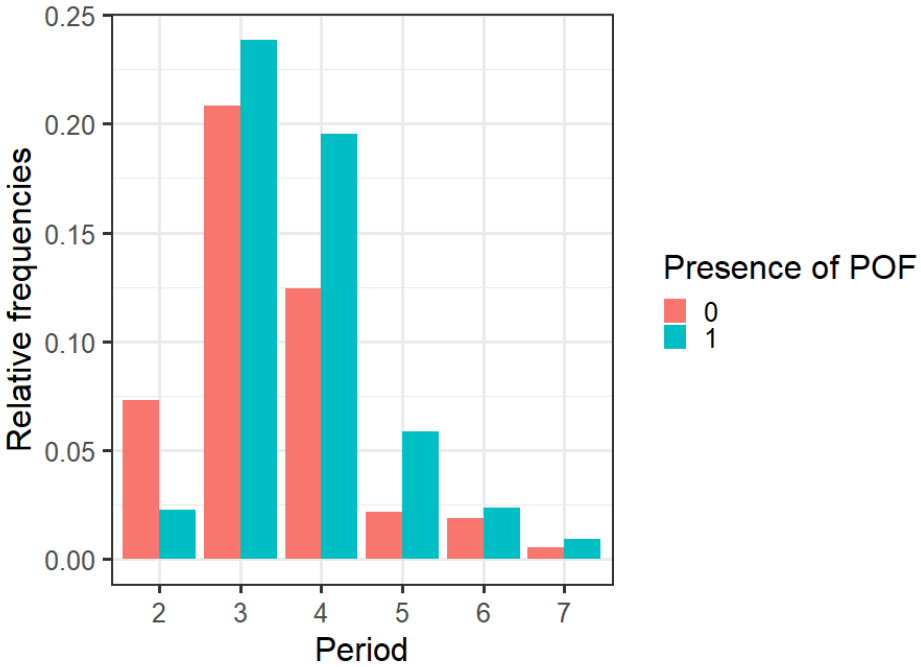

Figure 3.22 Frequencies of POF presence/absence among screened ovaries in each period.

3.5.3.3 Potential Fecundity in the Western and Southern combined components

For all mackerel females used for potential fecundity analysis an initial check (Figure 3.23 a-d) was done on the distribution of fish length, weight, Fulton's condition factor (100 × weight/length^3), and gonad-somatic index (GSI; 100 × Ovary weight/Fish weight).

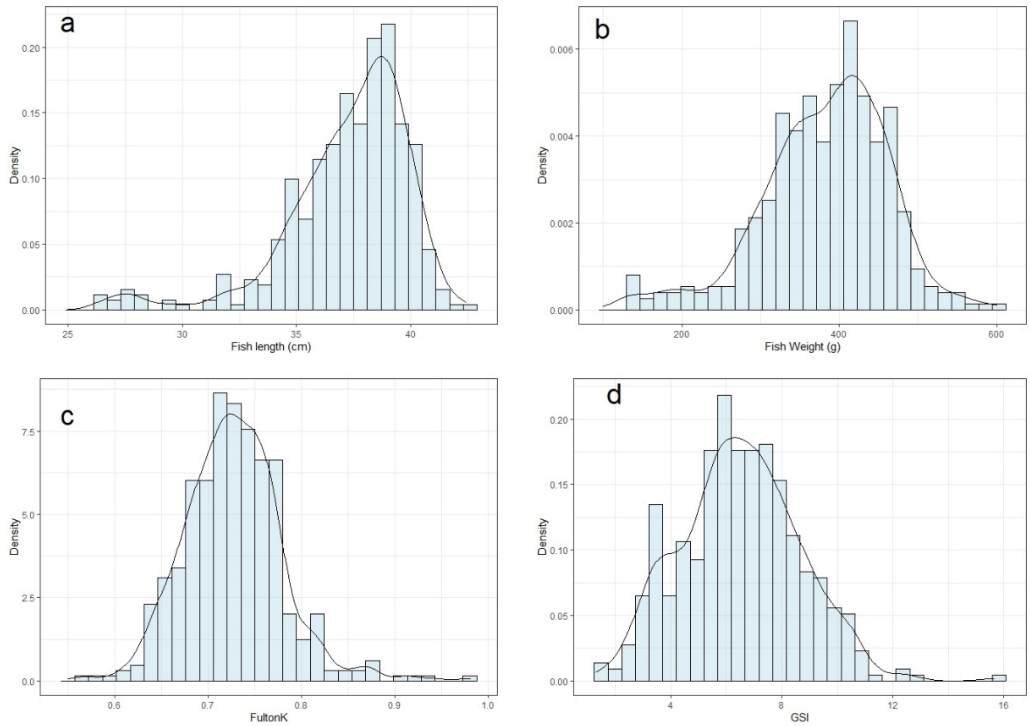

Figure 3.23 Histogram of the distribution of a) Fish length b) Fish weight, c) FultonK index and d) GSI of individuals analysed for fecundity.

Similar to the previous surveys only fish with condition factor between 0.5 and 1.2, and GSI between 1 and 25 were included (ICES 2014) in the fecundity and atresia estimates. In 2022, as in 2019, no females were excluded from the analysis based on these biological parameters.

Relative potential fecundity in 2022 ranged from 34 to 3212 oocytes/g fish, with a median value of 1313 oocytes/g fish (Figure 3.24). In surveys prior to 2013, values below 300 and above 2100 were excluded. Since the 2013 survey (ICES 2014) it was agreed not to delete them however, but instead replace the use of arithmetic mean by median. The median is considered to be more robust. In 2019, this issue was discussed again, and it was agreed to test a trimmed mean as an alternative to the median. WGMEGS analysed the time-series (ICES 2021, Figure 3.4.3.3.4) and found that the median estimates were close to the mean and trimmed mean estimates. In 2022 the trimmed mean, removing 10% of the data, was 1311 oocytes/g fish, practically similar to the median and mean estimations. For consistency with previous years, we continue to use the median and calculate realised fecundity based on the detailed calculation manual completed with corresponding STATA and R-code by the working group in 2020.

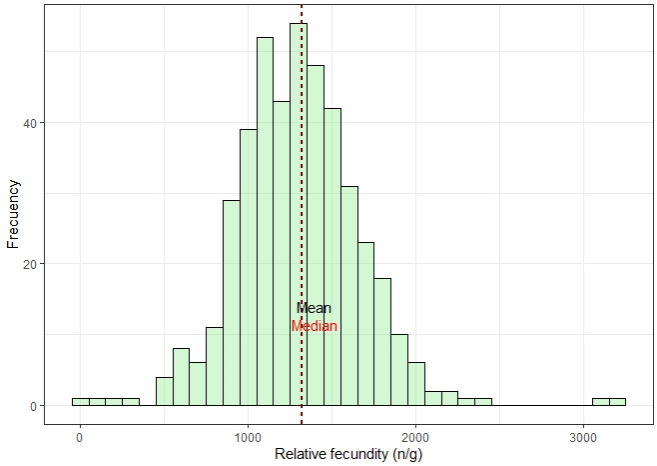

Figure 3.24 Relative fecundity values of 2022 mackerel samples. The red and black dotted lines are the median and mean values of relative potential fecundity (1313 n oocytes/g fish and 1319 n oocytes/g fish, respectively).

Potential fecundity against fish length (Figure 3.25a) and weight (Figure 3.25b) showed a positive trend that was similar to those found in previous years (ICES 2017 and ICES 2019c).

Relative potential fecundity vs. length or weight (Figure 3.26a and 3.26b) showed no clear trends. Relative potential fecundity vs. latitude showed a similar range of values throughout the sampling area, and no trend was detected (Figure 3.27).

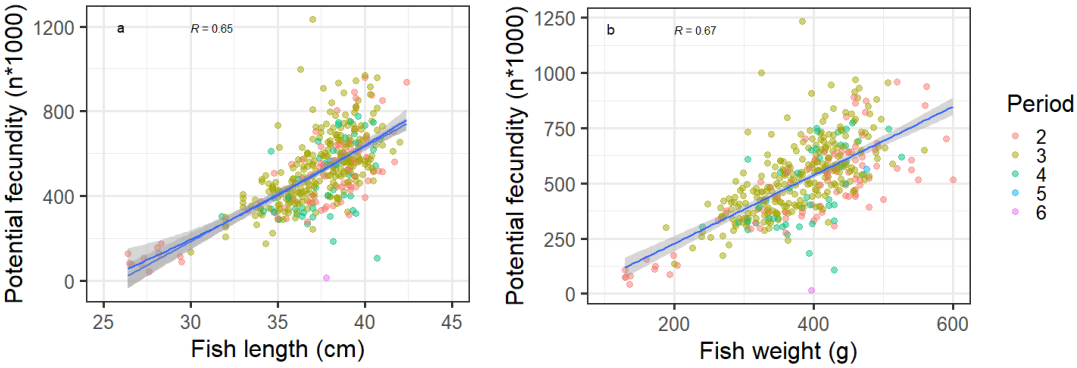

Figure 3.25 Regression analysis for potential fecundity on fish length (a) and fish weight (b) respectively.

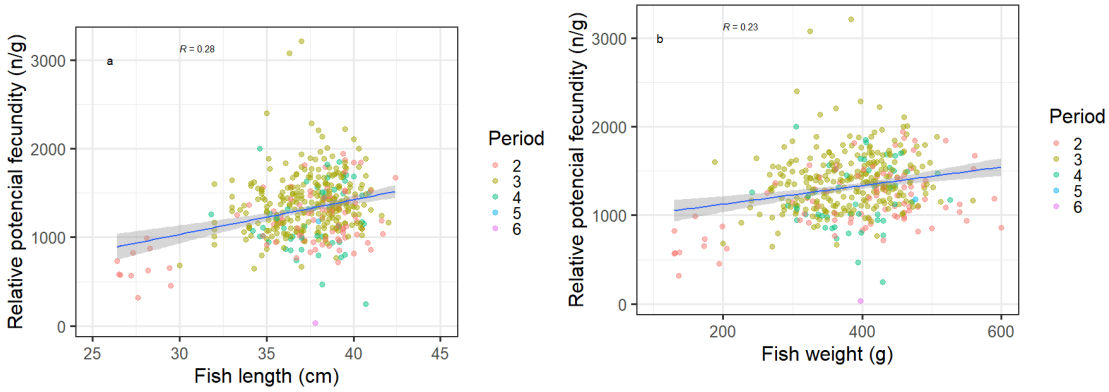

Figure 3.26 Regression analysis for relative potential fecundity on fish length (a) and fish weight (b) respectively.

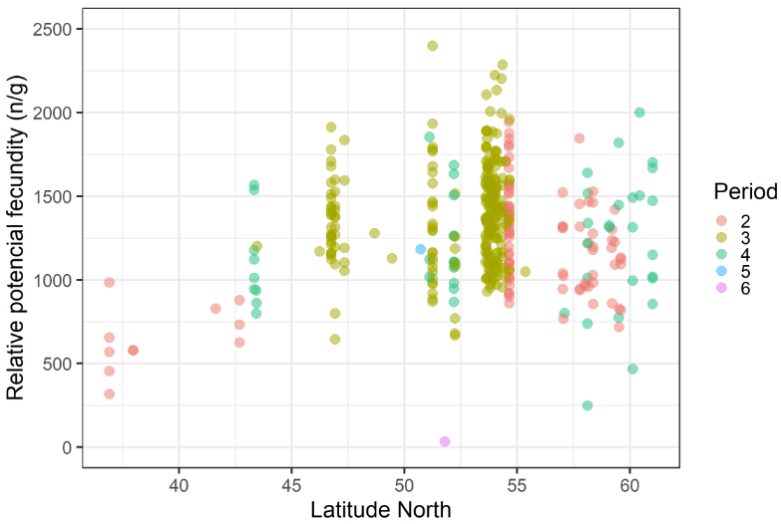

Figure 3.27 Regression analysis for relative potential fecundity on latitude.

As previously mentioned about the fecundity estimate, (section 3.5.3.2), we this year also included ovary samples with stage 4 oocytes. Oocyte stage 4 samples represented about half the total number of fecundity samples and had almost similar median fecundity value as the other samples; 1314 versus 1302 (n/g). This difference was not significant (P = 0.726, Pearson median test).

In 2022 the Netherlands pelagic commercial fleet contributed significantly to the sampling of adult fish. WGMEGS was concerned about the impact of this new supplier on the size distribution of fish. As described above, fecundity is size-dependent, and the fecundity in 2022 was 10% higher than in 2019. Thus, if the samples provided by the commercial fleet had come from a different fraction of the population, i.e., considering that commercial fishing gear selects larger fish compared to scientific gear), this could have affected fecundity. The mean and scatter plot of fish length distribution by sampling source (Figure 3.28) indicates no difference between the length distribution of fish caught in scientific (letter code A-O) or commercial surveys (letter code V and X).

The only sample clearly different from the rest was the one collected in Portuguese waters (letter O) in period 2. It is likely that these specimens correspond to a resident population of young mackerel of age 2 predominantly, presumably in their first year of maturity.

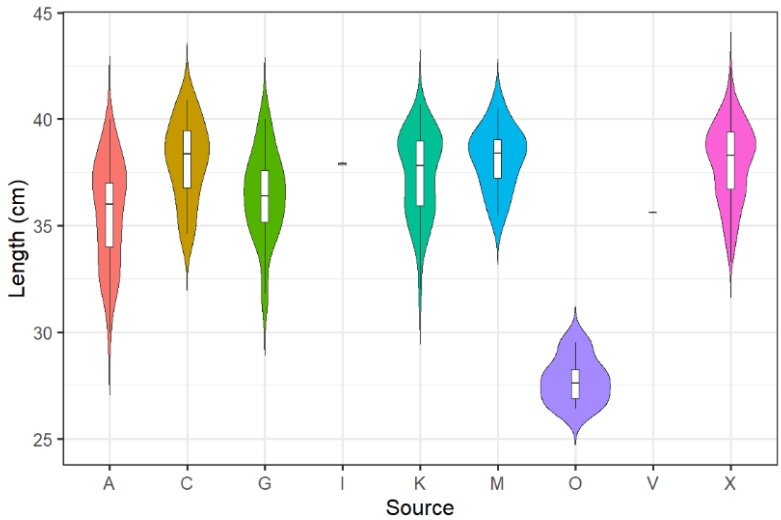

Figure 3.28 Violin plot to show the variability of length by sampling source. Letter code: A: Ireland, C: Scotland. G: Germany, I: Netherlands, K: AZTI-Spain, M: IEO-Spain, O: Portugal, X and V: Commercial fleet.

3.5.3.4 Atresia and realized fecundity

The samples used for the analysis of atresia were collected from the entire survey area and during all periods. Of the 858 fish which were classified as spawning, 243 showed signs of early alpha atresia, which resulted in a prevalence of 28% (Table 3.7). This value was similar to the value obtained in 2019 (Table 3.7). For the 2022 surveys, 74 samples were analysed for intensity of atresia. The geometric mean for the intensity of atresia for 2022 was slightly higher than found for 2019 (20 vs 19 n/g) as was also the loss per day (45 vs 43 n/g) and total loss during the spawning period (45 vs 43 n/g). However, since the potential fecundity was higher for 2022 compared to 2019 and previous years back to 1998, the percentage loss was the lowest recorded; 3 % for 2022 versus 4 % for 2019, which was the previous lowest.

By subtracting the atretic loss from the potential fecundity, a realized fecundity of 1268 (oocytes/g fish) was obtained. From 1998 to 2019 (Table 3.7), the final estimates of realized fecundity ranged from 1002 to 1209 (grand mean = 1076, SD = 71). The 2022 estimate of realized fecundity (1268 oocytes/g fish) is 18% higher than the mean for those years. Furthermore, the number of samples analysed in 2022 was the highest in the series, indicating that the fecundity estimate sufficiently reflects the stock fecundity of 2022. Therefore, it is considered suitable for calculating the 2022 SSB.

Table 3.7 Time series of adults' parameters estimation.

Parameter	Y1998	Y2001	Y2004	Y2007	Y2010	Y2013	Y2016	Y2019	Y2022
Fecundity samples (n)	96	187	205	176	74	132	97	62	396
Prevalence of atresia (n)	112	290	348	416	511	735	713	252	243
Intensity of atresia (n)	112	290	348	416	511	56	66	64	74
Relative potential fecundity (n/g)	1206	1097	1127	1098	1140	1257	1159	1191	1313
Prevalence of atresia	0.55	0.2	0.28	0.38	0.33	0.22	0.3	0.28	0.28
Geometric mean intensity of atresia (n/g	46	40	33	30	26	27	30	19	20
Potential fecundity lost per day (n/g)	3.37	1.07	1.25	1.48	1.16	0.8	1.2	0.71	0.75
Potential fecundity lost (n/g)	202	64	75	89	70	48	72	43	45
Relative potential fecundity lost (%)	17	6	7	9	6	4	6	4	3
Realised fecundity (n/g)	1002	1033	1052	1009	1070	1209	1087	1147	1268

3.5.4 Biomass estimation of Northeast Atlantic mackerel

Total spawning stock biomass (SSB) was estimated using the realised fecundity estimate of 1268 oocytes/gr female, a sex ratio of 1:1 and a raising factor of 1.08 (ICES, 1987). According to the Annual Egg production Method (AEPM) the spawning stock biomass (SSB) was estimated as shown below:

$$SSB = \frac{TAEP}{F'} * s * cf$$

Where

F′ = realized fecundity,

s = sex ratio of 1:1,

cf = 1.08 (fixed raising factor to convert pre-spawning to spawning fish)

Giving an estimate of spawning stock biomass of:

- 3.065 million tonnes for western component (2019: 2.301).
- 0.499 million tonnes for southern component (2019: 0.792).
- 3.565 million tonnes for western and southern components combined (2019: 3.093)

This is an increase in SSB estimate of 18% compared to the 2019 SSB estimate (Figure 3.29 and Table 3.8).

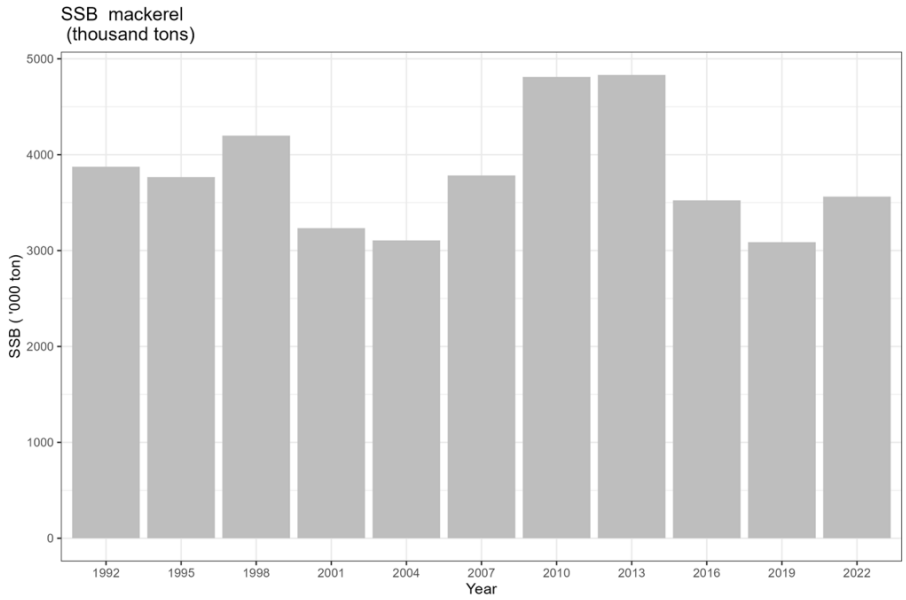

Figure 3.29 SSB estimates for NEA mackerel. 1992-2022

Table 3.8 NE Atlantic Mackerel SSB (kt) and Total Annual egg production (TAEP) derived from the mackerel egg surveys for the Southern, Western and combined survey area.

Year	Component	TAEP	SSB (kt)
1992	Combined	2.57*e15	3874.5
1995	Combined	$2.23*e^{15}$	3766.4
1998	Combined	$2.02*e^{15}$	4198.6
2001	Combined	$1.67*e^{15}$	3233.8
2004	Combined	$1.50*e^{15}$	3106.8
2007	Combined	$1.77*e^{15}$	3783.0
2010	Combined	$2.38*e^{15}$	4810.8
2013	Combined	$2.70*e^{15}$	4831.9
2016	Combined	$1.77*e^{15}$	3524.1
2019	Combined	$1.64*e^{15}$	3087.5
2022	Combined	$2.09*e^{15}$	3563.5
1992	Southern	$3.36*e^{14}$	507.2
1995	Southern	$1.86*e^{14}$	370.4
1998	Southern	$4.79*e^{14}$	882.9
2001	Southern	$3.18*e^{14}$	417.5
2004	Southern	$1.38*e^{14}$	309.2

2007	Southern	$3.48*e^{14}$	744.7
2010	Southern	$4.59*e^{14}$	926.3
2013	Southern	$5.06*e^{14}$	904.0
2016	Southern	$2.25*e^{14}$	447.3
2019	Southern	4.23*e14	796.7
2022	Southern	2.93*e14	499.0
1992	Western	$2.23*e^{15}$	3367.2
1995	Western	$2.05*e^{15}$	3396.0
1998	Western	$1.54*e^{15}$	3315.8
2001	Western	$1.35*e^{15}$	2816.4
2004	Western	$1.36*e^{15}$	2797.6
2007	Western	$1.42*e^{15}$	3038.3
2010	Western	$1.92*e^{15}$	3884.4
2013	Western	$2.20*e^{15}$	3927.9
2016	Western	$1.55*e^{15}$	3076.8
2019	Western	$1.22*e^{15}$	2290.8
2022	Western	1.80*e15	3065.0

3.6 Horse mackerel in the western spawning area

3.6.1 Spatial Distribution of Stage I Horse Mackerel Eggs

Period 3 – In period 3 horse mackerel spawning started in the Cantabrian Sea and southern Biscay, but numbers of eggs found were very low. Higher spawning took place in the Celtic Sea but again numbers were still low (Figure 3.30).

Period 4 – Horse mackerel spawning continued in the Cantabrian Sea, extending into southern Biscay. Eggs were again found in the Celtic Sea but numbers were lower than in period 3 (Figure 3.31).

Period 5 – Horse mackerel spawning continues in the Cantabrian Sea, Celtic Sea and northern Bay of Biscay, but still in low numbers. Some eggs were also found south and west of Ireland (Figure 3.32.).

Period 6 –Spawning continued in northern Biscay, the Celtic Sea and to the southwest of Ireland. For the first time in a number of years large numbers of eggs were reported in a number of stations close to the 200m contour. Peak spawning took place during this period (Figure 3.33).

Period 7 – Eggs were found from northern Biscay to west of Scotland, being concentrated off the southwest of Ireland. In general egg numbers were low but occasional stations with moderate to high counts were observed (Figure 3.34).

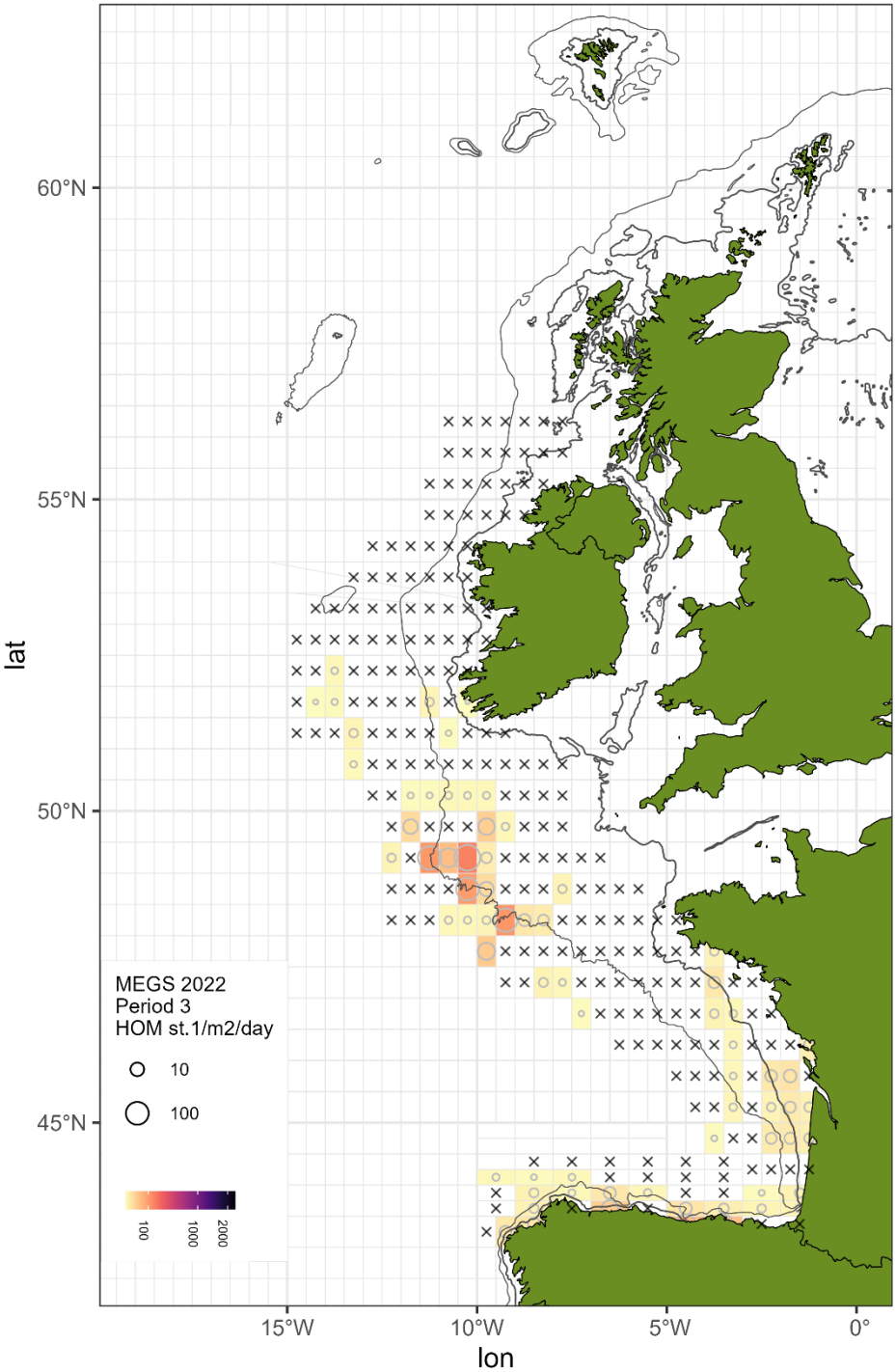

Figure 3.30. Horse mackerel egg production by half rectangle for period 3 (March 4th – April 8th). Circle areas and colour scale represent horse mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

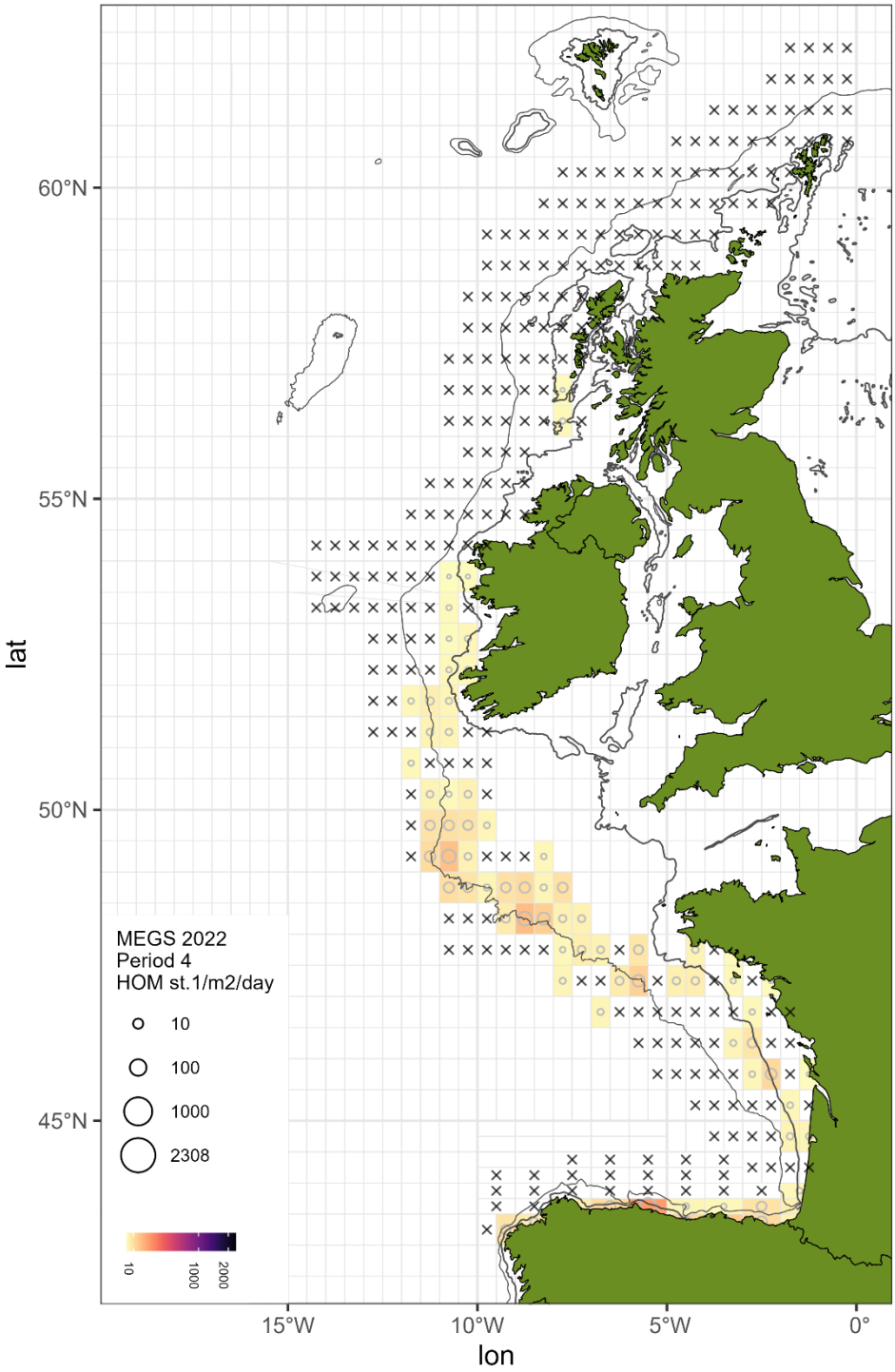

Figure 3.31 Horse mackerel egg production by half rectangle for period 4 (April 9th – 29th). Circle areas and colour scale represent horse mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

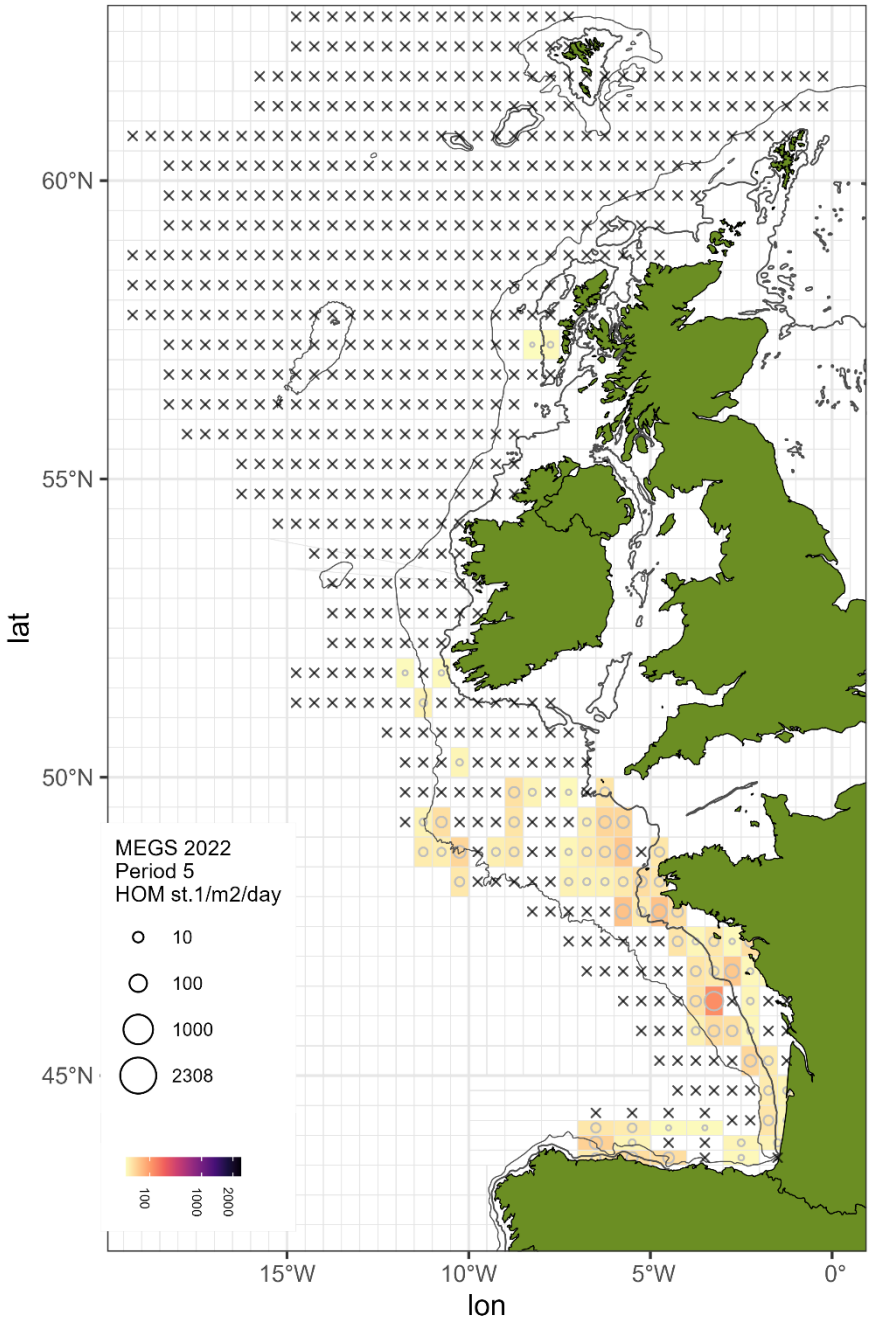

Figure 3.32 Horse mackerel egg production by half rectangle for period 5 (Apr 30th – May 31st). Circle areas and colour scale represent horse mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

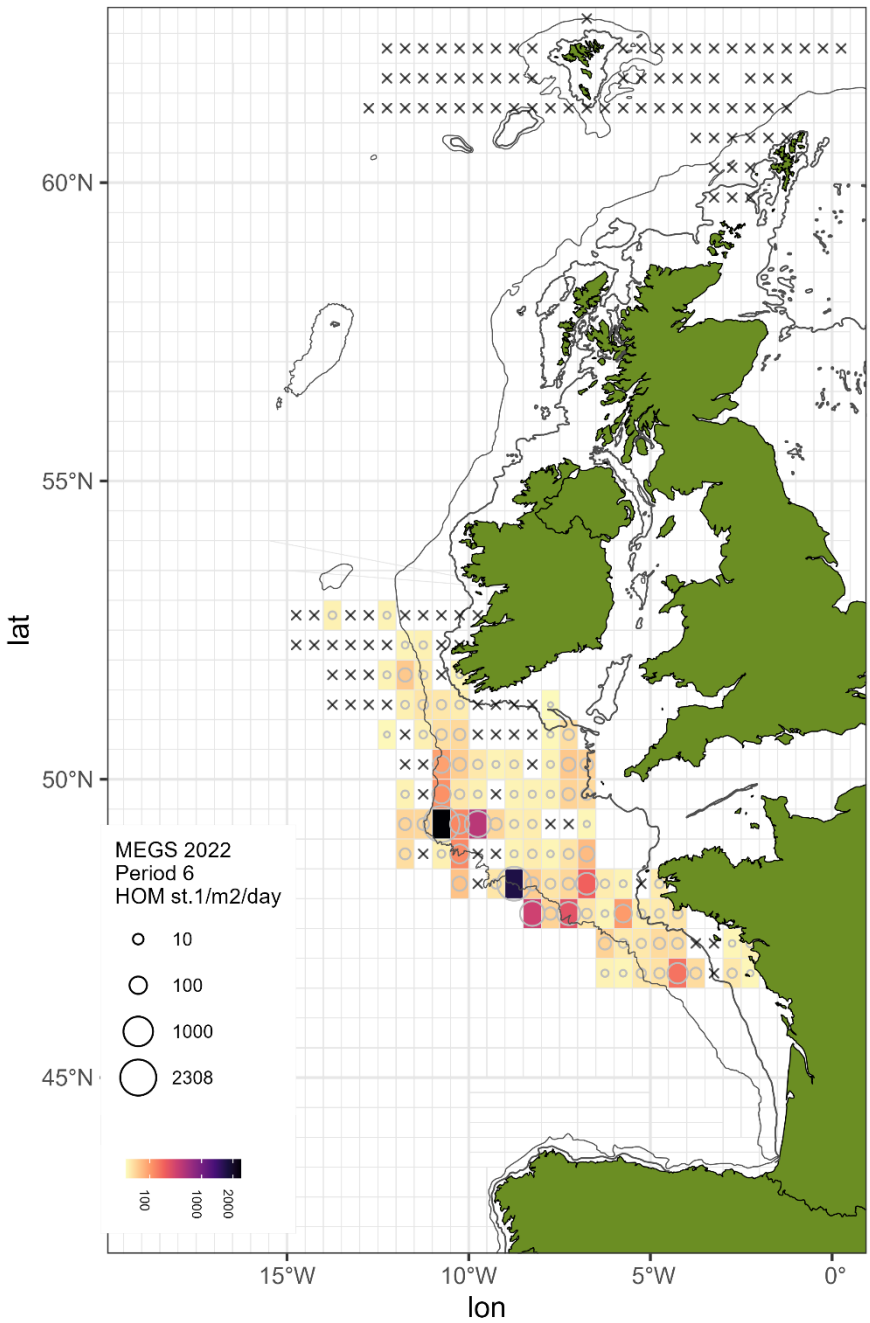

Figure 3.33 Horse mackerel egg production by half rectangle for period 6 (June 1st – 30th). Circle areas and colour scale represent horse mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

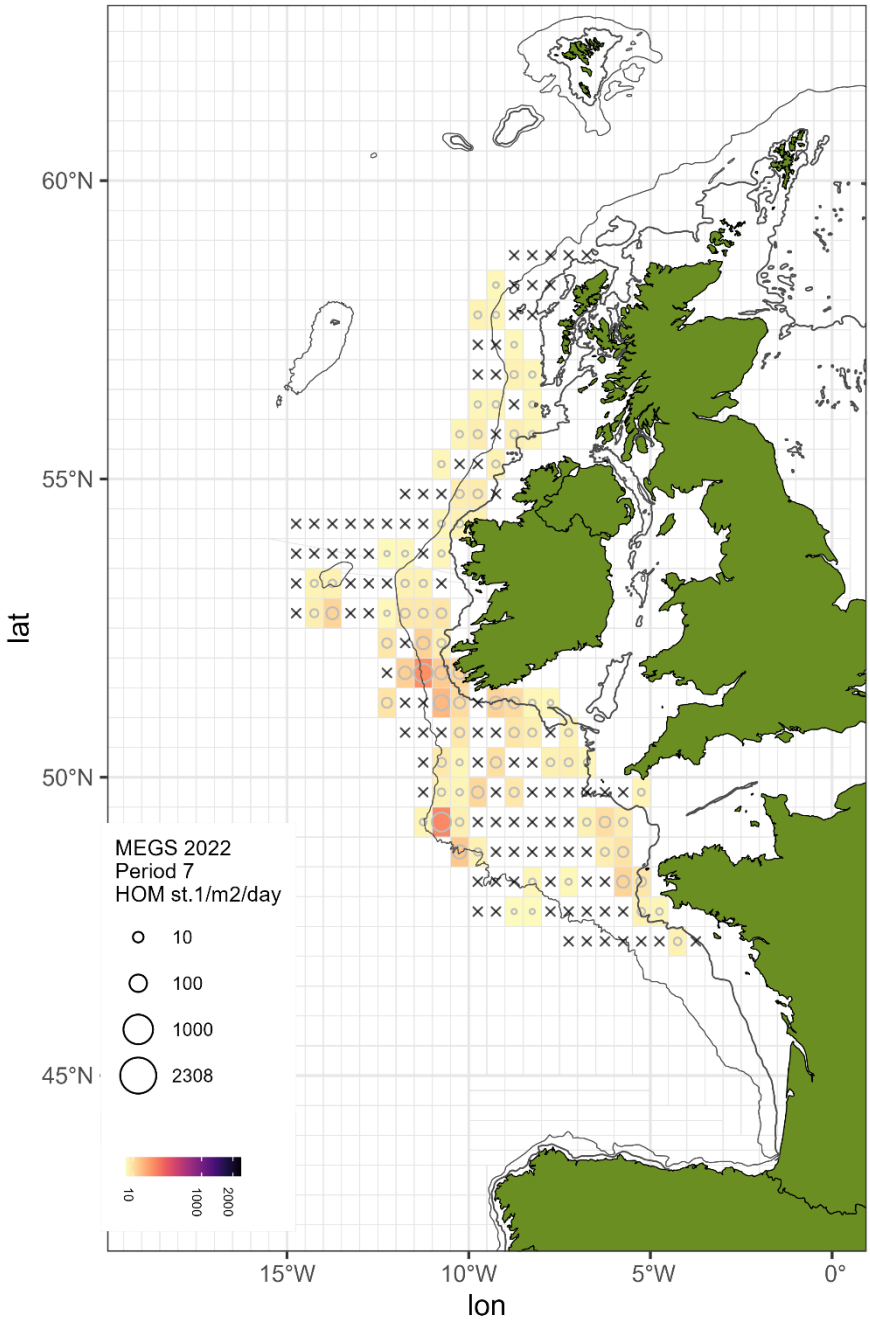

Figure 3.34 Horse mackerel egg production by half rectangle for period 7 (July 1st – July 31st). Circle areas and colour scale represent horse mackerel stage I eggs/m2/day by half rectangle. Crosses represent zero values.

3.6.2 Egg Production in Western Horse Mackerel

Period number and duration are the same as those used to estimate the western mackerel stock, as are the dates defining the start and end of spawning (Table 3.9). The shape of the egg production curve does not suggest that those dates should be altered for 2022 (Figure 3.35). An exercise, similar to the one carried out for mackerel in period 6, was not carried out for horse mackerel as WGMEGS feel that the Netherlands period 6 survey adequately delineated the northern boundary of horse mackerel spawning during this period. The total annual egg production was estimated at **5.51 x 10^{14}**. This is almost a threefold increase on 2019 which at 1.78 × 10^{14} was the lowest estimate of annual egg production ever recorded for this species (Figure 3.36). Horse mackerel egg production by period since 2007 is shown in Figure 3.37.

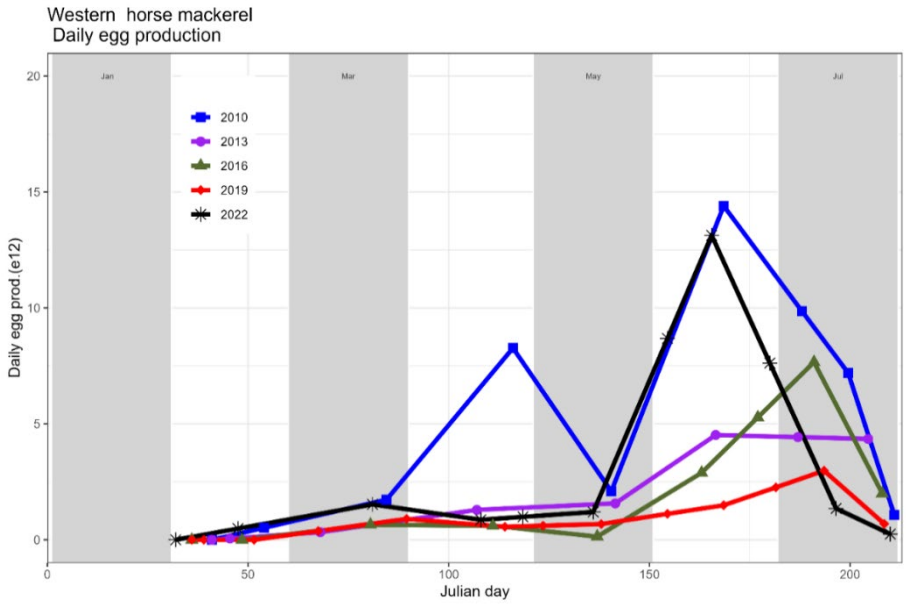

Figure 3.35 Annual egg production curve for western horse mackerel for 2022, (black line). The curves for 2010, 2013, 2016 and 2019 are included for comparison.

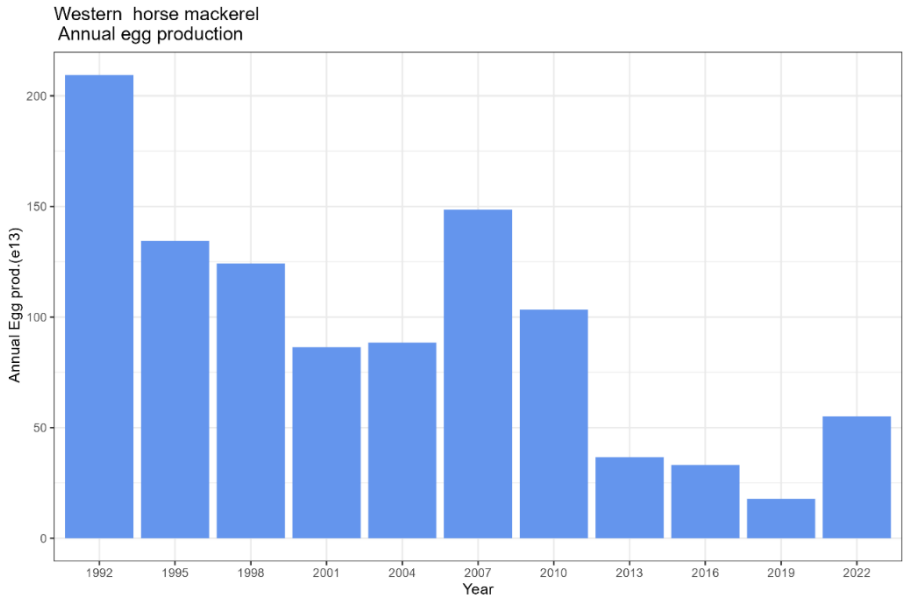

Figure 3.36 The total annual horse mackerel egg production for 1992 – 2022 for the western stock.

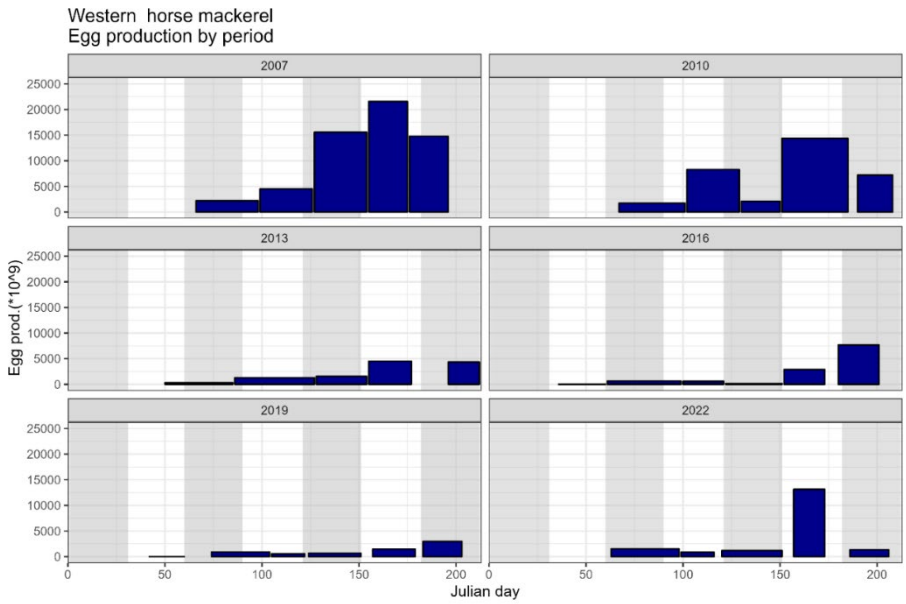

Figure 3.37 Egg production by period for the western horse mackerel spawning component since 2007.

Table 3.9 Estimate of western horse mackerel total stage I egg production by period using the histogram method for 2022.

Dates	Period	Days	Annual stage I egg production * 10^{15}
Feb 1st – Mar 3rd	Pre 3	31	0.015
Mar 4th – Apr 8th	3	36	0.055
Apr 9th – 26th	4	18	0.016
Apr 27th – 29th	4 - 5	3	0.003
Apr 30th – May 31st	5	32	0.040
Jun 1st – 5th	5 - 6	5	0.047
Jun 6th – 22nd	6	17	0.246
Jun 23rd – Jul 4th	6 – 7	12	0.010
Jul 5th – 25th	7	21	0.028
July 26th – July 31st	Post 7	6	0.001
Total		0.551	

3.6.3 Horse mackerel fecundity sampling

3.6.3.1 Adult Sampling

During the 2002 MEGS surveys, it was planned to collect samples of 1840 female horse mackerel in the peak of spawning (periods 6 and 7) (Table 3.10). In total 1658 horse mackerel were caught from 41 trawl hauls between 46.70°N and 60.70°N (Figure 3.38). Of these fish, 587 were females and these ovaries were used for the application of the DEPM. Regarding achieving the sampling goal, only 32% of the planned samples were collected (Table 3.11). Difficulties in reaching the adult sampling target are common during WGMEGS surveys, so deviation from the initial plan was perceived in both periods. Nevertheless, this year the number of females collected increased considerably (587compared to 182 in 2019) thanks to the sampling contribution of the commercial fleet.

Table 3.10 Summary of the number of samples collected and used to estimate the different parameters. P = Period, Haul= Number of hauls, Fish= Number of fish measured, RFish= Number of individual randomly sampled and measured, DFish = Number of individual fish sampled by direct sampling and measured, MatFe= number of mature females, SpawFe= Number of mature females in maturity stage 4 (Hydrated), MatF_C: No. of ovaries from mature females that were collected, MatF_H: Number of ovaries from collected mature females that were histologically screened, POFAge: No. of ovaries assigned as "with presence of POF" in histological screening, nNcent: No. of ovaries analysed for batch fecundity.

Period	nHaul	nFish	R_nFish	D_nFish	nMatFem	nSpawFem	nMatFem_C	nMatFem_H	nMatFem_H_R	nPOFAge	nNcent
6	15	800	792	8	382	38	276	265	257	265	39
7	20	858	828	30	401	79	311	168	138	168	32
Total	35	1658	1620	38	783	117	587	433	395	433	71

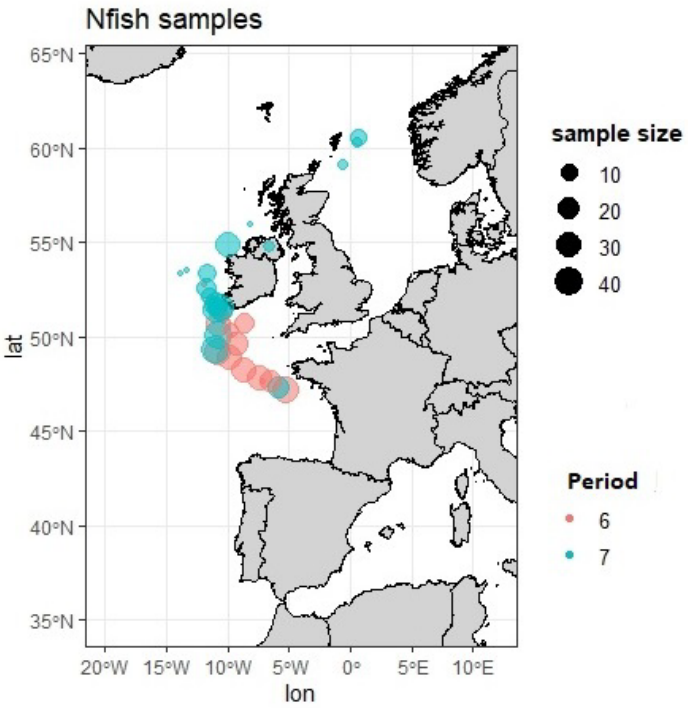

Figure 3.38 Horse mackerel ovary samples collected in 2022 for DEPM by period.

Table 3.11 Summary of fishing effort and the number of horse mackerel samples collected for DEPM during the 2022 survey in Western stock. Positive and negative hauls show the number of hauls where horse mackerel was present or absent, respectively. The number of collected and planned ovary samples are shown both in numbers and as percentages (number of collected samples compared to planned).

Parameter	Period 6	Period 7	Total
Positive hauls	15	25	40
Negative hauls	1	0	1
Ovary samples retained	276	311	587
Planned	920	920	1840
Percentage (%)	30%	36%	33%

Horse mackerel length varied from 19.9 to 42 cm in period 6 and from 22 to 40.5 cm in period 7 (Figure 3.39). The mode was slightly higher in period 6 (31.6 cm) than in period 7 (30.2 cm). Total weight ranged from 70-548 g in period 6 and from 96.5 to 550 g in period 7 (Figure 3.40). As for length, the mode for weight was 253 and 230 g for period 6 and period 7 respectively.

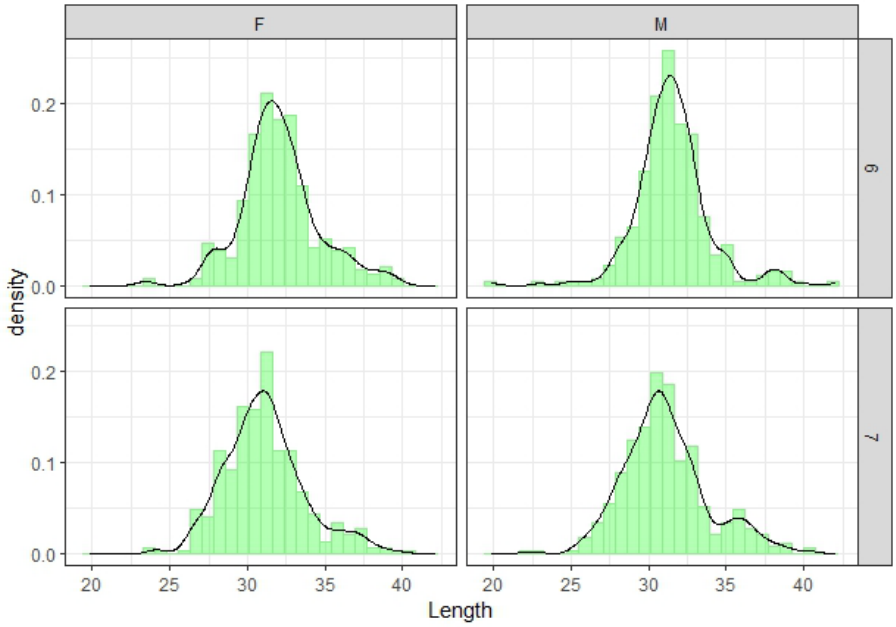

Figure 3.39 Histograms of length distribution of horse mackerel by period (6 and 7) and sex. F: Female and M: Male.

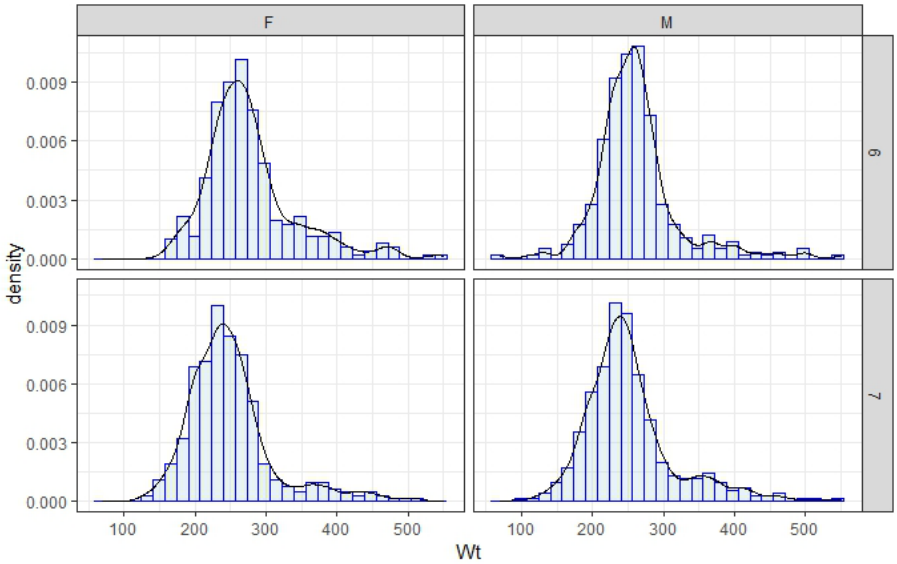

Figure 3.40 Histograms of weight distribution of horse mackerel by period (6 and 7) and sex. F: Female and M: Male.

Mean length and weight values by period and sex are presented in Table 3.12. T-test analysis applied to the length indicates that the mean lengths were statistically different (t = 4.947, df = 1441, p-value = 8.4e-07) between periods, with the mean length in period 6 being higher (L = 31.78) than in period 7 (L = 31.11). By sex, lengths were statistically different in period 6 (t = 2.911, df = 634.84, p-value = 0.003734, females were higher than males), but not in period 7 (t = 0.033, df = 799.39, p-value = 0.9735).

Table 3.12 Mean length, mean weight and modes of the horse mackerel captured in 2022 by period.

Period	Mean Length (cm)		Mean Weight (g)		Mode Length (cm)		Mode Weight (g)	
	M	F	M	F	M	F	M	F
6	31.5	32.1	261	277	31.5	31.3	254	225
7	31.1	31.1	252	250	30.5	31.5	236	230

3.6.3.2 Histological Screening

The histological screening was conducted to define the oocyte development stage of 433 ovaries collected in period 6 (265) and period 7 (168) (see Table 3.10 above). 328 out of 462 samples showed spawning markers, i.e., migratory nucleus stage, hydrating oocytes, eggs, and post-ovulatory follicles (POF). A total of 37 samples showed the presence of hydrated oocytes without considering those that were classified as "spent" or having "massive atresia", and the presence of POFs was recorded in 206 ovaries. As regards the oocyte development stage, in both periods, in most ovaries, stage 3 was the dominant stage (53% of the total), while ovaries with hydrated oocytes accounted for 13% (Table 3.12).

Table 3.12 Summary of horse mackerel screening results.

Period	Hydrated	POFs	Spent	Massive Atresia
6	43	177	2	1
7	16	68	5	8
Total	59	245	7	9

3.6.3.3 Mean Weight

Female mean weight per haul is estimated based on the observed female total weight data obtained from the fish sampling. However, before the estimation, it is necessary to consider the extra weight of hydrated females due to the hydration process.

To do that, the total weight of the hydrated females sampled was first corrected by applying a linear regression between the total weight of the sampled non-hydrated females (oocytes=4 and 5; POF= 1,2,3,4,5,6 and 7) and their corresponding gonad-free weight (Wnov, Figure 3.41) and then obtaining the expected total weight of all females. The extra females taken not at random, for batch fecundity, were not considered. The model fitted the data adequately ($R^2_{adj} = 0.9864$, n= 666).

Figure 3.41 Linear regression model between gonad-free-weight and total weight fitted to non-hydrated females. Equation: Total weight = -17.8594 + 1.112043 Wnov (n = 666, R2adj = 0.9864, p = 0.001).

The female mean weight was obtained as the weighted mean of the average expected female total weights per haul (Lasker, 1985), provided that the number of mature females in the haul was 20 or more. The variance was estimated using the methodology of Picquelle and Stauffer (1985). The mean weight of females estimated for period 6 was slightly higher than for period 7, 275.44 (n = 326) and 243.4 g (n = 305), respectively) (Table 3.13).

Table 3.13 Expected female mean weight estimates for the 2022 Western horse mackerel DEPM survey for period 6 and period 7.

Period	Female Mean Weight (g)	var	cv
6	275.444	124.919	0.673
7	243.450	136.128	0.748

3.6.3.4 Sex Ratio

The sex ratio in weight per haul is estimated as the ratio between the average female weight and the sum of the average female and male weights of the horse mackerel in each of the hauls. 11 and 12 hauls were used to estimate the sex ratio for period 6 and period 7 respectively.

The mean sex ratio was then obtained as the weighted mean of the sex ratio among hauls. The weighting was provided by the number of randomly sampled mature individuals in the haul, this being 20 or more to be considered in the calcultation. The variance was estimated using the methodology of Picquelle and Stauffer (1985). The mean sex ratio in period 6 was 0.508 (n=777) while it was 0.5 in period 7 (n=771) (Table 3.14).

Table 3.14 Mean sex ratio estimates for the 2022 Western horse mackerel DEPM survey for period 6 and period 7.

Period	Mean Sex Ratio	var	cv
6	0.508	0	0.006
7	0.500	0	0.005

3.6.3.5 Batch Fecundity and relative batch fecundity

Only females with most advanced oocyte developmental stage > 3, i.e., females with migratory nucleus stage and hydration stage, with no eggs or signs of being spent can be used to correctly estimate the batch fecundity. 152 samples met this criterion and were considered to estimate the batch fecundity by counting the total number of oocytes higher than 400 um by means of whole mount image analysis. The oocyte frequency size distribution of these samples (Figure 3.42) showed the presence of a separate set of oocytes (a batch) at a size of 750 um (Figure 3.43), but only in those samples where the most advanced stage of the oocyte was 5 (hydration stage).

Those samples at stage 4 (migratory nucleus stage) were rejected and the number of valid batch samples decreased to 26. In addition, valid samples of batch fecundity analysis have to meet the criterion of having a batch size above 100 oocytes; otherwise, samples in which the batch was not completely recruited would be included in the analysis and would bias the batch fecundity. This criterion reduced the number of samples from 26 to 13.

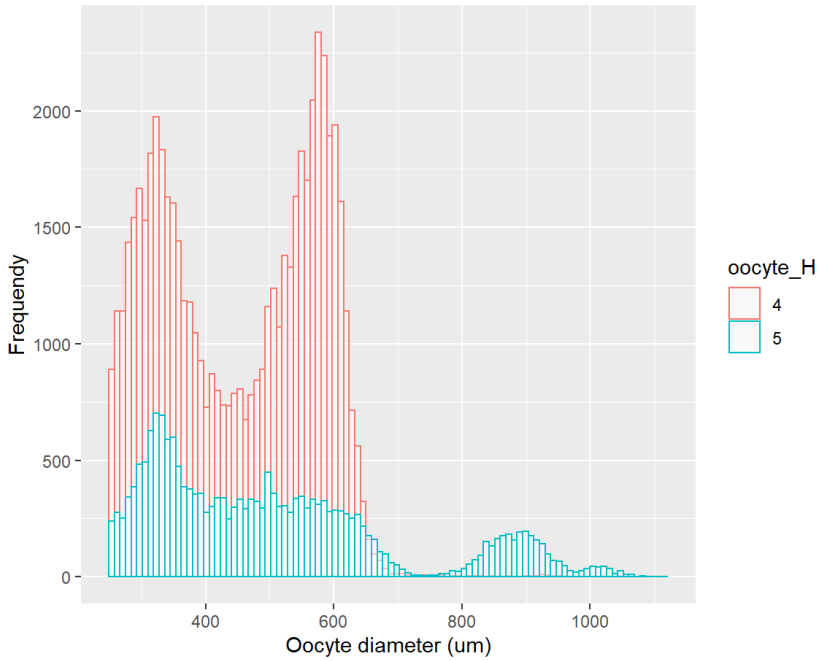

Figure 3.42 Oocyte frequency distribution of ovary samples selected for batch fecundity analysis. Oocyte_4 refers to females in which the more advanced oocyte development was migratory nucleus stage and Oocyte_5 refers to females in which the more advanced oocyte development was hydration stage.

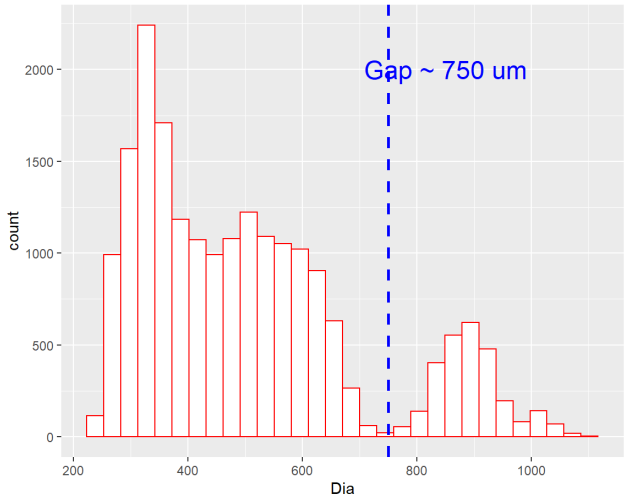

Figure 3.43 Oocyte frequency distribution of ovaries in oocyte_5 stage. The Blue dotted line shows the size at which a set of separated oocytes (batch) was observed.

Linear regression was selected to relate the individual number of oocytes per batch (batch.ov) and the corresponding female gonad-free weight (Wnov). It is assumed that relative fecundity is constant throughout horse mackerel life (ICES 2019a). Despite the low number of valid samples, the model was statistically significant but weak ($Batch._{ov}$ = 7280.5014 + 200.0639 W_{nov}, R^2 adj = 0.1769, n = 13); the female weight explains only 17.7% of the variability of the number of oocytes per batch. The fitted model was used to obtain the expected individual batch fecundity (Fexp) for all mature females (hydrated and non-hydrated) sampled per haul.

The mean batch fecundity was obtained as the weighted mean of the average expected individual batch fecundity per haul. The weighting factor was provided as the number of randonly sampled mature females together with the number of mature females obtained by direct sampling in the haul, this being above 20 to be considered in the calculation. The variance was estimated using the methodology of Picquelle and Stauffer (1985). The mean batch fecundity for the period 6 was slightly higher than for the period 7, 59860 oocytes (n = 334)and 55614 oocytes (n = 338), respectively (Tables 3.15 and 3.16).

Table 3.15 Mean batch fecundity and relative batch fecundity estimates for the 2022 Western horse mackerel DEPM survey for period 6 and period 7.

Period	Mean batch fecundity (No.eggs)	var	cv
6	59860.067	4173054.46	8.349
7	55613.873	5575229.01	10.012

Table 3.16 Relative batch fecundity estimates for the 2022 Western horse mackerel DEPM survey for period 6 and period 7.

Period	Relative mean batch fecundity (Frel) (No.eggs/g female)	var	cv
6	219.522	2.56	0.108
7	223.644	4.43	0.141

3.6.3.6 Spawning Fraction

Spawning fraction, i.e., the fraction of females spawning per day, is determined by applying the POFs' methodology described in the pelagic survey series for sardine (Masse et al., 2018). Thus, POF degeneration is divided into 7 histo-morphological stages as described in SIPS 5 manual (ICES 2019a, Table 7.1 and Figures 7.1 to 7.13). The spawning fraction per haul was estimated based on the average number of females with Day-1 or Day-2 POFs, divided by the total number of mature females in the sample. The haul was included in the estimation if the number of randomly sampled mature females in the haul are 20 or more females.

The mean spawning fraction was obtained as the weighted mean of the average spawning fraction per haul. The weighting factor was provided as the number of randonly sampled mature femalesThe variance of spawning fraction were calculated according to the equations developed by Picquelle and Stauffer (1985). The spawning fraction was 18.7% in period 6 (n = 326) while it decreased to 14.4% in period 7 (n = 305) (Table 3.17).

Table 3.17 Mean Spawning fraction estimates for the 2022 Western horse mackerel DEPM survey for period 6 and period 7.

Period	Mean Spawning Fraction	var	cv
6	0.187	0.00	0.049
7	0.144	0.00	0.056

The inverse of the spawning fractions gives the average spawning frequency of the mature females. The average spawning frequency was 5.3 and 6.9 days for period 6 and period 7 respectively.

3.6.3.7 Daily Fecundity

Daily fecundity (DF) is defined as the relationship between the sex ratio (R, in weight), the batch fecundity (Bfec, eggs per batch per female weight) and the spawning fraction (S, percentage of females spawning per day) divided by the female mean weight (Wf).

$$DF = \frac{R * Bfec * S}{Wf}$$

The mean daily fecundity for each period then was estimated using the formula above and the mean obtained in each period for each parameter as input, i.e., daily fecundity is not estimated by haul. Estimates of 20.86 and 16.38 eggs day^{-1} g^{-1} in period 6 and period 7 were obtained respectively. The difference may be influenced by the variation in spawning fraction between periods (Table 3.18).

Table 3.18 Mean daily fecundity estimates for the 2022 Western horse mackerel DEPM survey for period 6 and period 7.

Period	Daily fecundity (DF) (No.eggs/g female day)	var	cv
6	20.865	NA	NA
7	16.378	NA	NA

3.6.3.8 Biomass

Eggs in stage 1a were accounted for daily egg production that peaked in period 6 (Table 3.19). Mean daily egg production was estimated as the mean of daily egg production m^{-2} among the stations with positive egg observations multiplied by the total spawning area (m^2) which includes stations both with positive egg observations and interpolated ones.

Table 3.19 Daily egg production estimate for the 2022 Western horse mackerel DEPM survey for period 6. Po is the daily egg production by m2 of spawning area which is the surveyed area and Ptot is the daily egg production.

Period	Po (No.eggs/m^2/day)	Spawning area (m^2) (x10^{11})	Ptot (No.eggs/day)(x10^{13})
6	133.857	1.390603962	0.186

The spawning stock biomass (SSB) is then calculated as the ratio between the total daily egg production (Ptot, eggs day^{-1}) and the daily fecundity (DF, eggs day^{-1} g^{-1} female) in period 6 (Table 3.20). The adult parameters in period 6 for DF calculation in period 6 are summarised in Table 3.21 for a more comprehensive reading.

Table 3.20 SSB estimate for the 2022 Western horse mackerel DEPM survey for period 6 which was the peak of spawning period in 2022.

Period	Daily fecundity (DF) (No.eggs/g female day)	Ptot (No.eggs/day)(x10^{13})	SSB (kt)
6	20.865	0.186	891.445

Table 3.21 Mean parameters estimates for adults in 2022 for period 6 which was the peak of spawning period that year.

Period	Parameter	mean	var	cv
6	Female Mean weight (g)	275.444	124.919	0.673
6	Mean Sex Ratio	0.508	0	0.006
6	Mean Spawning Fraction	0.187	0	0.049
6	Mean batch fecundity (No.eggs)	59860.07	4173054.46	8.349
6	Relative mean batch fecundity (Frel) (No.eggs/g female)	219.522	2.558	0.108
6	Daily fecundity (DF) (No.eggs/g female day)	20.865	NA	NA

- **SSB revision for 2016**

In this sense, DEPM estimates of 2016 also were revised in 2022. In 2016 the total daily egg production was higher in period 7 than in period 6, the opposite of 2022, hence adult parameters were recalculated for that period. Note that for the daily egg production in 2016 Stage 1 egg numbers were used, while in 2022 Stage 1a egg numbers were used, so the SSB comparison between 2016 and 2022 is not straightforward. This should be revised.

Females mean weight in the peak of spawning was higher in 2016 (period 7) than in 2022 (period 6), 302.15 g (Table 3.22) and 275.44 g respectively (Table 3.21). However, relative batch fecundity was lower in 2016 (204.85 eggs g^{-1} female) than in 2022 (219.52 eggs g^{-1} female, Table 3.21). Note that batch fecundity in 2016 was recalculated with samples from 2016 and 2022, due to extremely low number of valid samples in 2016 that prevented doing any analysis with only samples from 2016. The spawning fraction was significantly lower in 2016 than in 2022, 0.106 and 0.187 (Table 3.21) respectively.

Table 3.22 Mean parameters estimates for adults in 2016 for period 7 which was the peak of spawning period that year.

Period	Parameter	mean	var	cv
7	Female Mean weight (g)	302.147	194.821	0.803
7	Mean Sex Ratio	0.510	0	0.011
7	Mean Spawning Fraction	0.106	0.003	0.156
7	Mean batch fecundity (No.eggs)	61299.21	3042269.98	7.045
7	Relative mean batch fecundity (Frel) (No.eggs/g female)	204.851	12.661	0.249
7	Daily fecundity (DF) (No.eggs/g female day)	10.956	NA	NA

Considering only the peak of spawning period in each year and the average daily fecundity, i.e., period 7 in 2016 and period 6 in 2022, the estimated SSB in each case shows a slight increase in SSB from 2016 to 2022, i.e., 699 160 tons (Table 3.23) to 891 445 tons (Tables 3.20) respectively.

Tables 3.23 SSB estimate for the 2016 Western horse mackerel DEPM survey for period 7 which was the peak of spawning period in 2016. Daily egg production was estimated using eggs in Stage 1.

Period	Daily fecundity (DF) (No.eggs/g female day)	Ptot (No.eggs/day)(x10^{13})	SSB (kt)
7	10.956	0.766	699.160

3.6.3.9 Quality of the data

The main aspects of the sampling affecting the quality of DEPM adults parameters estimation are:

Sampling process: The difficulty in collecting hydrated ovaries for batch fecundity estimation is evident. Even when samples are macroscopically staged as hydrated, many of them are histologically classified as non-valid because of the presence of ovulated oocytes. To overcome this handicap, the use of the migratory-nucleus oocytes stage as a valid stage to define the batch was tested. However, as it has been proved this year, this stage is not suitable for this purpose, i.e., the size gap between vitellogenic oocytes and the oocytes that consitute the batch is not formed. This results in a low number of samples for batch fecundity estimation.

Batch definition: The exclusive use of the hydrated stage also does not ensure the validity of the samples. Small well-defined batches have been detected in oocyte size frequency analysis above the size gap. This raises doubts about the full recruitment of oocytes into the batch could lead to an underestimation of batch fecundity. In this regard, at the moment it has not been studied what threshold might be used to define when a group of hydrated oocytes can be considered a batch. In the current year, those samples in which the number of oocytes in the batch was less than 100 were removed, assuming that the low of oocytes number in batch was because spawning had already started or the batch was not recruited completely.

Spawning frequency: The application of the POF method to estimate the spawning fraction requires knowledge of how POFs degrade over time, to assign an age to the POF stages observed in the ovaries. This process is species-specific and temperature dependent. In the absence of data for horse mackerel, we use the information obtained for sardine. Nevertheless, to achieve more realistic estimates of spawning frequency, specific experiments are needed to determine the age of horse mackerel's POFs.

Minimum sample size: The minimum number of samples in the haul was set to 20 to be considered to weight the estimation of the adults' parameters, i.e., mean female weight, spawning fraction, batch fecundity and sex ratio. This number is close to that established in the sampling protocol which indicates that 30 females should be collected randonly per haul. Whether this minimum weighting is adequate must be explored.

3.7 Horse mackerel in the southern spawning area

3.7.1 Egg distribution, spawning area and egg production

The horse-mackerel egg density (eggs/m2) distribution, during the 2022 survey, is shown in figure 3.44. The spatial pattern observed was, as is normally found, quite patchy. In 2022, in the northern region, abundances were lower than in other years, contrasting with the southern region where a higher than usual number of eggs were collected. Higher egg densities were observed in mid-outer shelf, particularly in the SW region, mid NW and Galician waters. Horse-mackerel eggs were found in 27% of the total 529 CalVET samples collected.

Following the laboratory work for identification and staging of all horse-mackerel eggs (using an 11-stage scale), all the calculations for area delimitation, egg ageing and model fitting for egg production (P0) estimation were obtained using modified routines and the functions available in the ichthyoanalysis package (http://sourceforge.net/projects/ichthyoanalysis). Peak spawning time was considered to be at 19h (+/- 2*3h) (WGALES 2016). Details on the laboratory processing and analyses of the eggs are described in the MEGS Manual (ICES 2019b).

The spawning area estimated for the 2022 survey was 26885 km^2 representing an increase of around 20% compared to the 2019 value.

The Total Egg Production estimated for the 2022 survey was 5.18 x 10^{11} Eggs/day (CV: 26.8%), 37% lower than the estimation for the previous survey, in 2019 (Figure 3.45).

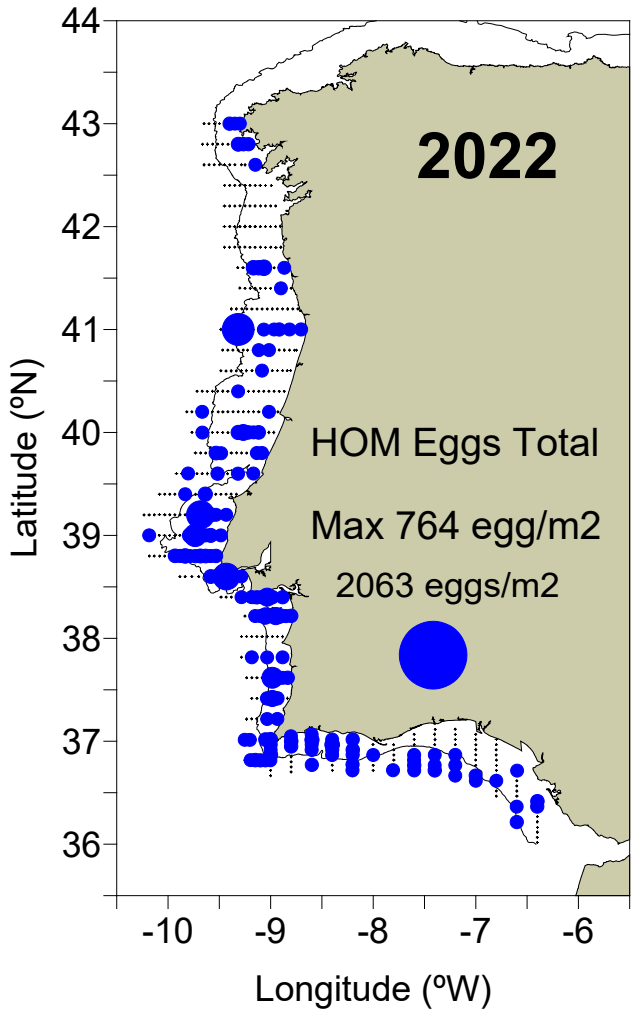

Figure 3.44 Horse-mackerel egg density distribution (eggs/m2) derived from the CalVET samples collected in the period 25 January – 17 February 2022.

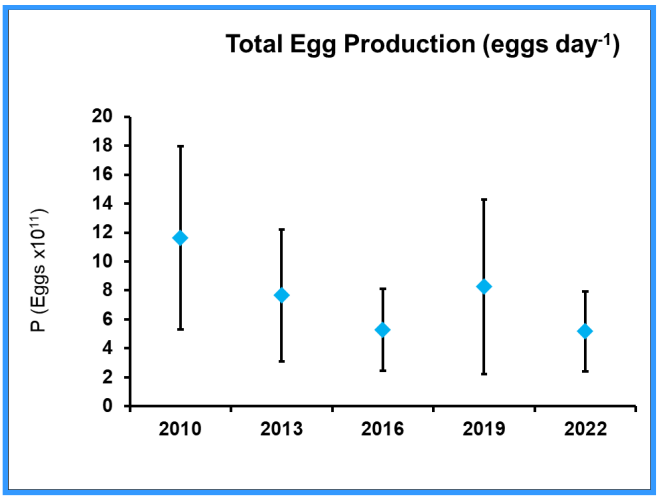

Figure 3.45. Horse-mackerel total egg production (eggs/day) for the survey series (2010-2022).

3.7.2 Adults parameters

From the fishing trawls carried out during the survey (Figure 3.46), biological data from 182 mackerel (MAC) and 2019 horse-mackerel (HOM) were recorded (ICES 2022). For MAC 56 ovary samples were collected for the estimations of the AEPM parameters (cf. section 3.5.3 of this report), while 800 HOM ovaries were processed histologically and analysed microscopically for the application of the DEPM to the HOM southern stock (including 44 hydrated ovaries effectively used for batch fecundity estimation).

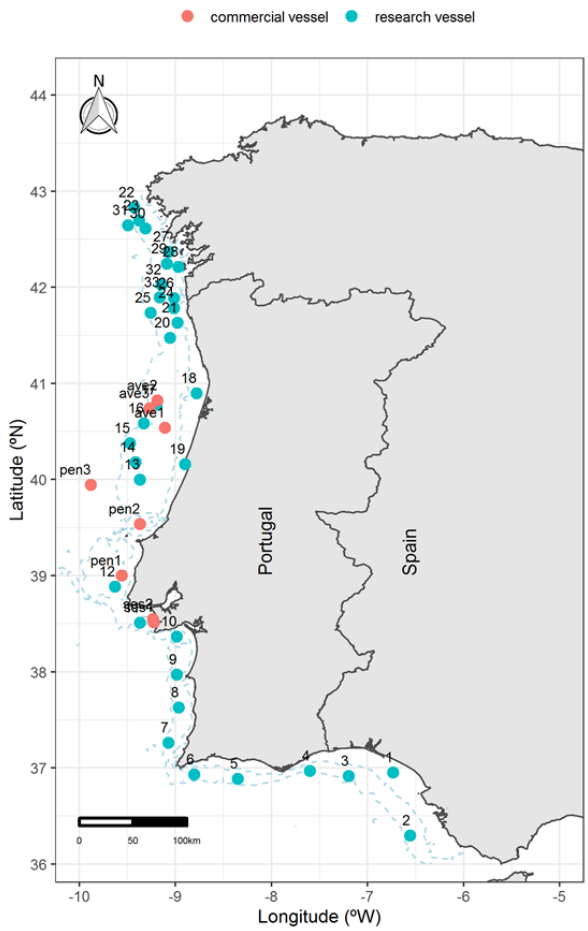

Figure 3.46 Position of the fishing hauls carried out during the survey onboard the research vessel or from the commercial fleet, from which horse mackerel samples were obtained for the estimation of the DEPM parameters, and mackerel samples for the application of the AEPM.

In the laboratory, the preserved ovaries were weighed, processed histologically, and the histological slides analysed according to the criteria described in the ICES SISP 5 (ICES 2019a). The estimation of the sex ratio (R), the mean female weight (W) and the mean female expected batch fecundity (F) were based on the biological data recorded from the fish samples. The preserved gonads and histological slides were used to measure the individual batch fecundity (Fobs), to assess the mature/immature condition of females, and to estimate the daily spawning fraction (S). Adult parameters (W, R, F, and S) were estimated independently for each fishing haul, using only the mature fish (macroscopic maturity stage >= 2), whereas for the whole surveyed area, means and CVs were calculated using the number of mature fish/females in the sample as weighing factor.

These adult parameter estimates resulting from the sampling during the 2022 DEPM survey couldn't be obtained for the present report, these final results being expected to be available for the ICES Horse mackerel benchmark meeting.

3.8 Daily Egg Production Method analyses for mackerel in the western, North Sea and Southern spawning areas

3.8.1 Egg production in Northeast Atlantic mackerel

3.8.1.1 Western and southern Mackerel

Following the recommendation of WKMSPA (ICES, 2012b) to compare the Annual Egg Production Method (AEPM) and the Daily Egg Production Method (DEPM), during 2022 the DEPM was implemented again next to the AEPM, as has been done in last MEGS surveys since 2013 forward. Daily egg production has been estimated using stage 1a mackerel eggs. The peak spawning for mackerel in the western and southern spawning areas is expected to be in Periods 3 and 4 (March and April) (ICES 2021).

The spawning area estimated for period 3 (271,648 Km^2) was approximately 20% less than in period 4 (323,863 km^2) (Table 3.24).

Large densities of stage 1a mackerel eggs were found around the 200m contour line in the Cantabrian Sea, Celtic Sea and southwest of Ireland during period 3. For period 4 bigger stage 1a egg densities were also found along the 200m contour line, primarily in the north part of Bay of Biscay and western Scotland (Figure 3.47). Mean Daily egg production (P0) using Stage 1a mackerel was estimated at 72.8 mackerel eggs/m^2/day for period 3 and 33.8 mackerel eggs/m^2/day for period 4 (Table 3.24).

Consequently, Total Daily Egg Production (Ptot) was estimated as $1.98 * 10^{13}$ eggs/day for period 3 and $1.09 * 10^{13}$ eggs/day for period 4. Therefore, P0 tot for period 3 is around twice as high as that for period 4.

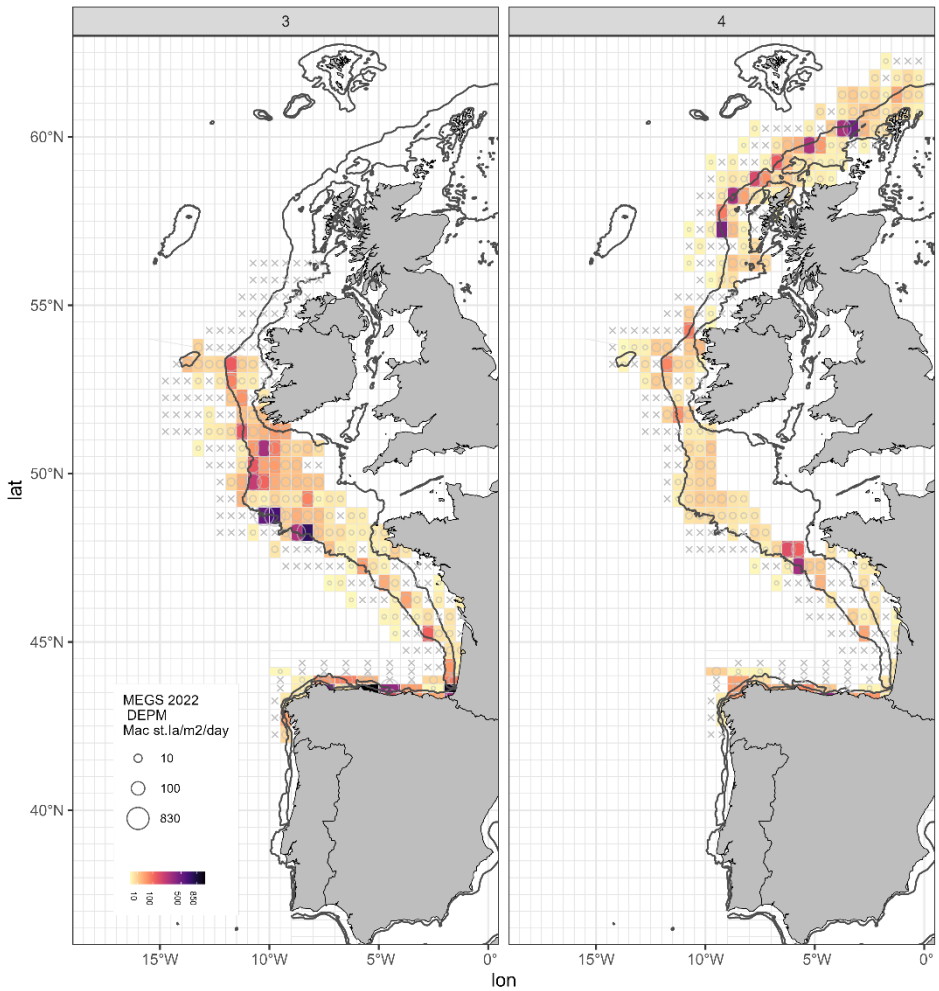

Figure 3.47 Daily egg production distribution for Mackerel (stage 1a eggs/m2/day) for periods 3 and 4.

Table 3.24 Estimated Daily egg production (P0) and spawning area using stage 1a mackerel eggs for Periods 3 and 4 (peak spawning)

Period	P0 (eggs/m²/day)	Spawning area (km²)	Ptot (eggs/day)(*10¹³)
3	72.8	271648	1.98
4	33.8	323863	1.09

3.8.1.2 North Sea Mackerel

The egg survey in the North Sea has been designed for utilizing the Daily Egg Production Method (DEPM) since 2020.

In 2022 Denmark, England and Norway conducted the North Sea mackerel egg survey in June (period 6). The samples were collected and analysed according to the WGMEGS manuals (ICES

2019a, 2019b). England and Norway sampled eggs with a Gulf VII plankton sampler while Denmark used a Nackthai sampler.

The North Sea mackerel survey was carried out from 5th June to 24th June (Table 3.3). During this period the spawning area between 53°N and 62°N was surveyed once, receiving a single coverage. The survey is designed to cover the entire spawning area with samples collected every half ICES statistical rectangle (ICES 2014).

The spatial stage 1a egg distribution is shown in Figure 3.48. Egg distributions are comparable to 2021, however egg numbers seemed to be more evenly distributed throughout the survey area this year. The egg production was calculated for the North Sea between 53°N and 62°N and bounded by the relevant coastlines to the east and west. No clear pattern in the distribution of egg densities can be observed.

Due to technical reasons, allied to the sampling, the majority of the stations along the transects between 53 and 54°N do not have valid quantitative data, however qualitative data describing the mackerel stage 1a and 1b egg abundance are available to interpret the overall egg distribution in this area. The two southern transects were sampled but there were issues with the accuracy of the flow data. This resulted in three valid stations south of 54°N being sampled, with a further three being interpolated. The invalid stations do give an indication of the presence and absence (qualitative data) of mackerel stage 1a and above over this area.

The total area sampled in 2022 was slightly smaller than the area sampled in 2021, the first full transect was started at 54° 15′N compared to 53° 15′N in 2021. The spawning area estimated for 2022 is 371126 km^2 and the mean Daily egg production (P0) using stage 1a mackerel eggs is 18.6 eggs/m^2/day. The total Daily egg production (P0total) was calculated for the total investigated area (Table 3.25). The total Daily egg production for 2022 was **$0.6909*10^{13}$** eggs/day. This is a 50% decrease in egg numbers reported in 2021 (Table 3.26).

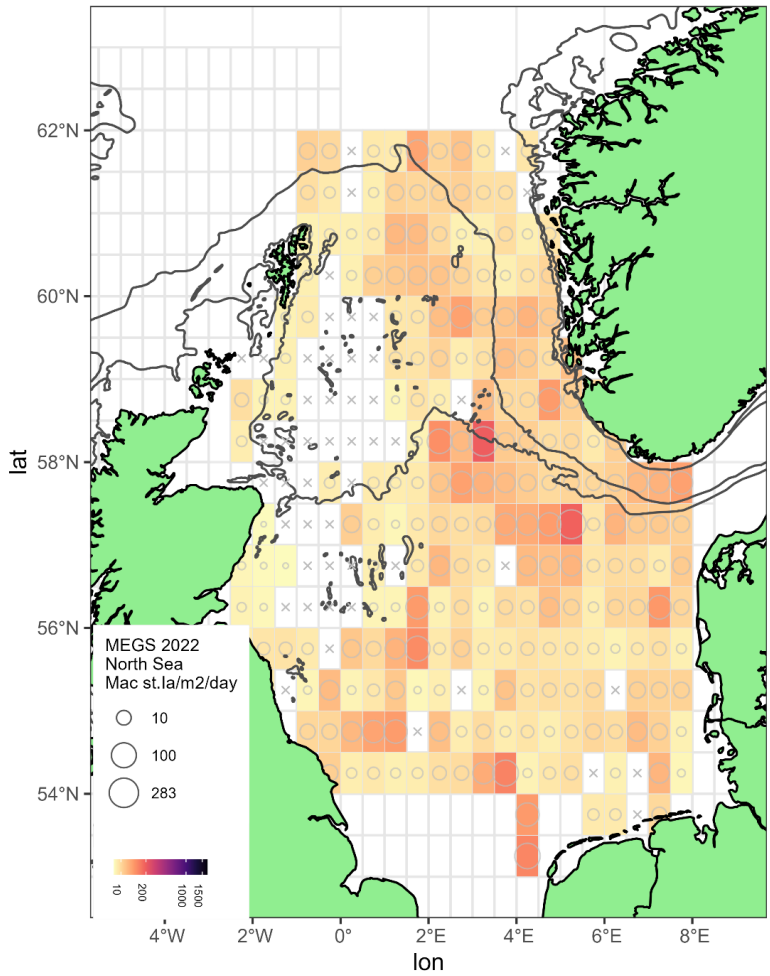

Figure 3.48 Heat map of Stage 1a mackerel egg production (eggs. m2. day-1) by half rectangle for the North Sea, 2022. Grey circles represent observed values, crosses represent observed zeros.

Table 3.25 Daily egg production estimate for mackerel (stage 1a)(P0) and spawning area in the North Sea in 2022.

Year	P0 (eggs/m2/day)	Spawning area (km2)	Ptot (eggs/day)(*10^{13})
2022	18.6	371126	0.69

Table 3.26 Comparison of Total Daily Egg production (Ptot) between 2022 and 2021.

Year	2022	2021
P0 total *1013	0.69	1.28

3.8.2 Fecundity of Northeast Atlantic mackerel

3.8.2.1 Western and southern Mackerel

The results for 2022 triennial are presented below. These results should be considered preliminary, as an extensive review of the application of the daily method in mackerel will be carried out next autumn at the WKMADE (see section 3.10.2).

DEPM adult sampling

The DEPM requires intensive sampling for adult parameters and it has proven to be difficult to achieve the planned number of samples. During the peak spawning the probability of finding valid samples increases and thus adult sampling should be directed on the months where peak spawning was expected to occur, i.e. periods 3 and 4. The optimum number of fish per haul for DEPM adult parameters estimation is 100 individuals. These fish should be randomly selected and total size, weight, sex, maturity and gonad weight taken (ICES 2022).

In 2022, sampling was more intense during the expected spawning peak, in periods 3 and 4 (Table 3.27). A total of 6050 mackerel were sampled, 71% of which were caught during peak spawning and between 40 and 60 °N latitude (Table 3.27), which covered most of the spawning area (see daily egg production maps in section 3.8.1.1).

Table 3.27 Number of mackerel (male and females) sampled by period (2 to 7) and latitude in 2022 (A) and 2019 (B). The proportion of the total fish in brackets. The periods corresponding to peak spawning are shaded.

A	Period												
2022	2		3		4		5		6		7		
Latitude °N	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	Total
36-40	64	(1.1)											64
40-44	185	(3.1)	378	(6.2)	627	(10.4)	82	(1.4)					1272
44-48			607	(10.0)			112	(1.9)	67	(1.1)			786
48-52			258	(4.3)	100	(1.7)	122	(2.0)	64	(1.1)	162	(2.7)	706
52-56			1516	(25.1)	203	(3.4)	4	(0.1)	100	(1.7)	3	(0.0)	1826
56-60	190	(3.1)	610	(10.1)			285	(4.7)					1085
60-65							211	(3.5)	100	(1.7)			311
Total n	439		3369		930		816		331		165		6050

B	Period												
2019	2		3		4		5		6		7		
Latitude °N	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	Total
36-40	81	(1.9)											81
41-45	109	(2.5)	1176	(27.2)	505	(11.7)	66	(1.5)					1856
46-50			733	(17.0)	100	(2.3)	418	(9.7)	49	(1.1)			1300
51-55			13	(0.3)	18	(0.4)			200	(4.6)	137	(3.2)	368
56-60			63	(1.5)	100	(2.3)	155	(3.6)	203	(4.7)			458
61-65							48	(1.1)	150	(3.5)			198
Total n	190		1922		723		687		602		137		4324

The total number of sampled specimens increased by 40% in 2022, compared to 2019. This is mainly due to the high sampling intensity between 52 and 60 degrees north, and despite the fact that sampling at more southerly latitudes was lower than in 2019 (Table 3.27). The optimum of 100 randomly sampled fish was reached in 27 hauls. In addition, there were another 27 hauls with at least 50 individuals (Figure 3.49).

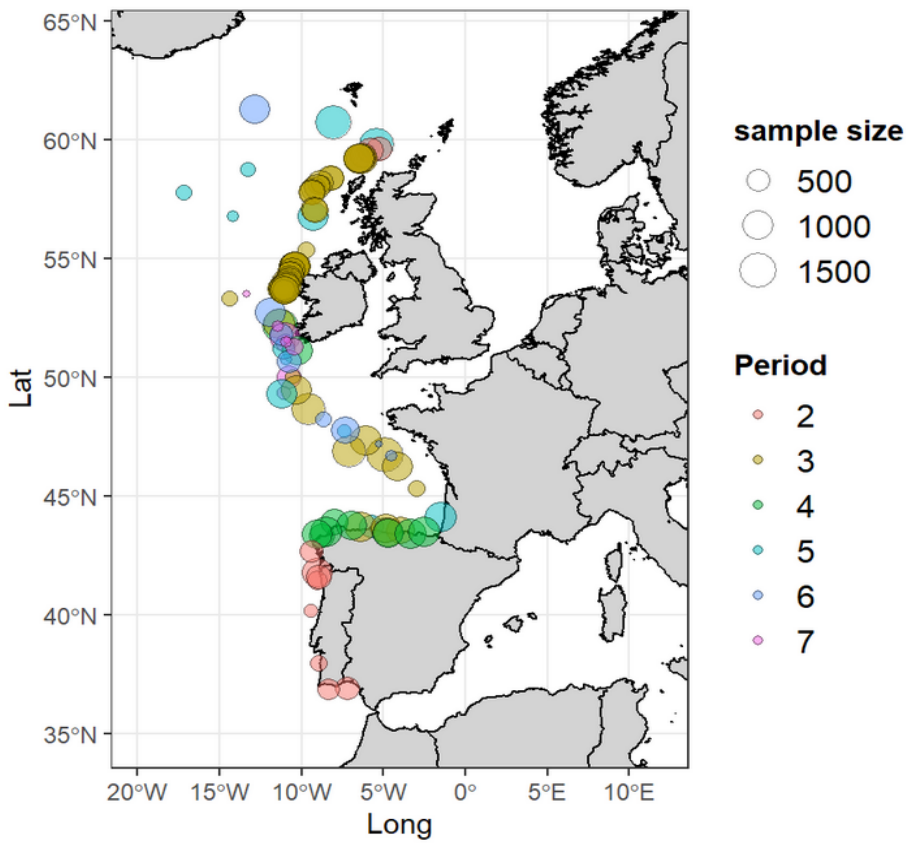

Figure 3.49 Total number of sampled fish per haul (optimum sample size is 100 individuals per haul). Different colours denote survey periods.

Mackerel total length ranged from 175 to 446 mm (Figure 3.50). Mackerel sizes did not vary with latitude, although in the most southern sampling area (36 to 40°N) smaller individuals were sampled compared to further north (Figure 3.51).

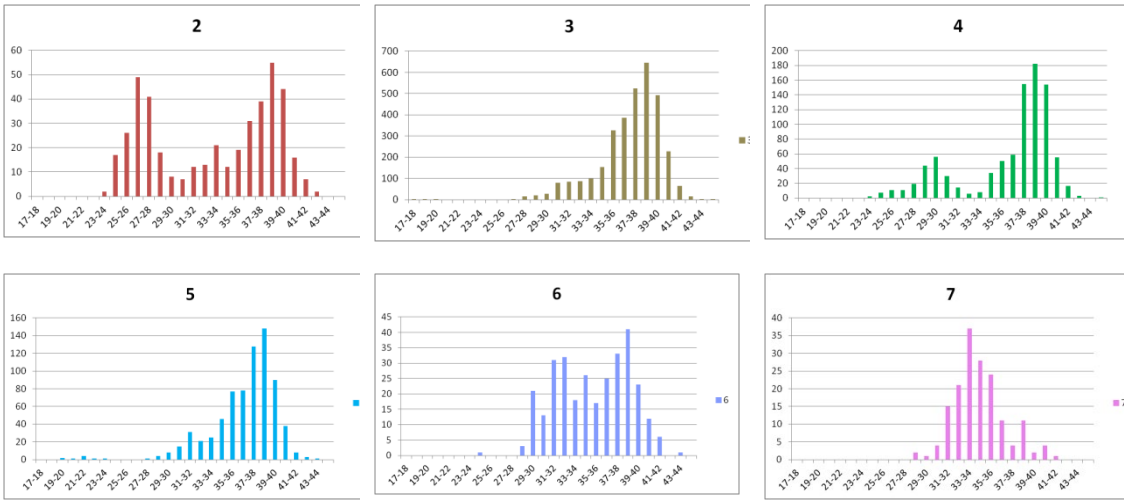

Figure 3.50 SW Atlantic Mackerel length (cm) frequency distribution of total sampled fish, males and females, in 2022, by periods 2 to 7.

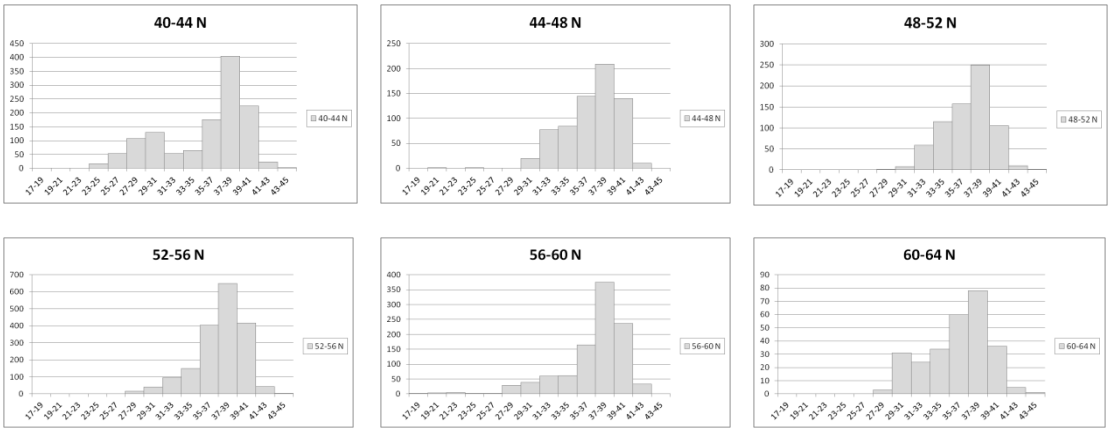

Figure 3.51 SW Atlantic Mackerel length (cm) frequency distribution of total sampled fish, males and females, in 2022, by latitude.

Screening for batch fecundity and spawning fraction estimations.

Next to the difficulty of collecting the number of individuals necessary for DEPM, ovary samples which are collected on board for batch fecundity and spawning fraction estimation are selected based on macroscopic maturity criteria. All these ovary samples must then be screened microscopically to check their suitability for each analysis following the fecundity manual (ICES 2019a). The most difficult to find are valid samples for batch fecundity. In total, 2952 mature females were caught (table 3), and 1605 ovary samples (Table 3.28) were taken and screened under the microscope. Almost 78% of the ovary samples were taken in the periods 3 and 4, when it is more likely that valid samples will be obtained, and show a good spatial distribution, ranging from 40 to 60°N (Table 3.28).

Table 3.28 Number of total ovary samples screened microscopically in 2022 by period and latitude.

	Period						**2022**
		Peak spawning					
Latitude	2	3	4	5	6	7	Total
61-65					32		32
56-60	11	41		84			136
51-55		380	140	7	40	19	586
46-50		321		30		7	358
41-45	69	137	231	50			487
36-40	6						6
Total	86	879	371	171	72	26	1605

Batch fecundity (F)

In 2022, from the total ovary samples, 136 corresponded to hydrated females that had no signs of recent spawning. These 136 samples were well distributed in the spawning area, especially in period 3 (Figure 3.52). For these females, the oocyte diameter size frequencies were examined by image analyses, looking for a clear (50 microns) hiatus. For Northeast Atlantic mackerel, hydrated females that do not show a clear hiatus are not valid for batch fecundity (Ganias et al., 2018). In total, 108 hydrated females showed a clear hiatus, and should be valid samples. Some of these samples contained eggs however, when analysed in the whole mount screening, which excluded them for batch fecundity estimates. The presence of eggs indicates that spawning has already started and the use of these samples for batch fecundity estimates would decrease the number of the eggs in the batch. Therefore, the number of samples used to calculate the batch fecundity was 45 (Table 3.29). However, to check for bias due to sample processing, samples with eggs present in the whole mount should be analysed. As said before, an extensive review of the application of DEPM in northern and southern NE Atlantic mackerel from 2013 to 2022 will be carried out next autumn at the WKMADE, including sampling screening and validity to the analysis of the different parameters.

Table 3.29 Summary table of DEPM sampling for 2022 survey, by period.

Period	Hauls	Total Fish	Mature Females	Spawning fraction samples	Batch Fecundity valid samples
2022					
2	12	439	225	39	0
3	60	3369	1775	461	29
4	11	930	457	250	11
5	16	816	313	118	4
6	8	331	132	39	0
7	9	165	50	14	1
Total	**116**	**6050**	**2952**	**921**	**45**

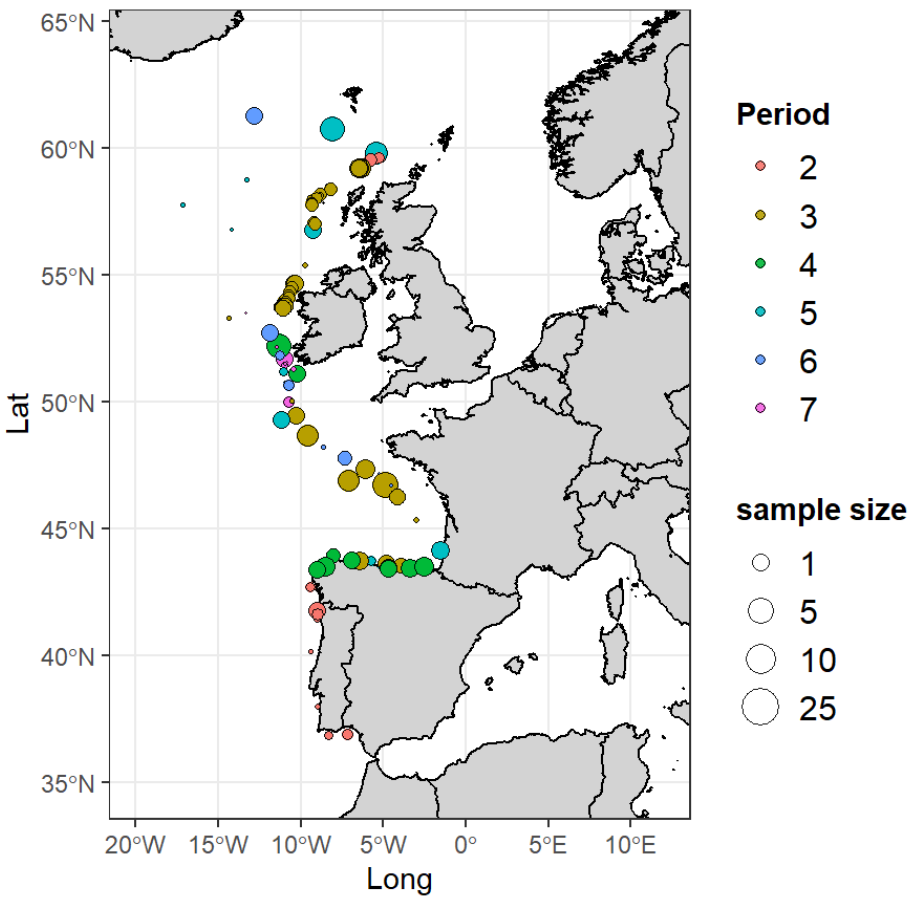

Figure 3.52 Spatial (latitude and longitude) and temporal (period) distribution of the total samples analysed for batch fecundity (F) estimation in 2022.

Spawning fraction (S)

In 2022 a total of 921 histological ovary sections (Table 3.30) were examined for POFs ages assignation according to the criteria described in the fecundity manual (ICES 2019a). Most of the ovary sections were taken during periods 3 and 4, that is, the peak of the spawning, and between 40 and 55 degrees north latitude. The spawning fraction (S) was estimated as the proportion of active females from the total of mature females in each haul. The number of active females in day 0 was estimated from the addition of females presenting day 1 and day 2 POFs (recent spawning) divided by 2, that is, the average of POFs in day 1 and 2. Finally, the total S was the average of the S by haul.

Table 3.30 Temporal and spatial distribution of total ovary samples analysed for spawning fraction (S) estimation in 2022.

S 2022	Period						
Latitude	2	3	4	5	6	7	Total
61-65					8		8
56-60	2	10		54			66
51-55		130	96	5	31	12	274
46-50		213		16			231
41-45	34	108	154	43			339
36-40	3						3
Total	39	461	250	118	39	14	921

Mackerel DEPM adult parameters

The adult parameters were estimated using a script in R that corrects for the expected weight of females to avoid weight bias produced by hydration, and estimates the sex ratio in weight (R), average weight of mature females (W), batch fecundity (F) and spawning fraction (S), first by haul and in a second step calculates the parameters average for all hauls combined.

The results of the DEPM adult parameters for all combined hauls are shown in Table 3.31; the average weight per female increases for the third consecutive year; the sex ratio remains stable at around 0.5; batch fecundity values decrease and are close to those of 2016 and the value of the spawning fraction is intermediate to that of previous years.

Table 3.31 Northeast Atlantic mackerel adult parameters estimated for 2016, 2019 and 2022 surveys, and coefficients of variation (cv).

	2016		2019		2022	
Adult parameters	estimate	cv	estimate	cv	estimate	cv
Average Female Weight (g)	326.77	0.0305	355.66	0.0218	365.08	0.565
Sex ratio (nº of females/total)	0.515	0.0052	0.520	0.0100	0.512	0.003
Batch Fecundity (n° eggs/batch)	8820	0.0413	12257	0.0106	9483	1.359
Spawning fraction (n° of spawning females)	0.163	0.1238	0.198	0.0904	0.145	0.041

3.8.2.2 North Sea Mackerel

The DEPM requires an intensive sampling to estimate adult parameters and it has proved to be difficult to achieve the planned number of samples. During the peak spawning, the probability of finding valid samples increases and therefore adult sampling should be targeted to the months when peak spawning is expected.

June is considered to be the peak spawning period in the North Sea. (Period 6). The samples were collected and analysed according to the WGMEGS manuals (ICES 2019a, 2019b).

DEPM adult sampling in North Sea

The survey was designed to cover the entire spawning area using half ICES rectangle samples (ICES, 2014) a total of 32 fishing hauls were performed opportunistically during the survey using mostly bottom trawl gear (Figure 3.53). 1823 individuals were sampled where 746 were mature females (Table 3.32).

Table 3.32 Number of hauls, individuals (male and females), mature females and spawning females sampled by month.

Area	Month	n. hauls	n. indiv.	n. Mature Females	n. Spawning Females	n. indiv. Random	n. indiv. NO.Random
North Sea	6	27	1724	693	183	1550	174
North Sea	7	5	99	53	1	99	0

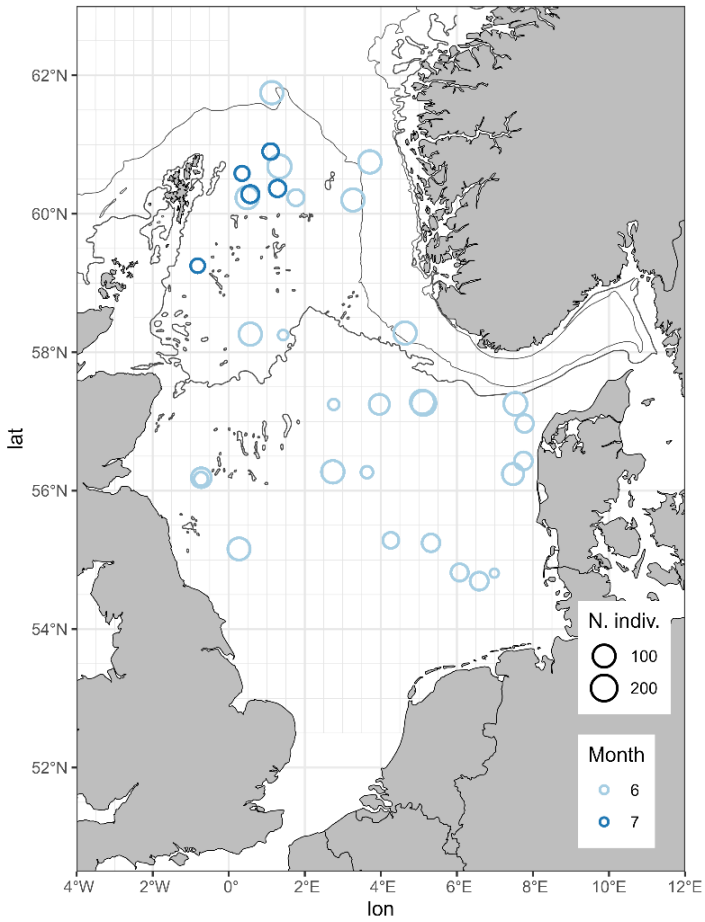

Figure 3.53. Position of the fishing hauls and number of sampled fish per haul during the North Sea survey

The sampled mackerel ranged in the size from 17.5 to 44.2 cm in June and from 29.3 to 38.0 cm in July (Figure 3.54).

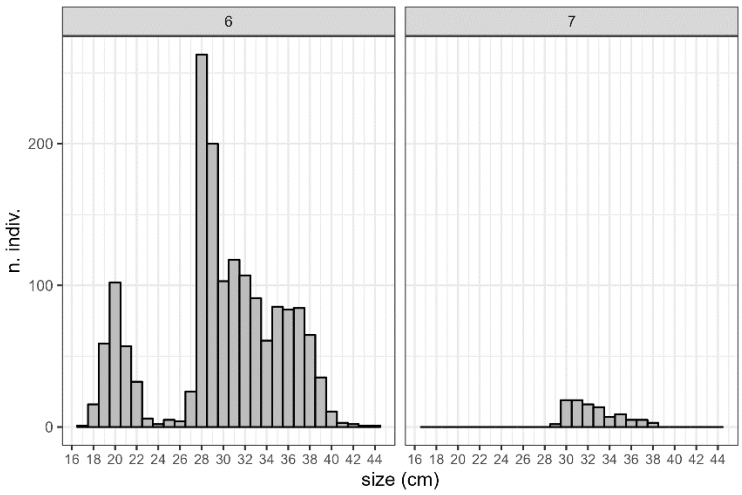

Figure 3.54 Length frequency distribution of mackerel sampled in North Sea by month (June and July).

Sex Ratio (R)

The sex ratio (R) was estimated as the weight ratio of females in the mature population. Sex ratio was estimated on the basis of individuals identified macroscopically at a maturity stage greater than 1 on Walsh scale. When estimate female weigh, the hydrated female weight (Walsh scale 4) was corrected with an expected weight to avoid weight bias due to ovary hydration,

The mean sex ratio was then calculated as the weighted mean of the sex ratios between hauls. The weighting was given by the number of randomly sampled mature individuals in the haul, which was 20 or more to be included in the calculation.

A total of 1625 mature individuals in 16 representative hauls, (more than 20 individuals per sample) (Figure 3.55) were used to estimate the sex ratio (R) for the month of June. The estimated mean sex ratio (R) for June was 0.503. Figure 3.55 shows the number of individuals by sex per haul in the North Sea

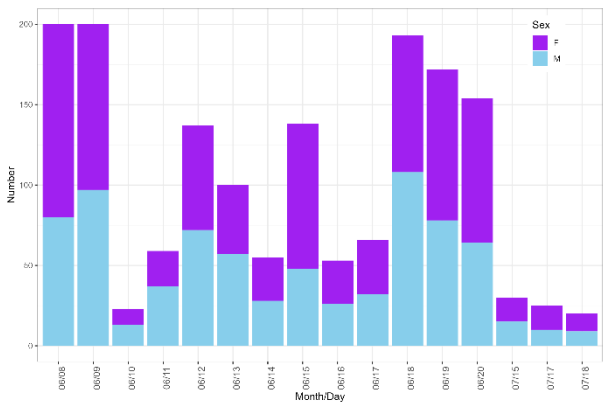

Figure 3.55 Number of individuals by sex per haul sampled in the North Sea

Batch fecundity (F)

In total, 56 hydrated females without POFs were available for batch fecundity estimation in North Sea. For the estimation of batch fecundity, all oocytes larger than 400 µm in whole mount preparations were considered.

For North Sea, batch fecundity was estimated using a generalised linear model (with a Gamma and an identity link) as a function of gonad-free weight of females. GLM was fitted to the subset of hydrated females without POFs and used to calculate the batch fecundity of all mature females (Figure 3.56).

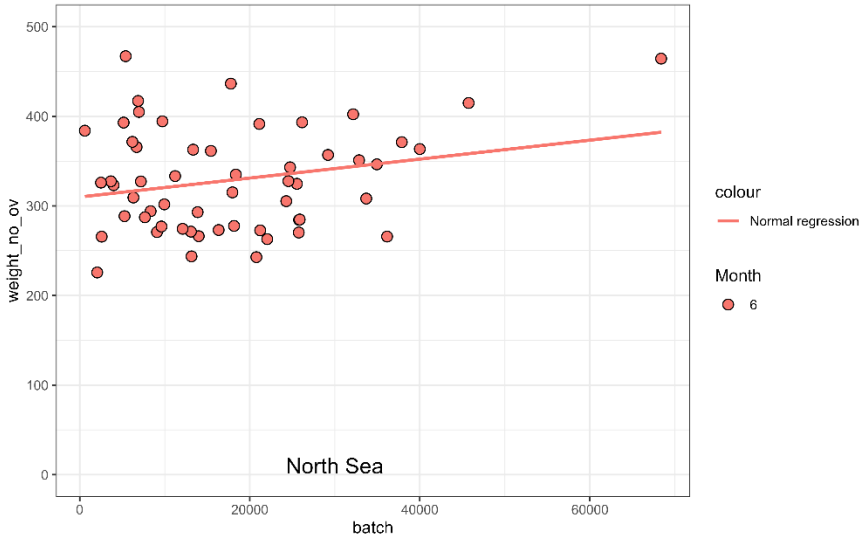

Figure 3.56 Batch fecundity by weight of the female.

Table 3.33 shows the main results of mean batch fecundity and mean mature female weight. Results were obtained as the weighted mean of the average expected female total weight/ batch fecundity per haul (Lasker, 1985), provided that the number of mature females in the haul was 20 or more.

Table 3.33 Mean batch fecundity, female weight and length obtained in the North Sea 2022 DEPM survey.

Area	Mean Batch fecundity	Mean weight female (g)	Mean length female (cm)	Relative mean batch fec. (ovoc./gr fem)	Number females	n. samples
NS	15751	302.96	32.3	52.2	412	13

Spawning fraction (S)

A total of 467 histological ovary sections (Table 3.34) were examined to assign POF ages according to the criteria described in the fecundity manual (ICES 2019a). The spawning fraction (S) was estimated as the proportion of active females of the total number of mature females in each haul.

The mean spawning fraction was calculated as the weighted mean of the mean spawning fraction per haul. The weighing factor was given as the number of mature females at random samples. The spawning fraction was 0.058 (Tables 3.34).

Table 3.34. Mean spawning fraction in June in the North Sea

area	Month	Sftot	n. hauls	n. samples
NS	6	0.0579	13	467

Mackerel DEPM adult parameters

The provisional results of the 2022 DEPM adult parameters for all combined hauls in North Sea are shown in above Table summary (Table 3.35).

Table 3.35 Summary of 2022 DEPM adults parameters in the North Sea.

Adult parameters	estimate
Average Female Weight (g)	302.96
Sex ratio (nº of females/total)	0.503
Batch Fecundity (F)	15751
Spawning fraction (SF)	0.058

3.9 Road map for integration of North Sea mackerel

A roadmap will be developed to guide the implementation and evaluation of DEPM-based SSB (spawning stock biomass) indices for different components of the Northeast Atlantic mackerel stock, including the Western, Southern, and North Sea regions. The aim is to explore the possibility of establishing a joint SSB index. Up to now, WGMEGS (Working Group on Mackerel and Horse Mackerel Egg Surveys) has produced an AEPM (annual egg production method)-based SSB index for the Western and Southern components. Since 2013, MEGS has also worked towards producing a DEPM (daily egg production method) based estimate. To date the North Sea (Subarea 4) has not been included due to a temporal mismatch in survey timing. Traditionally, the North Sea was surveyed using the AEPM (Annual Egg Production Method) one year later than the other components, due to the lack of vessel availability to cover all areas in the same year. These North Sea data were provided to WGWIDE for use in the NEA mackerel assessment.

In 2018, WGMEGS decided to carry out the North Sea survey as a DEPM survey. This was first conducted in 2021. In 2020 WGMEGS decided, due to the involvement of new participants, that from 2022, the North Sea would be surveyed in the same year as the Western and Southern components. Moving forward, MEGS intends to survey all three components in the same year. The institutes involved in sampling the North Sea include DTU Aqua, IMR, and CEFAS.

Surveying all components in the same year presents an opportunity to establish a joint DEPM-based egg production and SSB index for the Western, Southern, and North Sea regions of the

mackerel stock. While the DEPM survey design and data analysis procedures to produce an egg estimate have been implemented, WGMEGS is not currently in a position to produce a DEPM SSB estimate. Therefore, it is not possible to include the North Sea component in a joint SSB index. The methodology for integration is yet to be developed and evaluated.

We suggest the following roadmap for the process:

1. Refine, streamline protocols and set deadlines for analysis of ovary samples among the participating laboratories. This should be done during WKAEPM, (Workshop on Adult Egg Production Methods Parameters Estimation in Mackerel and Horse Mackerel) in the autumn of 2024.
2. Perform a quality check to ensure the suitability of the 2022 North Sea batch fecundity and staging of post ovulatory follicles (POF) (for spawning fraction) data for inclusion in any assessment performed at the WKMADE (Workshop on mackerel daily egg production) workshop in November 2023.
3. Calculate and evaluate indices for daily egg production for Subarea 4 in 2022. Use the same methodology that is being developed for the Western and Southern components of the Atlantic mackerel stock. This could be finalised during the WKMADE workshop in November 2023.
4. Evaluate the potential for developing a joint DEPM-based SSB estimate for the Western, Southern, and North Sea components. If suitable, establish the methodology for integrating the DEPM SSB data from the North Sea for 2022 and future survey years.
5. Review survey protocols, particularly for survey coverage in Subarea 4. Ensure these protocols are compatible with the protocols for the Western and Southern components of the mackerel stock. This work should be finalised during the WGMEGS meeting in 2024.

3.10 Hake eggs abundance during MEGS surveys

In 2016, WGMEGS recommended to include hake as a target species and to identify its eggs during the fish egg identification process. Despite this recommendation, not all participants contributed to the task. In 2016 and 2022, four participants reported the presence of hake eggs, while in 2019, only one reported having identified hake eggs. Therefore, the spatial distribution of hake eggs shown in this report is heavily limited by the absence of data in a significant portion of the hake distribution area.

3.10.1 Spatial distribution of stage 1 hake eggs in 2016.

Spatial distribution of stage 1 hake eggs in 2016 in Figure 3.57

Period 2 – Sampling was undertaken by Ireland (Celtic Sea, Biscay, and the eastern Cantabrian Sea) and Scotland (Northwest Ireland and West of Scotland). Survey coverage was good with 176 stations sampled. Hake eggs stage 1 occurred close to the 200m contour from the south of the Bay of Biscay to northwest of Ireland and west of Scotland. High numbers were recorded at Porcupine bank.

Period 3 – In period 3 the German vessel was operating to the West of Ireland, Celtic Sea and N Biscay. The Bay of Biscay, the Cantabrian Sea and Galicia were covered by Spain (IEO and AZTI).

Hake eggs were high to moderate in the Bay of Biscay, southwest of Ireland and Porcupine bank. In the Cantabrian Sea no hake eggs were reported.

Period 4 - Scotland was operating to the west of Scotland to the west of Ireland and northern Celtic Sea, and Netherlands in the southern Celtic Sea, to the west of Ireland and Biscay. Spain (IEO) sampled southern Biscay, the Cantabrian Sea and Galicia. No hake eggs were declared by Spain. A signal of hake spawning was observed in the southwest of Ireland (Goban Spur) and close to the coast in the Northeast of the Bay of Biscay. Hake eggs appeared in low numbers. Hake eggs were practically absent north to 50°N.

Period 5 – In period 5 four countries surveyed the area and only 3 reported hake eggs. AZTI conducted their DEPM survey in southern Biscay and the Cantabrian Sea targeting anchovies and sardines. Netherlands sampled the Celtic Sea and northern Biscay, with Scotland surveying west of Ireland and west of Scotland as well as Rockall and Hatton Banks. In this period hake eggs were collected in low numbers. A few scattered positive stations from the Bay of Biscay to the northwest of Scotland and in Rockall and Hatton Banks were reported.

Period 6 – This period was covered by Ireland, Netherlands and Norway, but only the two first reported hake eggs. Signals of hake spawning were noticeable in the west of Ireland and in the Hatton banks. South of 49°N the hake eggs were absent.

Period 7 – Period 7 was surveyed entirely by Scotland, sampling on alternate transects, from 47°45N in the South to the most northerly station at 63°15N (Figure 3.57). In this period the presence of hake eggs reduced considerably. The southern boundary was delineated at 47.15°N and only very low levels of spawning were observed during this period, mainly to the west of Ireland with very little reported for the Celtic Sea.

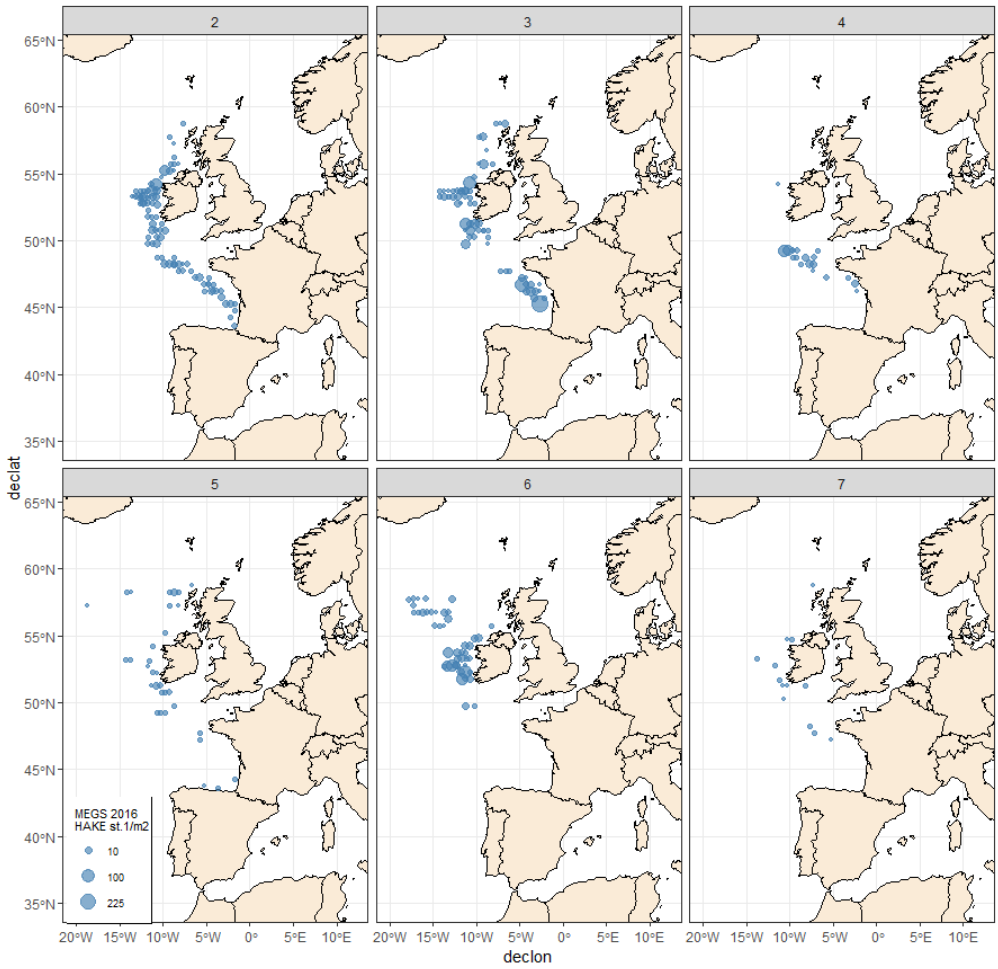

Figure 3.57. Hake egg stage 1 by half rectangle for all periods for 2016. Circles represent mackerel stage I eggs/m2 by station.

3.10.2 Spatial distribution of stage 1 hake eggs in 2022

Spatial distribution of stage 1 hake eggs in 2022 in Figure 3.58.

Period 3 – Two institutes identified hake eggs. Egg numbers were relatively high in the southwest of Ireland. Further south and north low numbers of eggs were found on the shelf (in the Bay of Biscay) or close to the 200m contour line (north 53°N).

Period 4 – In this period only Scotland reported hake eggs. Hake spawning occurred in the north-west of Scottish waters. Eggs were found in low numbers, and their presence extended to 63°N. The lack of information south of this coverage does not allow an assessment of the actual extent of hake spawning in this period.

Period 5 – In period 5, almost all participants contributed to the identification of hake eggs, so the map illustrates what was actually observed. In this period, coverage extended from the Bay of Biscay to the north of Scotland. The decline in hake egg density was marked. A few scattered positive stations were found in the Cantabrian Sea, the Bay of Biscay and the Celtic Sea. Eggs were found mainly on the continental shelf. Residual spawning was also observed around the Hebrides.

Period 6 – During period 6, hake eggs were reported in the northern Biscay, northwards from 46°N and also in the Celtic Sea up to 53°N. Hake eggs were found on the Celtic Sea shelf (around the Goban spur) and outside the 200 m contour line in the west of Ireland. The number of eggs was low.

Period 7 – No lack of information there was in this period since the hake eggs reported covers the entire area surveyed. Hake spawning continues in the Celtic Sea, west of Ireland and north of Hebrides islands in lesser intensive than previously.

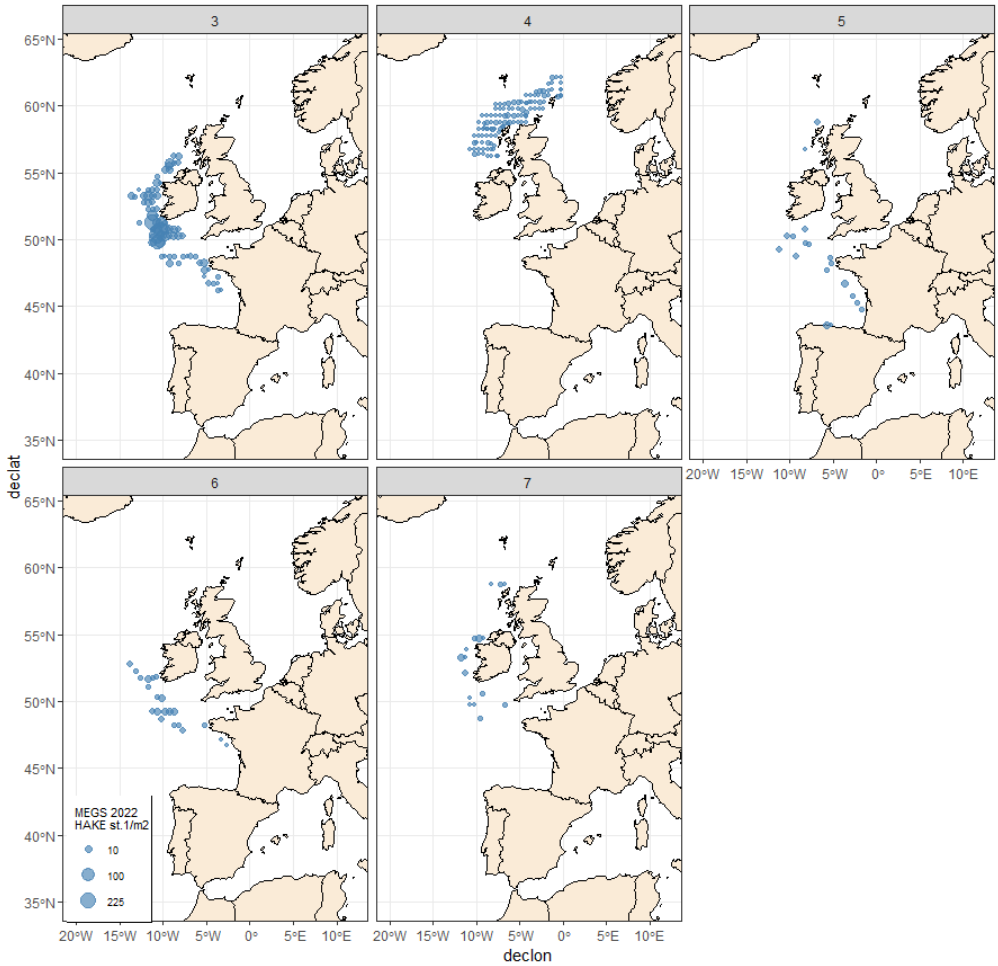

Figure 3.58. 2022 Hake egg stage 1 by half rectangle for all periods for 2022. Circles represent mackerel stage I eggs/m2 by station.

3.10.3 Comparison between years

The results suggest hake has a prolonged spawning period, which can last 5 to 6 months. Although the peak of spawning was consistently observed in March, in 2016 two events of high egg abundance occurred in February and June. Unfortunately, in 2022 February was not surveyed and in June of that year, the second peak of spawning was not detected -the density of hake eggs remained low when compared to 2016 (Figure 3.59). In 2022 the abundance of hake eggs 1 decreased by 35%.

The distribution of spawning and high-concentration areas of hake eggs can be observed when plotting the estimated abundance for each year together (Figure 3.60). The maps revealed that the hake spawning area extended from the southern end of the Bay of Biscay to the north of Scotland, and the area is closely linked to the contour of the 200m contour. Some hotspots of hake eggs were evident. For example, in 2016, the most significant egg aggregations were observed in the Bay of Biscay and west of Ireland, but in 2022, they were located in the Celtic Sea.

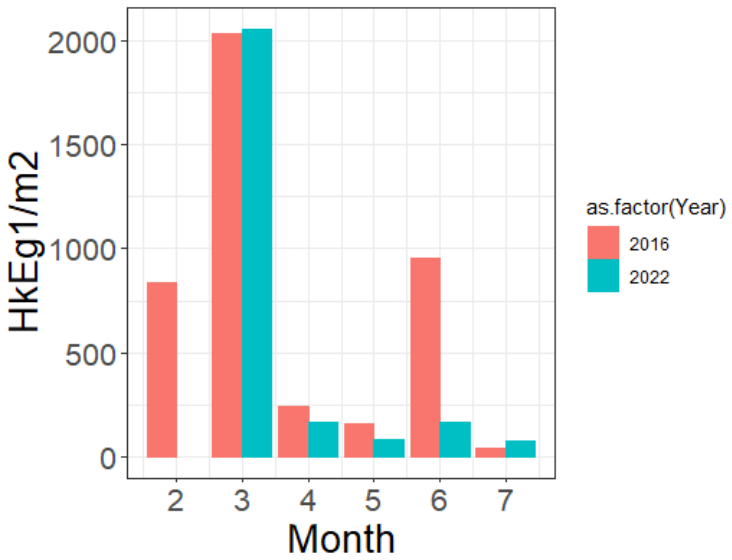

Figure 3.59 Histogram showing the monthly variability of hake egg 1 abundance (No./m2) for the years 2016 and 2022. The abundance per month was estimated as the sum of all hake egg 1 collected each month.

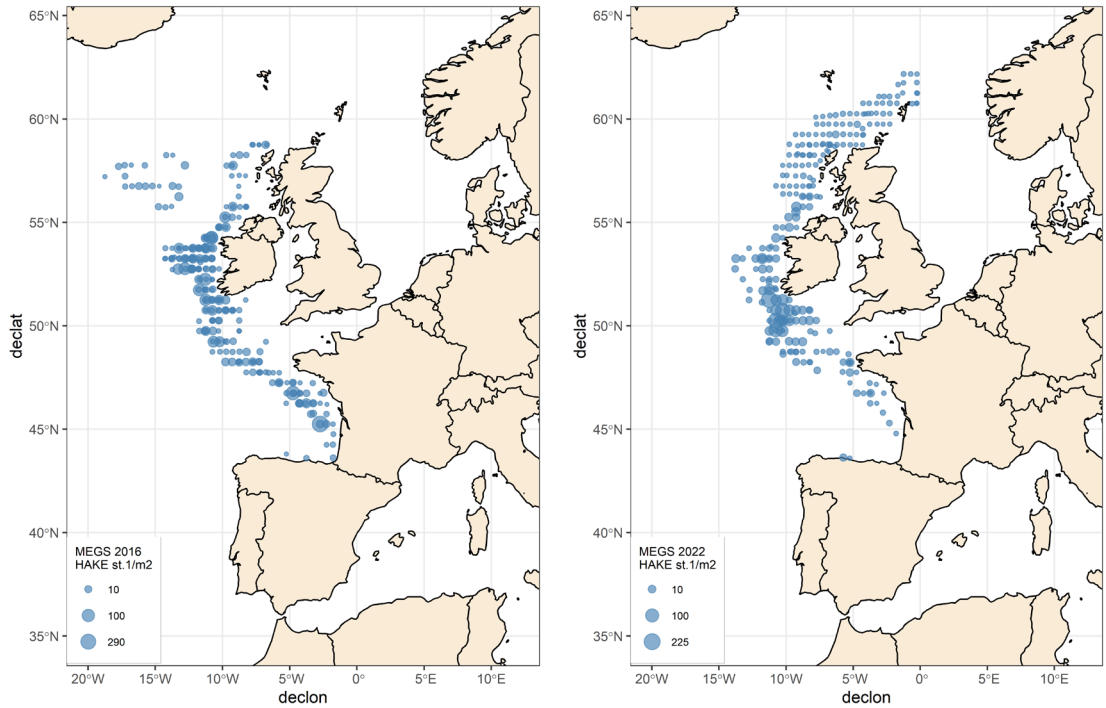

Figure 3.60 Annual abundance of hake egg stage 1 by half rectangle year 2016 and 2022. Circles represent mackerel stage I eggs/m2 by station.

3.11 Quality aspects of the MEGS surveys

3.11.1 Horse mackerel genetic results

ICES has long considered horse mackerel in the northeast Atlantic to consist of three stocks; the Southern (Division 9.a), the North Sea (Divisions 3.a, 4.a (Q1-2), 4.b-c, and 7.d), and the Western (Subarea 8 and Divisions 2.a, 4.a (Q3-4), 5.b, 6.a, and 7a–c, e–k). These stock definitions were based on a variety of factors including the temporal and spatial distribution of the fishery, the observed egg and larval distributions, information from acoustic and trawl surveys and from parasite infestation rates. Further refinements of the definitions of stock units were based on the results from the EU-funded HOMSIR project (2000-2003), which utilised a multidisciplinary approach including various genetic approaches (allozymes, mitochondrial DNA and microsatellites), parasites as biological tags, body morphometrics, otolith shape analysis and the comparative study of life history traits (growth, reproduction and distribution) (Abaunza et al., 2008).

The resulting stock definitions were broadly similar to that previously considered by ICES through Division 8.c was reassigned to the Western stock. It was also observed that the population structure in the western European coasts could be more complicated and that more research was needed to clarify the migration patterns.

In an effort to address this, the fishing industry commissioned a series of research projects to further develop the genetic methods for discriminating the stocks. Initial studies using 'traditional' genetic approaches (see Mariani, 2012) did not have sufficient discriminatory power to further clarify the structure. Therefore, Next Generation Sequencing (NGS) based approaches were used to identify more informative genetic markers and to screen a larger number of samples, which indicated a clear separation of the southern North Sea samples from other regions and further, less pronounced structure along the northeast Atlantic continental shelf (Brunel et al., 2016; Farrell & Carlsson, 2018). However, it was concluded that further genetic analyses were warranted to increase the numbers and types of genetic markers available for horse mackerel, which would improve the capacity for accurate genetic assignment.

In 2019 the Northern Pelagic Working Group (NPWG) of the European Association of Fish Producers Organisations (EAPO) commissioned a further project to develop a reference genome assembly for horse mackerel and to undertake whole genome sequencing of pooled DNA in order to identify informative single-base genetic markers (or Single Nucleotide Polymorphisms - SNPs). Analyses of ~12.8 million SNPs indicated that the North Sea samples were the most genetically differentiated group, whilst the structure among the western, southern and north African samples was less clear, though a north-south split was observed with a potential mixing zone between the Western and Southern stocks in Division 9.a, near Lisbon in southern Portugal (Fuentes-Pardo et al., in press). A large number of informative SNPs were identified during this study and c.4,000 of these, spread across the twenty-four chromosomes, were recently included on the IdentiGEN DNA TRACEBACK® Fisheries array (FSHSTK1D). Inclusion on the genotyping array (SNP chip) makes these markers more accessible for follow up studies.

In late 2022 the NPWG commissioned the development of a genetic baseline using the new SNP chip and the development of a genetic assignment model. In total 35 samples, comprising 2,304 individuals were genotyped (Figure 3.61), including temporal replicates from all three stocks. Preliminary analyses of the data and the development of an exploratory assignment model indicated that the samples from division 4.a. assigned to the Western stock regardless of quarter and that the samples in division 7.d. comprised a mix of Western and North Sea horse mackerel. Therefore, the current delineation of the North Sea stock appears to be inappropriate for the purposes of assessment. Preliminary analyses also revealed that all spawning samples from division 9.a assigned to the Western Stock, suggesting that the mixing between the Western and Southern stock areas may be more extensive than identified in Fuentes-Pardo et al. (in press).

Further analyses are ongoing and plans being made to increase the sampling of both baseline spawning samples and also potentially mixed samples across the NE Atlantic.

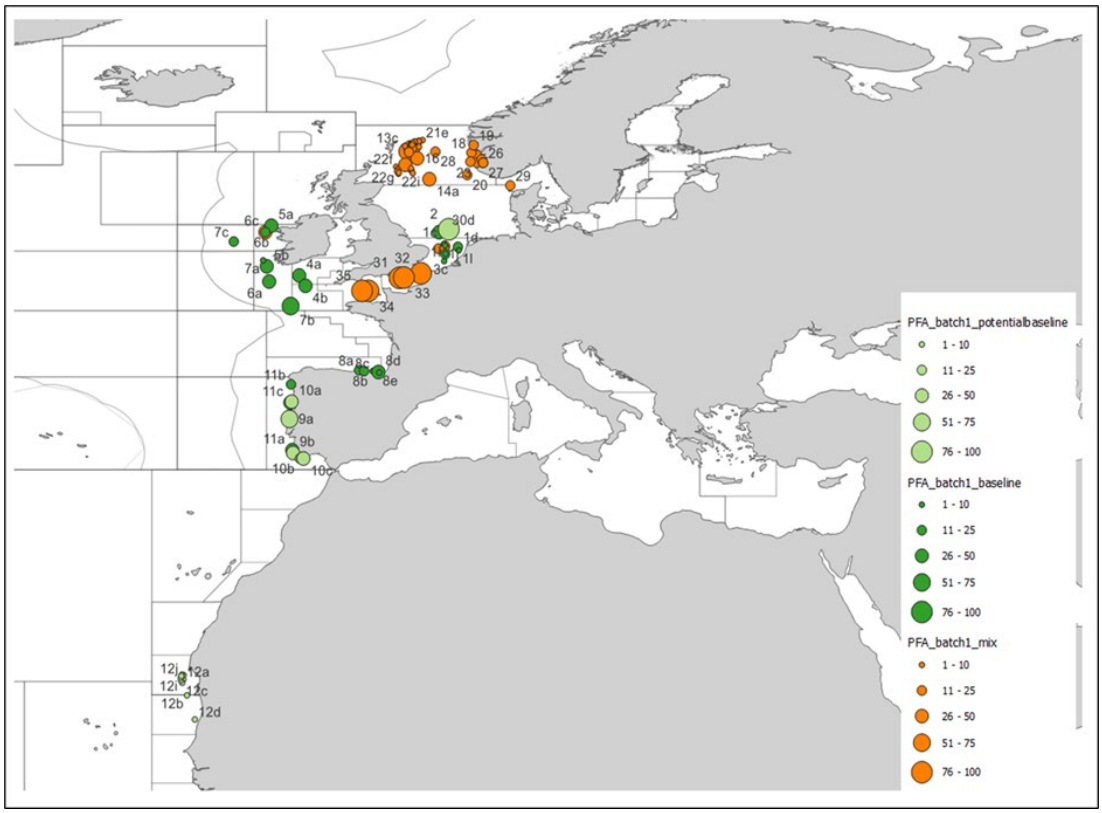

Figure 3.61 The sample locations for the samples genotyped with the SNP chip.

3.11.2 WKMADE

In recent years questions have been raised to whether mackerel can still be classed as a determinate spawner, or should they be reclassified as an indeterminate species. Work has been carried out by WGMEGS to try to answer this question. Since the 2013 triennial survey WGMEGS has been collecting additional adult samples to estimate Daily Egg Production Method (DEPM) adult parameters at the same time as the Annual Egg Production Method (AEPM) calculations were made.

A thorough analysis of all information collected will be carried out at the Workshop on Mackerel Daily Egg production (WKMADE) next autumn. The workshop will look into the calculations of spawning fraction and batch fecundity and derive a Daily Egg Production Method (DEPM) based estimates of Spawning Stock Biomass (SSB) for each of the four survey years, 2013 to 2022. The accuracy and precision of the newly derived time series of the DEPM method will be compared to the time series of the standard Annual Egg Production Method (AEPM).

3.11.3 Oocytes measurements analysis and whether mackerel is a determinate or indeterminate spawner

The annual egg production method (AEPM), used in the mackerel assessment, relies on the assumption of determinate fecundity. The classical definition of a determined spawner, as defined by Hunter et al. (1992), states that the number of oocytes is pre-determinate prior spawning, and it decreases throughout the spawning season since no new oocyte recruitment takes place after

the spawning has started. In indeterminate spawners, on the other hand, the fecundity is not predeterminate before spawning and oocytes can be recruited during the spawning season.

In 2021, two papers related to the reproductive biology of Northeast Atlantic Mackerel were published. These papers addressed issues surrounding the use of the AEPM. From the first paper by Jansen et al. (2021), the key finding, as understood by this working group, can be summarized as follows:

"…we document that the body surplus energy has varied substantially over time, with a significant drop to historically low levels following a stock increase from 2005 to 2015. This fluctuating pattern is in stark contrast to the stable relative fecundity (oocyte g females) measured in connection with the egg surveys."

In conclusion, the authors suggest that mackerel is an indeterminate spawner, meaning that the number of oocytes recruited for maturation and spawning is regulated based on available energy during the spawning season. This contradicts the working group's assumption that mackerel is a determinate spawner, where all oocytes destined for maturation and spawning are pre-determinate before the spawning season begins. The scientific support for this working group's assumption was based on the paper published by Greer-Walker et al. (1994). This study found, among eight lines of evidence investigated, including the lack of a distinct gap between previtellogenic and vitellogenic oocytes, that mackerel can for practical purposes be considered determinate spawners by including oocytes within the previtellogenic size range, with a defined size threshold of 185 μm.

As a follow-up to the papers by Greer-Walker et al. (1994) and Jansen et al. (2021), dos Santos Schmidt et al. (2021) investigated the issue of determinacy using histology and wholemount analyses, then applied the oocyte ratio (Anderson et al. 2020) and oocyte packing density (OPD; Kurita & Kjesbu, 2009). The study documented that the earliest histological oocyte stage that is depleted (= standing stock) during spawning is the PVO 4C, while earlier stages remained constant. PVO 4C is a previtellogenic oocyte stage that has been found in many fish species as the first true sign of maturation for the upcoming season (e.g., Kjesbu et al. 2011; Serrat et al. 2019). The paper concludes that, based on the classical definition of determinacy by Hunter et al. (1992), mackerel is indeed an indeterminate spawner. However, it also supports the findings of Greer-Walker et al. (1994) that mackerel at the onset of spawning can be considered determinate for practical purposes if including PVO 4C, however further investigation needs to be performed to confirm at which point the fecundity is fixed. Nevertheless, the results indicate that the whole mount diameter of a PVO 4C is approximately 230 μm, which is higher than the current 185 μm threshold used by the working group.

In light of this, the working group selected a subset of fecundity samples from the 2022 survey to measure the size of all oocytes above 185 μm. This approach aimed to estimate the difference between the two size thresholds. Preliminary statistical analysis of the data revealed that if all samples were pooled, a 230 μm size limit instead of 185 μm resulted in an overall 6% reduction in mean relative fecundity. However, there were considerable differences between institutes in terms of the number of samples analyzed and the mean reduction. Two institutes observed a reduction of approximately 3.5%, while others reported reductions ranging from 12% to 19%. The presenter recommends the working group to follow up on these issues towards the next triannual survey.

It is also important to consider that fish can regulate egg production during the spawning period in two ways: through recruitment of new oocytes from the non-maturing pool into the maturing pool or by omitting the spawning of some maturing oocytes. The former strategy is typically associated with indeterminate spawners, while the latter is a known regulation strategy also among fish considered to be determinate spawners. In this case, the unspawned maturing oocytes may undergo reabsorption through atresia or in principle be retained until a later

spawning season. Mackerel does not seem to retain maturing oocytes for a later spawning season (dos Santos Schmidt et al. 2021).

The paper by Jansen et al. (2021) suggests that mackerel fecundity exhibits greater variation than what has been reported by the working group. This discrepancy could possibly be attributed to deficiencies in the working group's procedures for estimating atresia. Currently, atretic loss is estimated based on the prevalence and intensity of atresia among spawning fish, excluding those classified as spent or showing massive atresia. However, preliminary histology observations of spent or massively atretic ovaries reveal significant numbers of small maturing oocytes that are unlikely to be spawned in the current season. These small maturing oocytes may account for a substantial loss that has not been accounted for previously, potentially explaining the unexpectedly low variation in fecundity highlighted by Jansen et al. (2021). To address these questions, the presenter recommends conducting a histology study using existing digital slides generated during the 2022 egg survey.

3.11.4 Mackerel component identification workshop

A Workshop on the Evaluation of NEA Mackerel stock components (WKEVALMAC) chaired by Richard Nash, UK and David Secor, USA will meet from 12th to 16th June 2023 in London (NEAFC Headquarters, 44 Baker Street, London W1U 7AL, United Kingdom) with the option of being a hybrid meeting. The full Terms of Reference are given in Annex 3.

Members of WGMEGS were asked to consider contributing to the workshop, primarily toward ToR A (Review information on stock identification of NEA Mackerel and develop a consensus understanding of population structure and key uncertainties). The specific question to be addressed is whether there is any evidence to support the notion that the mackerel in the Northeast Atlantic comprises of a number of distinct components or even constitutes a number of stocks.

3.11.5 Mackerel egg development experiments

Introduction

Information regarding embryonic developmental competence and survival in North Sea mackerel in relation to temperature optima and thresholds is scarce and even debated for the Atlantic mackerel stock. As such, in 2021, as part of the Danish Mackerel Egg Survey, mature mackerel females and males were caught in the North Sea, strip spawned and gametes collected for in-vitro fertilization and subsequent experimental incubation until hatch.

Materials and Methods

A pool of eggs from several North Sea mackerel females were mixed with a pool of milt from several mackerel males, while gamete activation and fertilization occurred at the previously reported optimal temperature of 12°C (Mendiola et al., 2006). The embryos produced were then incubated at 5 different temperatures (9-16°C), representing the thermal range experienced at different depths within the North Sea distribution area.

Floating embryos were reared in customized 2 L incubators featuring bottom inlets with flow rates of ~150 mL/min and a 250 µm mesh subsurface outlet.

Each temperature treatment was represented by 6 replicated 2 L incubators, connected to a separate mobile recirculating aquaculture system (RAS). A steady upwelling flow created enough turbulence to keep the embryos/larvae in suspension and maintain optimal oxygen levels for rearing.

Embryos were reared until hatching and categorized as dead if they turned white and/or sank to the bottom of the incubator. Dead embryos were enumerated and removed daily. Time to hatch was considered when >50% of larvae had hatched. Once hatching was completed, all embryos and larvae within each incubator were counted, larval deformities assessed and hatching success and survival calculated. Photos of the mackerel offspring were taken throughout development.

Results and discussion

As expected, temperature had a significant effect on embryonic development, leading to an increased stage duration at the coldest temperature investigated, where larvae hatched at 262 hours post fertilization (hpf) and a decreased stage duration at the warmest temperature investigated, where larvae hatched at 86 hpf (Figure 3.62).

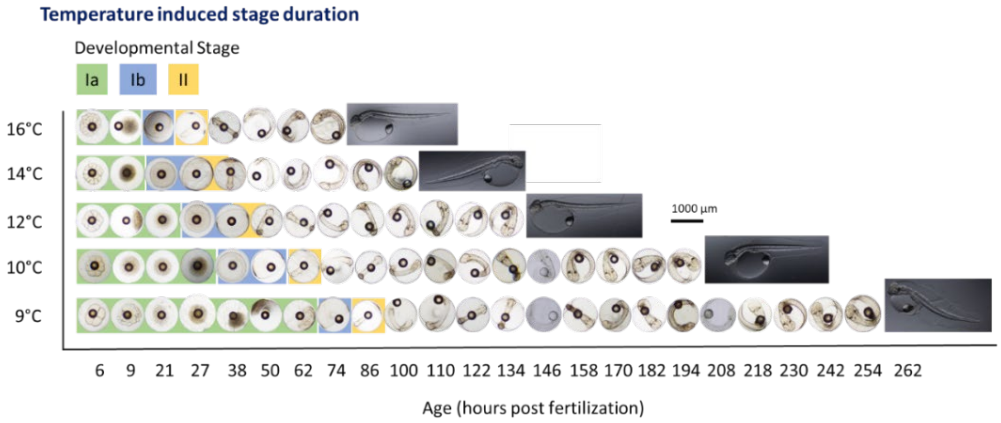

Figure 3.62 Temperature induced stage duration of North Sea mackerel offspring, reared at 5 temperatures, representing the thermal range experienced at different depths within the North Sea distribution area.

When comparing developmental times at different temperatures, we observed a much steeper slope compared to previously reported results, especially at the colder temperature investigated (Figure 3.63).

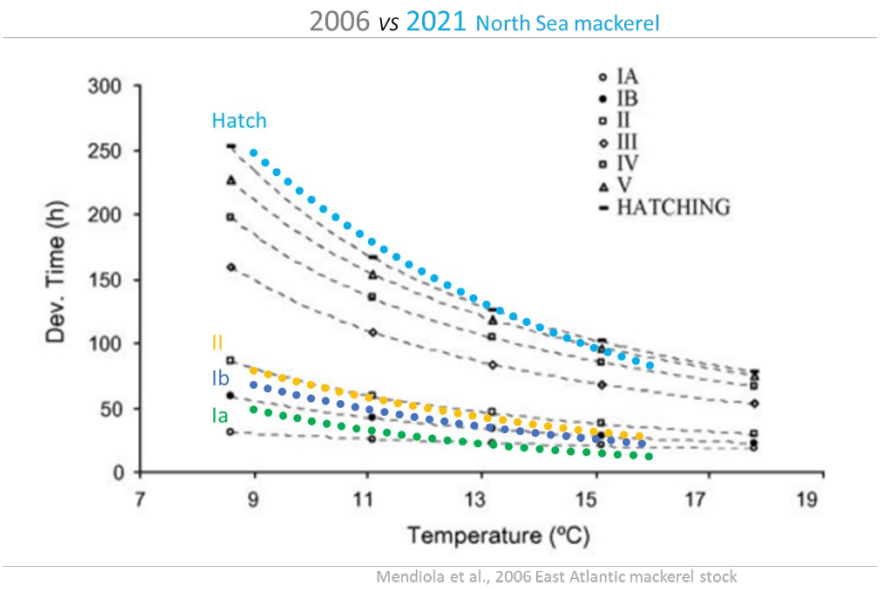

Figure 3.63 Functional relationships of developmental time in relation to incubation temperature; comparison between East Atlantic (2006) and North Sea (2021) mackerel offspring development.

Survival at 9°C, dropped to ~12%, approximately 5 times lower than at the other temperatures (Figure 3.64A). Hatching success was highest at 12°C and lowest at 9°C (Figure 3.64B), while the very few larvae that managed to hatch at the coldest temperature were almost all deformed (Figure 3.64C), probably indicating the coldest thermal limit for this species.

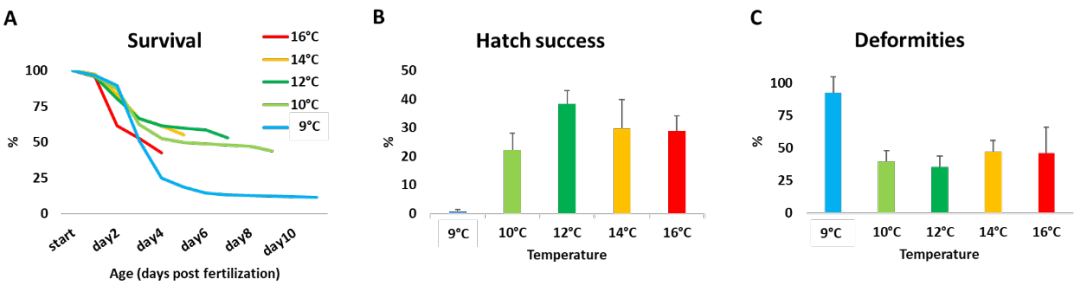

Figure 3.64 A) Survival, B) Hatch success and C) Deformities of North Sea mackerel offspring, reared at 5 temperatures, representing the thermal range experienced at different depths within the North Sea distribution area.

Survival showed a dome-shaped relationship with temperature (Figure 3.65), potentially indicating an optimal window between 12 and 14°C for North Sea mackerel embryonic development.

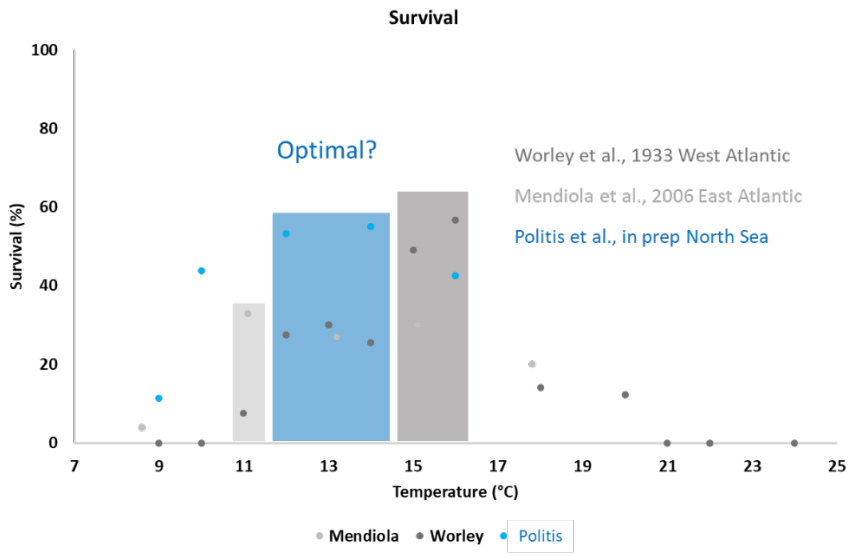

Figure 3.65 Survival of mackerel offspring at different temperatures; comparison between West Atlantic, East Atlantic and North Sea mackerel.

3.11.6 Clogging during the 2022 surveys

Clogging causes the meshes of the sampler to become coated thereby reducing or stopping the flow of water through the sampler. This then has an obvious impact on the volume of water that can be filtered by the sampler and of course by implication also its ability to sample eggs in the water column.

Several surveys during the 2022 MEGS programme reported significantly higher numbers of stations being affected by clogging than from the same area and timing in previous surveys. These were typically from later survey periods (periods 5, 6 and 7; May-July) and from across several areas. Clogging in 2022 was reported in areas of the Rockall Trough, West of Ireland, Celtic Sea and northern Biscay. Clogging is and has typically been observed both on the shallower continental shelf stations as well as the deep stations within the Rockall Trough and offshore areas such as Rockall and Hatton Bank. Clogging within the former being typically due to sources such as phytoplankton whereas in the latter the cause was often the result of gelatinous zooplankton such as salps. However, in 2022 clogging was also observed within many of the deeper continental slope stations to the West of Ireland and Northern Biscay. In this case being attributed to unknown gelatinous organisms. The Dutch surveys in period 5 and 6 in 2022 reported that almost 50% of all the plankton deployments recorded reduced flowmeter counts, whereas the Scottish surveys in period 5 and 6 recorded a 100% increase (on results from 2019) in the number of stations displaying flowmeter counts that were lower than expected and which equated to almost 30% of the total plankton stations from these surveys.

The Gulf VII sampler used during the Dutch and Scottish egg surveys is fitted with a 280 µm mesh as the survey manual prescribes. The Dutch sampler has an internal and external flowmeter mounted on it. During the surveys regular calibration of flowmeters is done. In good situations the internal flowmeter calibration is 1.2 times the external flowmeter (Table 3.36). However, in some areas the internal flowmeter revolutions was 0.5 times the external flowmeter during a calibration without the codend (Fig 3.66). In that situation the external flowmeter was also somewhat lower compared to the situation without clogging (Table 3.36). During the Scottish surveys the internal flowmeter revolutions were screened against the distance towed during the haul

(Fig. 3.67). This also highlighted low flowmeter counts during the hauls where much phytoplankton and/or gelatinous substances were present in the samples (Fig. 3.67).

Table 3.36 Internal and external calibration factors for the Dutch 2022 surveys.

Period	Flowmeter	Calibration factor	Internal revolutions / External revolutions
5	Internal	9.75	1.20
	External	8.12	
6	Internal	9.86	1.22
	External	8.06	
Clogged	Internal	4.06	0.51
	External	8.02	

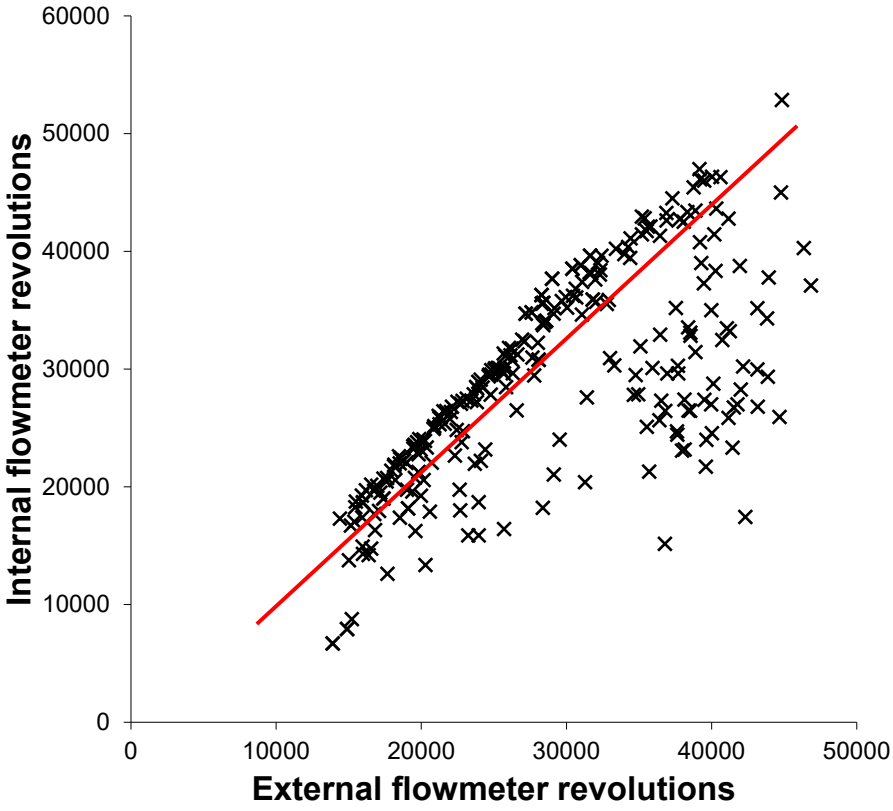

Figure 3.66 Internal versus external flowmeter revolutions during the Dutch 2022 egg surveys. Points below the red line show hauls were the internal flowmeter revolutions are lower than expected due to clogging of the net.

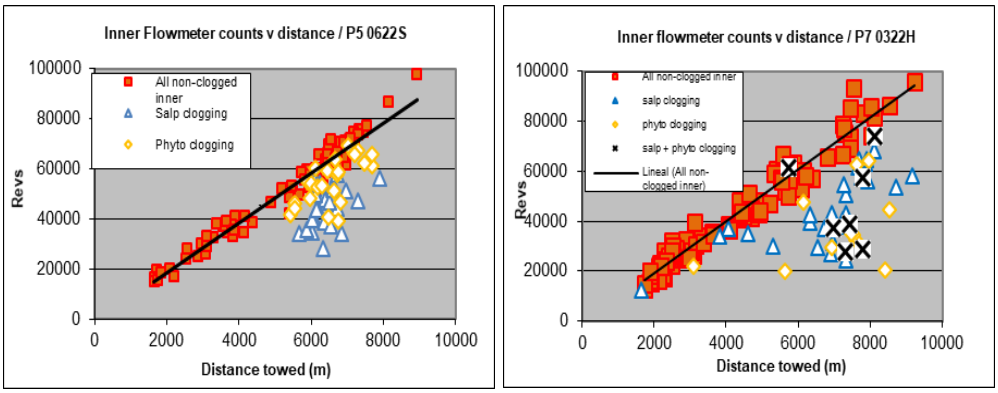

Figure 3.67 Internal flowmeter revolutions versus distance towed during the period 5 (left) and period 7 (right) Scottish 2022 egg surveys. The red squares show hauls without clogging, the blue triangles hauls with clogging due to gelatinous substances, yellow markers are hauls with clogging due to phytoplankton and the black crosses hauls were clogging occurred due to both phytoplankton and gelatinous substances.

WMR has constructed a clogging severity scale that was estimated from the flowmeter readings following ICES vocabulary. (WGMEGS will adopt this scale for the triennial survey in 2025.) It is based on measuring the relative impact of clogging on the comparative efficiency of the inner flowmeter relative to the external or control flowmeter. Under normal circumstances the inner flowmeter could be expected to have a relative efficiency of around 1.2 compared to that of the external unit however (Table 3.37) when clogging is detected this will decrease and more so with increasing severity of clogging. The suggested clogging scale (as devised by WMR) and how it maps to the existing ICES coding are provided in Table 3.37.

Table 3.37 Net clogging description as used for estimating the clogging severity for the Dutch 2022 surveys.

NetClogging	Description	Internal revolutions / External revolutions
0	None	>1.1
1	Mild	1.1 < x < 1.0
2	Moderate	1.0 < x < 0.75
3	Severe	<0.75

About 1/3 of all the stations sampled in both months showed major to severe clogging (Figure 3.66 and Table 3.38). A huge number of those samples were found in deep waters, off the continental shelf (Figure 3.68). In the past clogging sometimes occurred due to phytoplankton in the shallow coastal areas, but never in the deeper waters. The clogging in the deeper waters occurred to transparent slime in the water, but no jellyfish, salps or other organisms could be recognised in the slime.

Table 3.38 Clogging severity per station during the Dutch 2022 egg surveys.

NetClogging	Description	Period 5	Period 6
0	None	71	65
1	Mild	9	10
2	Moderate	23	25
3	Severe	18	21

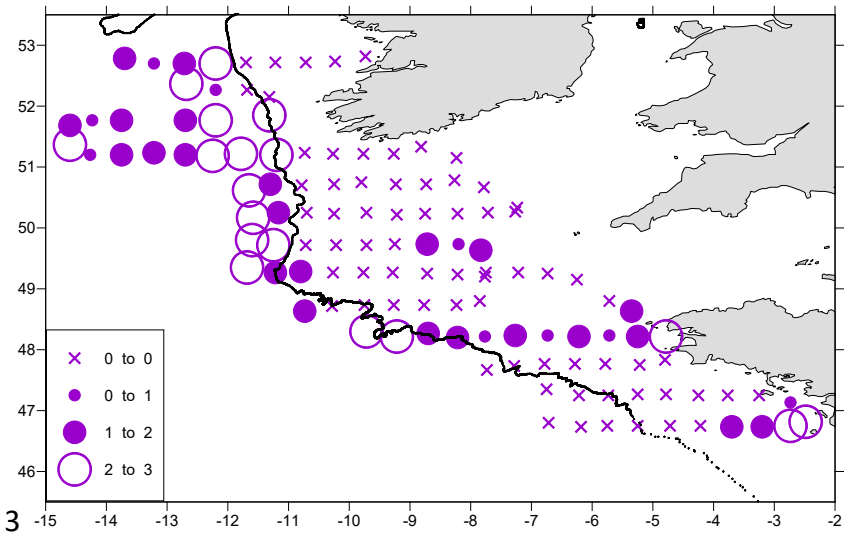

Figure 3.68a. Clogging severity per station during the period 5 Dutch 2022 egg survey. (Black dotted line is the 200m depth contour.)

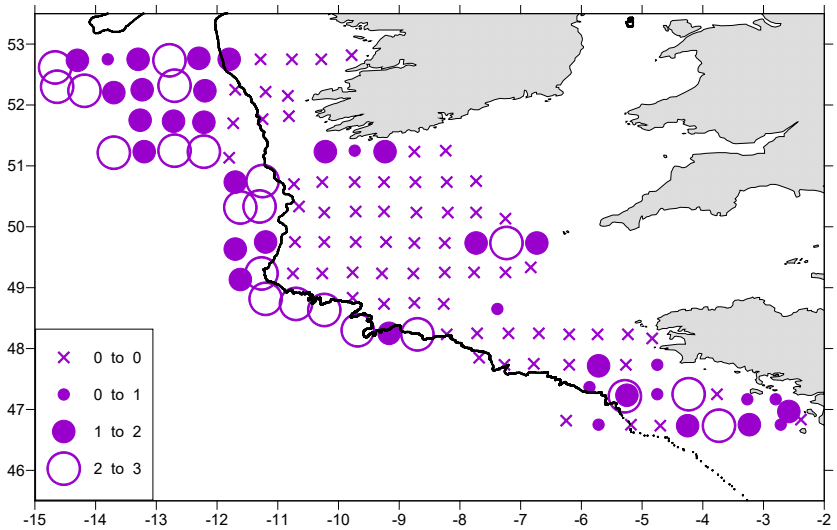

Figure 3.68b. Clogging severity per station during the period 6 Dutch 2022 egg survey. (Black dotted line is the 200m depth contour.)

3.11.7 Proposed 2024 clogging surveys

Clogging causes the meshes of the sampler to become coated thereby reducing the flow of water through the sampler. This has a detrimental impact on the volume of water that can be filtered by the sampler, and of course by implication also the samplers ability to satisfactorily sample eggs in the water column. Both Scotland and the Netherlands intend during 2024 to conduct exploratory surveys that it is hoped will shed some light on several operational as well as scientific challenges surrounding clogging and its impact on the wider MEGS survey and notably the vertical distribution/abundance of plankton in the water column within some of the affected areas mentioned.

Marine Scotland intends to carry out an exploratory survey during May 2024 and within the Rockall Trough and Porcupine Bank region. The intention will be to carry out a series of experimental deployments and at several sites utilising a Hydrobios multi-net midi plankton sampler. This will enable discrete depth stratified samples to be collected from 4 pre-determined depth ranges spanning the entire 0 – 200m MEGS depth range. The main aim of this survey would be to gather information and ideally determine patterns of vertical distribution of gelatinous zooplankton within the target depth range and area being surveyed. A linked objective would be to try and establish whether there is any correlation between egg abundance of target species and density of gelatinous zooplankton in the water column.

WMR will apply for internal funding to allow it to undertake a similar project during May/June 2024 and with very comparable aims surrounding the issue of 'missed eggs' as preliminary analysis delivered during the presentation points squarely to a situation where several samples marked as severely clogged still contained significant counts of eggs and crucially also those of target species. The main area of investigation will focus around trialling the use of a Gulf VII sampler with a 500 µm plankton net alongside a second Gulf VII sampler with the standard 280 µm net and within a specially constructed frame housing both samplers. The 500 µm net is the standard mesh size utilised during the North Sea MEGS survey and the justification for the increase in mesh size on that survey is largely due to the generally increased quantities of zooplankton observed during that survey. The primary objective will be to investigate and compare sampler performance for each net and specifically with regards to clogging and assess whether the 500 µm net performs any better within these areas where significant clogging was observed during the Dutch surveys in 2022.

Both surveys will also collect samples from gelatinous organisms for DNA analysis/identification. Results from both surveys will be reported to WGMEGS and WGWIDE prior to the next triennial MEGS survey in 2025.

3.11.8 Later egg stages

Egg staging is the process of classifying fish eggs into different developmental stages based on their physical characteristics. This is done to estimate the age of the eggs and to track the progress of embryonic development. Egg staging is important because it can provide information about the timing and location of spawning events. Egg age is estimated by staging the eggs and determining their developmental stage. Knowing the duration of each egg stage and the temperature-dependent rate of development, the age of the eggs can be estimated.

The relationship between egg stage duration and fish egg distribution is that the duration of the egg stage is one of the factors that affects the distribution of fish eggs. The duration of the egg

stage varies depending on the species of fish and environmental conditions such as temperature and salinity. Temperature is an important factor that influences the development of fish eggs. In general, the rate of development increases with increasing temperature. The duration of each stage depends on the temperature and salinity of the water, as well as the size and condition of the eggs. The higher the temperature, the faster the development of the eggs. The development time of mackerel eggs can vary from 4 to 10 days depending on these factors.

The average sea temperature (20 m) at stations where mackerel eggs were found in the MEGGS (2004-2019) surveys was estimated to be around 11 ºC. Based on Mendiola *et al* 2006 the estimated age for each mackerel egg stage at 11.1 ºC is shown in table 3.39:

Table 3.39

Egg stage	Temp. (ºC)	Estimated age (h)	Estimated age (day)
Ia	11.1	25.9	1.08
Ib	11.1	42.1	1.75
II	11.1	59	2.5
III	11.1	108.4	4.5
IV	11.1	134.6	5.6
V	11.1	153.6	6-7

Usually WGMEGS maps showing the mackerel egg production per period represent the spatial distribution of stage 1 eggs.

This work aims to explore how the spatiotemporal abundance and distribution of mackerel egg stages, interact with physical factors (e.g., ocean currents, temperature, salinity) to affect the dynamics of ichthyoplankton.

One possible way to identify the important spawning grounds of mackerel is to analyse the distribution of egg stages at sea. By creating and comparing maps of mackerel egg stages by year and period, we could infer which areas have high spawning activity, as the later egg stages indicate that spawning had been taking place a few days before the station was sampled.

The visual inspection of maps of mackerel egg stage densities for the 2004 – 2019 surveys (Figures 3.69 – 3.74) show that main regions where mackerel have consistently spawned at high intensity since 2004 are the Cantabrian Sea, the area west of Ireland and, more recently, the area west of Scotland. The Celtic Sea used to be an important spawning ground for mackerel, but it has shown a decline in the recent surveys. The spawning patterns of Atlantic mackerel vary according to their location and time of year. In the Cantabrian Sea and west of Ireland, the majority of mackerel spawn in March and April, while in the west of Scotland they spawn in April and May. Spawning and feeding migration routes may account for these different spawning grounds.

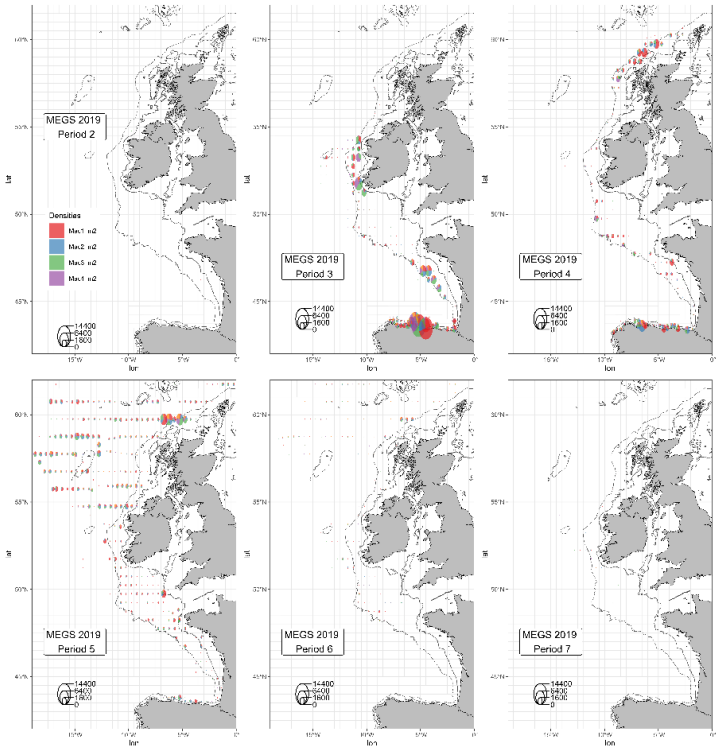

Figure 3.69 Mackerel egg stage densities by station and period for the 2019 survey. Circle areas represent mackerel egg/m2 and colour scale represent mackerel stage I-V).

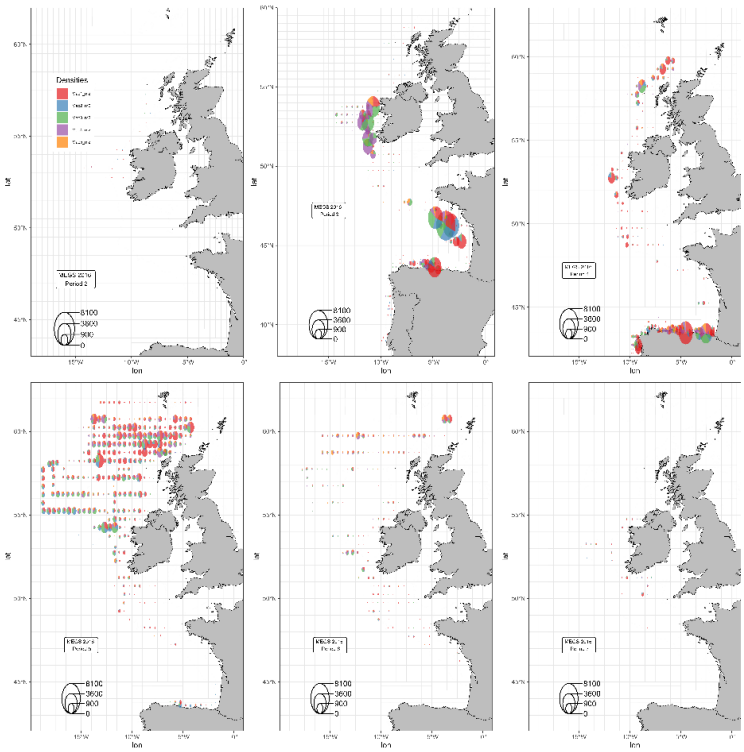

Figure 3.70 Mackerel egg stage densities by station and period for the 2016 survey. Circle areas represent mackerel egg/m2 and colour scale represent mackerel stage I-V).

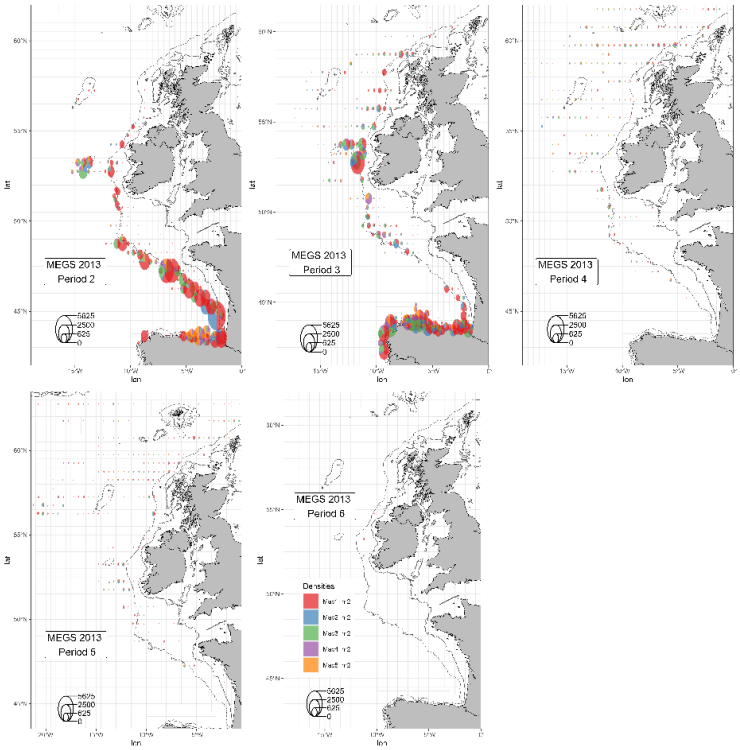

Figure 3.71 Mackerel egg stage densities by station and period for the 2013 survey. Circle areas represent mackerel egg/m2 and colour scale represent mackerel stage I-V).

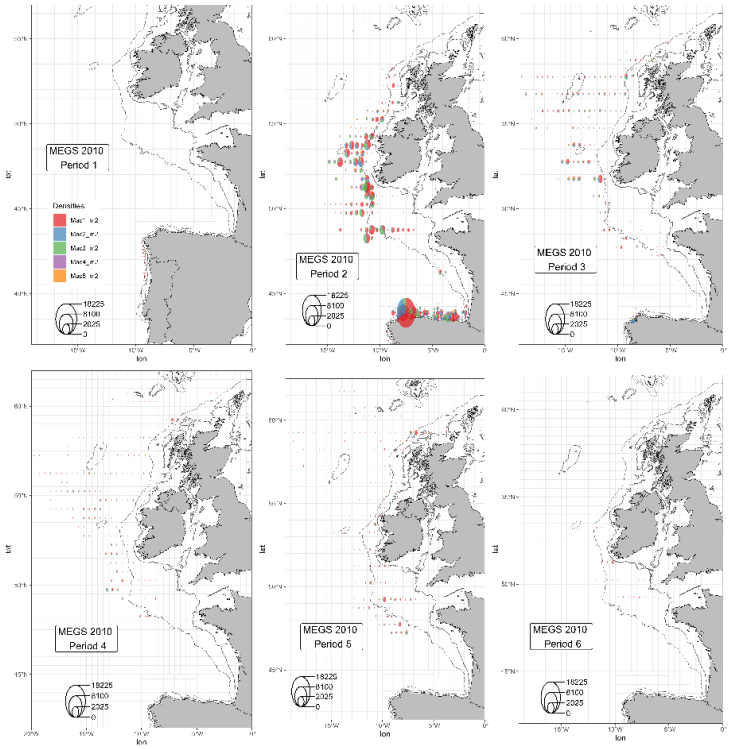

Figure 3.72 Mackerel egg stage densities by station and period for the 2010 survey. Circle areas represent mackerel egg/m2 and colour scale represent mackerel stage I-V).

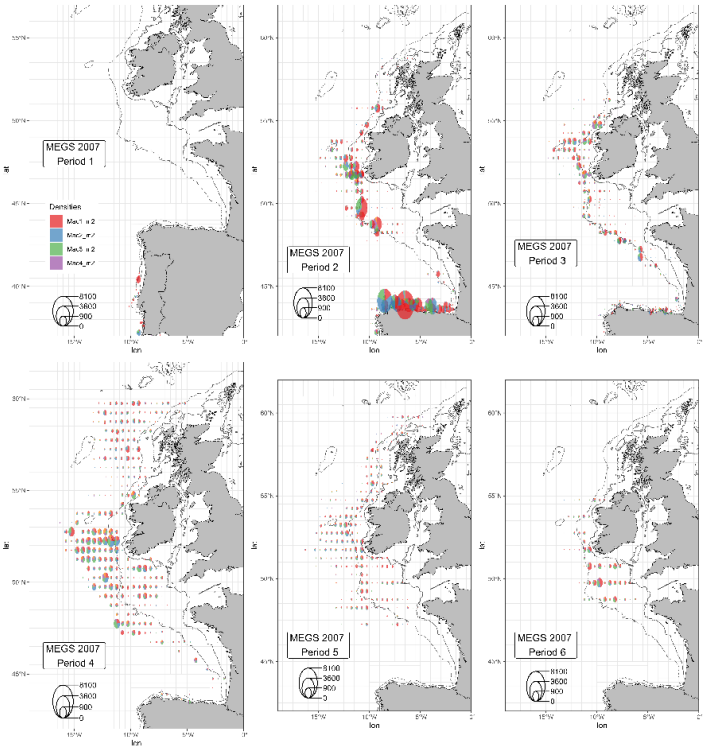

Figure 3.73 Mackerel egg stage densities by station and period for the 2007 survey. Circle areas represent mackerel egg/m2 and colour scale represent mackerel stage I-V).

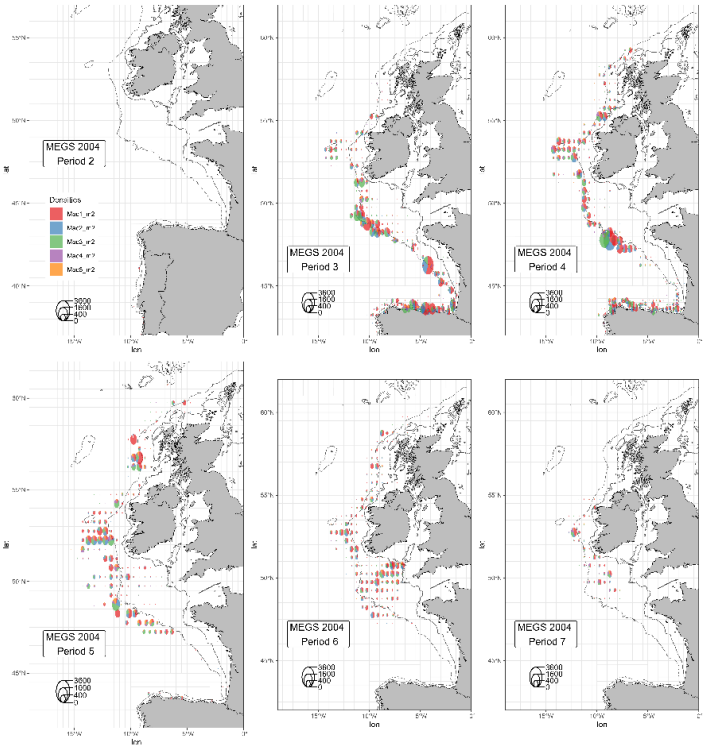

Figure 3.74 Mackerel egg stage densities by station and period for the 2004 survey. Circle areas represent mackerel egg/m² and colour scale represent mackerel stage I-V).

3.11.9 TIMES manual

WGMEGS discussed converting the SISP 5, (manual for AEPM and DEPM estimation of fecundity in mackerel and horse mackerel), and SISP 6, (manual for mackerel and horse mackerel egg surveys, sampling at sea), manuals into the TIMES format. A decision was taken to concentrate on the SISP 6 survey manual in 2023. The plan is to produce a TIMES survey manual, incorporating new survey techniques developed in recent years, by the end of 2023, for publication in 2024. Revising the SISP 5 manual will be more time consuming. In addition, WKMADE, the Workshop on mackerel daily egg production, may make recommendations for inclusion in this manual. This second manual is due for completion by the end of 2024, for publication in 2025.

3.11.10 Western horse mackerel benchmark in 2024

The three horse mackerel stocks - southern horse mackerel, western horse mackerel, North Sea horse mackerel – will be benchmarked in 2024. The process will start with a data compilation workshop in late 2023.

In this context, WGMEGS was addressed by the assessor of the western horse mackerel stock regarding the following questions:

- Do you consider that the egg surveys are covering the peak season and spawning area for this stock, and therefore the survey index still can be used in the assessment? Should the uncertainty of this data in the model inflated? If the peak season is not covered, can other approaches be considered (E.g. collect additional data during the spring acoustic surveys)?

Response: *WGMEGS is confident that peak spawning for horse mackerel is covered. In 2016 and 2019 the number of horse mackerel eggs collected was so low that it was difficult to decide whether June or July was the peak spawning period. In 2022 however, there was a very definite peak in June.*

Horse mackerel egg numbers have been low for quite a number of surveys. In 2016 Ireland organised an additional survey off the west coast in August to see if peak spawning was occurring later. We got very low numbers of horse mackerel eggs. Therefore, we were confident that the spawning season was not extended into August.

With regards to the uncertainty, other factors tend to suggest that uncertainty is increasing e.g. the use of alternate transects in 2019 or unsampled areas in 2022. This indicates that the uncertainty index in the model should be inflated.

- If WGMEGS switch to DEPM, how will the survey design be affected? Will be both mackerel and horse mackerel still covered?

Response: *Before switching to a DEPM survey WGMEGS would have to give a lot of considerations to the survey design. Due to the wide distribution of mackerel, peak spawning can take place in different areas and during different survey periods. WGMEGS is also conscious of the fact that the survey provides data on two species, and the impact on any change in survey design on horse mackerel will need to be considered very carefully.*

WGMEGS will conduct a workshop later in 2023, WKMADE, to look at the parameters used in calculating a DEPM for mackerel. If the group eventually decide to switch to a DEPM survey, a separate workshop would have to be arranged to look at survey design.

- The current model assumes that egg production is equivalent to SSB and the assessor would like to explore other alternatives, e.g. the use of fecundity at age if available.

Response*: Since 2013 the mackerel and horse mackerel egg surveys no longer collect fecundity samples for horse mackerel, only samples for batch fecundity. Therefore, data of fecundity at age are only available from a limited number of samples.*

Furthermore, WGMEGS discussed the benchmark issue list in order to identify possible other inputs from WGMEGS into the benchmark. In conclusion, WGMEGS will explore the possibility to use the horse mackerel egg survey for producing an alternative survey index. Another possible input could be the supply of an updated maturity ogive derived from the adult biological sampling.

3.11.11 Reviewing and improving spatiotemporal modelling approaches for mackerel's total annual egg production

Starting in 2007, the mackerel's spawning area has been expanding to the North and North West, far beyond the traditional survey boundaries. Also due to limited survey budgets, it was not possible to cover the complete spawning area anymore, leading to a decrease in replicates and an increase of unsampled spaces between observations. This has initially motivated the search for an alternative, more elaborated analysis to replace the present spatial interpolation of egg production estimates based on arithmetic means of neighboring samples. Another problem that has been noted relating the traditional method is that individual observations are used in the calculation of total annual egg production (TAEP), regardless of their probability of occurrence. Considering any observation of egg production (even the extremely large outliers) as representative of the complete sampling rectangle can potentially bias the estimate of TAEP high. Partially trying to overcome this and other shortcomings of the traditional calculation of TAEP, six previous studies (Borchers et al 1997, Augustin et al 1998, Beare and Reid 2002, Hughes et al 2014, Bruge et al 2016 and Brunel et al 2017) have modeled the spatio-temporal distribution of eggs with generalized additive models (GAMs). In these studies, models with penalized splines smoothers alone were used and only few interactions of covariates were tested. None of those studies have attempted to model the effect of population size on the spatial distribution of spawning mackerel.

In the present study, we attempt to improve over both the traditional and previous modeling methods to calculate TAEP. We model the spatial distribution of egg production with a Tweedie distribution and test more than 452 functional forms, including new predictors. Most of the models tested included complex covariate interactions and a proxy of population size as predictor, explicitly modeling the effect of population size on the habitat preference of spawning mackerel. We choose the best model with various metrics, including the score of a 10-fold cross validation. Comparison of the spawning stock biomass (SSB) estimated from both modeled and traditional TAEP with the SSB from the ICES advice suggest that our model improves over the traditional method. The performance metrics of our best model also indicate an improvement in comparison to a model with only non-interacting penalized spline smoothers (i.e., over the previous modeling efforts). In the time to come, it will be evaluated by the WG MEGS if our modeling approach (or some other similar one) could eventually replace the traditional method to yield a more accurate estimate of TAEP for the assessment.

3.12 Database (ToR)

3.12.1 ICES Eggs and Larvae database (ELDB) status and updates

A short presentation on the status of the ICES-hosted Eggs and Larvae database was done by ICES secretariat. In short, the submissions to the database for several surveys are now well established. The general structure and information available from the web page was reviewed https://www.ices.dk/data/data-portals/Pages/Eggs-and-larvae.aspx and a reminder of the format and checks location was shown. The ICES data portal was presented as a new way of visualizing all ICES-hosted data.

The main topic to be discussed with the group was the creation of a joint Governance Group for both Eggs and Larvae and Fecundity and Atresia databases. In the case of Eggs and Larvae database (ELDB), until now the role of governance was attributed to WGALES as overarching group, but since the database is more functional and actively used, it is clear hat there is a need of a more operational governance group, in order to make timely and relevant decisions on content, format, structure and any other business related to the database. WGMEGS received this proposal very positively, agreed on the need and utility for this governance, and several participants showed their interest in being involved in the development of this governance group.

3.12.2 ICES fecundity database

A short overview on the status of the ICES-hosted Fecundity and Atresia database was presented by ICES secretariat. The establishment of this database was originally requested by WGMEGS in 2014. The database was recently signed off on. It will contain information on the survey, fishing hauls, fish measurements, whole mount and histology screening data, as well as fecundity, batch fecundity and atresia data. There are a small number of challenges still to be solved, however the database will be available for testing in the near future.

3.12.3 Smartdots

ICES secretariat presented on the egg and larval module of SmartDots. This platform has been used for fish larvae, but in recent years its use has been extended to facilitate maturity and egg identification events. It can be a useful tool in training exercises, particularly on occasions when physical meetings are not possible. Of interest to MEGS events can be set up where participants are able to measure, identify and stage fish eggs. In these exercises it is possible to measure both the egg diameter, but also that of oil globules. Annotation parameters for each exercise are customisable. Once an event is finished it is possible to see all annotations. Other features of SmartDots include the possibility of re-using events, more than one person can organise an event, and the organisers can define what parameters are mandatory for each exercise.

3.12.4 TAF processes

ICES secretariat briefly presented the Transparent Assessment Framework, focusing on how it is an approach rather than a method. WGMEGS is calculating many indices used in stock assessments and hence also in advice provision. The inclusion of the assessments in TAF is not

mandatory until stocks go through benchmark. It was suggested to start using TAF approaches in the way WGMEGS works as preparation for the future. As many people in WGMEGS are proficient R users, the suggestion was well received and already several indexes procedures were shared in the group's github repo (https://github.com/ices-eg/wg_WGMEGS). There were also some interesting discussions on how to better share preparation work for data submission.

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Annex 2: Resolutions

2020/FT/EOSG01 A **Working Group on Mackerel and Horse Mackerel Egg Surveys (WGMEGS)**, chaired by Gersom Costas, Spain and Brendan O'Hea, Ireland, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2021	26–30 April	Online meeting	Interim report by 14 June 2021 to ACOM/SCICOM	Brendan O'Hea and Gersom Costas confirmed as new chairs.
Year 2022	22-23 August	Copenhagen, Denmark (ICES HQ)	Interim report by 30 September 2022 to ACOM/SCICOM	second meeting of group via correspondence and remotely as WebEx conference as it falls within the year of the triennial MEGS Survey. The date for report delivery is set after the WGWIDE meeting to be able to include the preliminary results of the 2022 survey.
Year 2023	17-21 April	Madrid, Spain	Final report by 26 May 2023 to ACOM/SCICOM	

WGMEGS ToRs 2021 – 2023

ToR	Description	Background	Science Plan Codes	Duration	Expected Deliverables
a	Plan and coordinate the Mackerel/Horse Mackerel Egg Surveys in the ICES areas 4 to 9.	The egg surveys in the Northeast Atlantic (ICES areas 5 to 9) and in the North Sea (ICES area 4) provide important data for fishery-independent stock indices for Northeast Atlantic mackerel and for both the western and the southern horse mackerel stocks. The survey is part of a time-series that commenced in 1977. With up to 10 nations and up to 18 individual cruises participating in the survey, careful and detailed planning and coordination of the surveys is essential.	3.1	years 1 – 3	Continuously updated survey plans and survey summary sheets of the surveys in 2022/23 on the WGMEGS sharepoint
b	Plan and Coordinate the sampling and laboratory analysis for mackerel/horse mackerel fecundity and atresia.	Reliable realized fecundity estimates are needed to convert the egg abundance data to SSBs. International coordination is needed to ensure that the samples collected on different survey are representative and collections efficient.	3.1	Year 1, 2 & 3	Coordinated Sampling Plan for the surveys in 2022/23 on the WGMEGS sharepoint

c	Review and update the manuals for the Mackerel and Horse Mackerel Egg Surveys and fecundity estimation	Well defined, standardized sampling and laboratory procedures are necessary to properly interpret the monitoring data as well as ensuring that rigorous and transparent QAQC procedures have been applied and can be evaluated by external reviewers.	3.1, 3.2	Year 1, 2 and 3	Updated manuals for both, egg surveys and fecundity estimation for WGMEGS on the sharepoint in years 1 and 2, for for publication in TIMES in year 3
d	Coordinate the quality-controlled data delivery to the ICES databases for both, egg abundance and fecundity data	x	3.1	Year 3	Updated ICES egg and larval database. ICES fecundity and atresia database
e	Organise and evaluate workshops aimed at developing survey specific expertise in fish egg identification and staging, and fecundity estimation	For quality assurance in the year before the Atlantic survey two workshops will be organized in which survey participants are obliged to participate in order to standardize egg identification and staging and fecundity estimation. The WGMEGS manual is required to be updated with the results from those workshops.	3.2, 3.3	Year 1 and 2	TIMES survey manual article
f	Prepare, organise and evaluate a workshop on mackerel and horse mackerel survey design and data quality assurance and control	Since the recent surveys and due to rapidly changing environmental conditions, the assumptions, under which the current survey design was determined, are being increasingly challenged. New survey strategies and techniques, as well as new methods for spatial data analysis need to be carefully implemented in order to maintain the integrity of the time series.	3.2, 3.3	Year 3	CRR
g	Provide relevant fisheries resources assessment groups with quality-controlled time series of indices on spawning stock biomass for mackerel, horse mackerel and hake in time fore the assessments.	Provisional estimates of mackerel SSB, and egg production of horse mackerel and hake are delivered in the year of the survey. The estimates however are finalized during the WGMEGS meeting in the year after the Atlantic survey.	1.3, 3.1, 5.1, 5.2	Years 2 and 3	

Summary of the Work Plan

Year 1	**Planning of the egg survey in 2022, conduct 2 workshops to develop survey specific expertise**
Year 2	Survey year, the Atlantic survey is conducted in 2022, a WebEx meeting will take place in year 2 after the survey to collate the survey results and provide preliminary results. A report, by correspondence, with the updated planning and manuals, and the preliminary results of the 2022 survey, is published.
Year 3	Reporting and finalizing of the results of the 2022 egg survey. Planning of the 2023 North Sea egg survey. Delivery of CRR on mackerel and horse mackerel survey design.

Supporting information

Priority	Essential. The egg survey provides important fishery-independent stock data used in the assessment for Northeast Atlantic mackerel and for the western horse mackerel stocks.
Resource requirements	No additional resources needed for ICES. For participants the surveys are all part of the national programs. The surveys and associated meetings are also partially funded under the EU fisheries data directive.
Participants	Usually ca. 15–20 participants from ICE, Far, N, NL, P, ESP, UK (E), UK (Scot), DE, DK, IRL.

Annex 3: Abstracts of presentations given during the WGMEGS

2022 International Mackerel and Horse Mackerel Egg Surveys - Final mackerel Results –

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Abstract

In 2022, the Mackerel Egg Survey (MEGS) was conducted in the Western Atlantic, specifically the Western and Southern areas. The survey applied the Annual Egg Production Method (AEPM) to estimate the Spawning Stock Biomass (SSB) of mackerel. Additionally, mackerel ovary samples were collected during the survey to estimate adult parameters for AEPM. Preliminary results for Annual Egg Production, fecundity, and SSB were reported in 2022. The Annual Egg Production in 2022 was estimated at 2.093x10^15 mackerel eggs for the Western and Southern areas. This represents a 28% increase compared to the 2019 survey. The realized fecundity was estimated at 1268 oocytes/g female, showing an increase (8%) from the preliminary result of 1178 oocytes/g female in 2022 which is an increase of 10% compared to the 2019 realized fecundity. According to AEPM, the spawning stock biomass in 2022 was estimated at 3.565 million tonnes. This estimate reflects an 18% increase compared to the 2019 SSB estimate.

2022 International Mackerel and Horse Mackerel Egg Surveys DEPM for mackerel

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Abstract

During the 2021 meeting of the WGMEGS, it was agreed that the periods identified as likely peak spawning periods were periods 3 and 4 for mackerel in the western Atlantic (western and southern area) and period 6 for the North Sea.
Therefore, the estimated Mean Daily Egg Production (P0) for mackerel was applied to periods 3 and 4.in the Western Atlantic and period 6 for the North Sea.
The spawning area in the western Atlantic for Period 3 () was 271,648 Km^2, which was about 20% less than the spawning area in Period 4 (323,863 km^2).The P0 for mackerel was estimated using stage Ia mackerel eggs. The P0 in the western and southern areas (western Atlantic) was 72.8 mackerel eggs/m2/day in period 3 and 33.8 mackerel eggs/m2/day for period 4.
The highest densities of stage Ia mackerel eggs were observed around the 200m contour line in the Western Atlantic in both periods 3 and 4
The North Sea spawning area of mackerel was at 371126 km2 for 2022 and the mean Daily egg production (stage 1a) was 18.6 eggs/m2/day. The total Daily egg production (P0total) was

$0.6909*10^{13}$ eggs/day. The distribution of stage 1a eggs in the North Sea did not show a clear pattern

Western and southern Mackerel Daily Egg Production Method (DEPM) adult parameters

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Abstract

Northeast Atlantic mackerel adult parameters and coefficients of variation were estimated in 2022, as it was made for 2016, and 2019 surveys. The average weight per female increases for the third consecutive year; the sex ratio remains stable at around 0.5; batch fecundity values decrease and are close to those of 2016 and the value of the spawning fraction is intermediate to that of previous years. These results should be considered preliminary, as thorough revision of laboratory methods and all information collected from 2013 to 2022 will be carried out at the Workshop on Mackerel Daily Egg production (WKMADE) next autumn.

Biological sampling for mackerel. 2022.

Gersom Costas[1], Jens Ulleweit[2], Maria Korta[3]

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[2] Thuenen-Institute of Sea Fisheries (Thunen, Germany)
[3] AZTI, Spain

Abstract

During the MEGS surveys in 2022, 162 hauls were conducted and 8190 mackerel were sampled (1721 in the North Sea and 6469 in the Western and Southern areas). Mackerel lengths ranged from 17.3 to 45 cm in the Western and Southern area and from17.5 to 44.2 cm in the North Sea area. The median length was 37 cm in Western and Southern area and 30.3 cm in North Sea area. In the western and southern area smallest mackerel were caught in January whereas mackerel sampled in the North Sea were smaller in general. Regarding age distributions by month and area were also shown, where it was observed that younger ages (1-3 years old) were more abundant in January and February and older ages (8-11+ years old) were more abundant in samples of March and April in the Western and Southern area, most abundant in the North Sea were younger ages (1-3 years old).

Applying DEPM for Horse Mackerel SSB estimation in 2022

Korta[1], Maria, Alvarez[2], Paula, Costas[3], Gersom and van Damme[4], Cindy

[1] AZTI, Spain
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[4]Wageningen Marine Research (WMR, The Netherlands)

Abstract

DEPM survey was conducted in 2022 during the peak spawning period to estimate the spawning stock biomass for the western stock horse mackerel. The survey covered the western Atlantic waters between 47ºN to 58ºN. The estimates of Egg production and adult parameters mean for period 6 (June) were presented at the 2023 WGMEGS meeting.

Based on the abundance of developmental stage 1a egg in June in the area surveyed, the daily egg production was estimated to be 0.186 1013 No. eggs/day. The resulting mean weight of female, mean sex ratio and mean batch fecundity were 275.44 g, 0.508 and 219.52 No. eggs/g female respectively. These parameters gave a daily fecundity of 20.86 No. eggs/g female/day as a result. The spawning stock biomass estimated using the above mentioned parameter values, reached 891 445 tonnes in 2022.

The missing eggs. The case of the mackerel and horse mackerel egg survey in 2022.

Cindy van Damme

[4]Wageningen Marine Research (WMR, The Netherlands)

Abstract

The Atlantic mackerel and horse mackerel egg survey was carried out in 2022. The Netherlands surveyed in May and June east of Ireland, Celtic Sea and northern Bay of Biscay. The Dutch survey is carried out with a Gulf VII with a 280 µm mesh as the survey manual prescribes, with an internal and external flowmeter mounted on the sampler.

During the surveys regular calibration of flowmeters is done. In good situations the internal flowmeter calibration is 1.2 times the external flowmeter. However, in some areas the internal flowmeter revolutions was 0.5 times the external flowmeter during a calibration without the codend. In that situation the external flowmeter was also somewhat lower compared to the situation without clogging.

Clogging severity was estimated following ICES vocabulary. About 1/3 of all the stations sampled in both months showed major to severe clogging. A huge number of those samples were found in deep waters, off the continental shelf. In the past clogging sometimes occurred due to phytoplankton in the shallow coastal areas, but never in the deeper waters. The clogging in the deeper waters occurred to transparent slime in the water, but no jellyfish, salps or other organisms could be recognised in the slime.

MSS Clogging Survey 2024

Finlay Burns

Marine Scotland Science (MSS, Scotland)

Abstract

During the period 5 *(May)* and period 7 *(July)* surveys undertaken by Scotland as part of the 2022 mackerel and horse mackerel egg *survey (MEGS)* MSS scientists encountered massively increased incidences of clogging being recorded during their Gulf 7 sampler deployments compared to those reported during the same surveys undertaken in 2019 during the previous MEGS survey of the western and southern areas. During period 5 *(0622S*) the increase was particularly significant with an almost 300% increase in the numbers of stations clogged whilst the period 7 survey

(0322H) saw an almost 100% increase. Overall this amounted to over 30% of the total combined Gulf 7 stations completed for both surveys.

In addition to the general overall increase in clogged stations being reported from both 2022 surveys changes were also noted in the location as well as the type of organism responsible for the clogging. A far higher proportion of gelatinous zooplankton (*as opposed to Phytoplankton*) were recorded as the cause of the clogging and with the majority of the affected stations now being located over deep water and often in locations where there had been no clogging reported in 2019.

Clogging causes the meshes of the sampler to become coated thereby reducing the flow of water through the sampler. This has an obvious impact on the volume of water that can be filtered by the sampler, and of course by implication also its ability to satisfactorily sample fish eggs within the sampled water column. In May 2024 MSS plans to conduct an exploratory survey that will attempt to collect information on the vertical distribution/abundance of plankton in the water column and within the worst affected areas of the South Rockall Trough and Porcupine Bank. This will involve deploying a multi-net plankton sampler that will enable samples to be collected from a range of different depths. The main aims would be to determine vertical distribution patterns, if any, of plankton in the water column and also to try and investigate whether a relationship exists between mackerel egg abundance and density of plankton in the water column. The intention would be to report the results of the survey to WGMEGS prior to the start of the next triennial MEGS survey in 2025.

How about all the mackerel egg stages?

Gersom Costas[1]

[1] Instituto Español de Oceanografía (IEO-CSIC, Spain)

Abstract

Egg staging is a method to classify fish eggs by their development stage based on how they look we can use the time of each egg stage and how fast they develop depending on the temperature to calculate their age . Usually, they develop faster when the temperature is higher. For example, mackerel eggs can take from 4 to 10 days to develop depending on these factors.

The average water temperature (20 m deep) where mackerel eggs were found in the MEGGS (2004-2019) surveys was about 11 ºC. Based on Mendiola et al 2006, we can estimate the age for each mackerel egg stage at 11.1 ºC.

Analysing the distribution of different egg stages at sea is one way of identifying important mackerel spawning grounds, as the later egg stages indicate that spawning has taken place a few days before the station had been performed.

Maps of mackerel egg stage densities for the 2004 – 2019 surveys have been analysed and it is noted that the main areas where mackerel have consistently spawned at high intensity since 2004 are the Cantabrian Sea, the area west of Ireland and, more recently, the area west of Scotland.

Reviewing and improving spatiotemporal modelling approaches for mackerel's total annual egg production

Ismael Nuñez-Riboni

Thuenen-Institute of Sea Fisheries (Thunen, Germany)

Abstract

The traditional calculation of total annual egg production (TAEP) has some shortcomings: egg production is estimated from arithmetic averages of individual observations regardless whether they are extreme, rarely observed values, and has shown difficulties to cope with the spatial expansion of mackerel spawning observed since 2007 (increasing the amount of interpolated estimates). Various previous modelling efforts attempted to obtain more accurate egg production estimates by using generalized additive models (GAMs). In this study, we review and improve these models by introducing new features: We model both the western and southern component of the mackerel stock with a Tweedie distribution and test more than 400 model forms, including new predictors (like population size) and complex covariate interactions. We choose the best model with various metrics, including the score of a 10-fold cross validation. Our results show that environmental variables should be included in the model as simple functional, unimodal terms. This leads to a model that is more similar to a generalized linear mixed model than the typical GAM with smoothers. Models that include only smoothers produced worse results because they are not able to extrapolate beyond the sampled region. Additionally, considering the effect of population size on the spatial distribution of eggs showed to be fundamental for a better model performance.

Annex 4: Meeting agenda

Proposed agenda WGMEGS April 2023, Madrid, Spain

Monday 17 April

10:00 Opening of the meeting, general stuff, introduction, etc.

10:30 Presentation: Results of the 2022 egg surveys, (Western and Southern) Mackerel **Brendan**

11:30 Coffee break

12:00 Presentation: Mackerel fecundity and atresia estimation from the 2022 survey **Anders / Maria K / Paula**

12:30 Presentation: New calculation of egg production and SSB estimation (Western and Southern) AEPM **Gersom**

13:00 **Lunch**

14:00 Presentation: Results of 2022 North Sea survey, Mackerel **Brendan**

14:30 Presentation: NS Mackerel Daily egg production calculation **Gersom**

15:00 Presentation: Oocyte measurement analysis and Thassya work **Anders** Discussion about implications for MEGS SSB calculations. Teunis paper.

15:30 Coffee break

16:00 Presentation: Mackerel DEPM estimation from 2022 survey **Lola**

16:30 Presentation: Biological data for mackerel **Jens / Maria K / Gersom**

17:00 Presentation: "Mackerel egg production" **Gersom**

17:30 End of the day

Tuesday 18 April

09:00 Presentation: Results of the 2022 egg surveys, Western horse mackerel **Brendan**

09:30 Presentation: Western horse mackerel DEPM fecundity parameter and SSB estimation. **Maria K / Paula /Cindy**

10:00 Presentation: Biological data for Western horse mackerel **Jens/ Maria K / Gersom**

10:30 Coffee break

11:00 Presentation: Horse mackerel genetic results **Ed Farrell**

11:30 Presentation: Southern horse mackerel DEPM 2022 estimation **Cristina / Maria M**

12:00 Presentation: Southern horse mackerel DEPM temporal series estimation (egg production and fecundity parameters) **Cristina / Maria M**

12:30 Presentation: Proposed work plan for WKMADE **Anders / Lola**

13:00 **Lunch**

14:00 Presentation: Mackerel component identification workshop **Richard**

14:30 Presentation: Clogging during the 2022 surveys **Cindy**

15:00 Presentation: Proposed 2024 clogging survey **Fin**

15:30 Coffee break

16:00 Presentation: Later egg stages **Gersom**

16:30 Presentation: Results of 2019 mackerel egg developments experiments **Paula / Isabel / Cindy**

17:00 Presentation: Results of 2021 North Sea mackerel egg developments experiments **Sebastian Politis**

Discussion on any new temperature development equations and implications for MEGS SSB calculations.

17:30 Allocation of and assign tasks for report

17:45 End of day

Wednesday 19 April

09:00 Discussion on possible switch from AEPM to DEPM for western surveys

09:30 Presentation: ICES egg and larval database uploads **Adriana**

10:00 Presentation: ICES fecundity database **Eva**

10:30 Coffee break

11:00 TIMES manuals **Gersom / Brendan**

12:00 Upcoming western horse mackerel benchmark in 2024 – discussion on possible data requests. **Gersom / Jens**

12:30 Annual Science Conference oral presentation **Lola**

13:00 **Lunch**

14:00 Presentation: Reviewing and improving spatiotemporal modelling approaches for mackerel's total annual egg production **Ismael**

14:30 TAF processes **Adriana**

15:00 Discuss and decide on report sections. Assigning report tasks

15:30 Coffee break

16:00 (Report back from) break out group(s)/Report writing

17:30 End of day

Thursday 20 April

09:00 Report writing

10:30 Coffee break

11:00 Progress status of report writing

13:00 **Lunch**

14:00 Next 3 years of WGMEGS

- New chairs
- New survey coordinator
- New multi-annual ToRs

15:30 Coffee break

16:00 New recommendations from WGMEGS

17:30 End of day

Friday 21 April

09:00 Plenary discussion of report sections

10:30 Coffee break

11:00 Plenary discussion of report sections

13:00 **Lunch**

14:00 Plenary discussion of report sections

16:00 End of meeting