Status of the main commercial fishes in the western Baltic Sea in 2020-2023: Results of working with local fishers

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Abstract and Summary

For the years 2020-2023, for cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), flounder (*Platichthys flesus*), dab (*Limanda limanda*), turbot (*Scophthalmus maximus*), and herring (*Clupea harengus*)) in Kiel Bight of the western Baltic Sea, the following key population data are presented, analyzed and discussed: Total length, wet weight, stomach weight, stomach content, sex, gonad weight, and gonad ripeness. The data are based in part on official surveys but mostly on data collection done by commercial fishermen in collaboration with GEOMAR. The study documents the four years just before the total collapse of western Baltic cod. It shows the many warning signs-- such as serrated length structure and catches as high as all adult cod present at the beginning of the year-- that were evident but ignored by management. In contrast, the data also show the good status and increasing biomass of the less-fished western Baltic plaice, flounder and dab, which reproduce in the same area at the same time as cod, confirming that not climate change but excessive fishing pressure has caused the collapse of cod. The study also shows that neither cod nor the other commercial species benefit from the prohibition of trawl fishing below 20 m of water depth from February 1 to March 31 for vessels longer than 15 m, because mature individuals regularly enter shallower waters. Official age estimates were found to be highly variable and misleading and a simplified growth equation is presented to deal with that. Legal mesh sizes are too small for cod, plaice, flounder and turbot, catching fish mostly before they have reached maturity. Minimum legal mesh sizes for these species should be increased by about 50%. In all examined species, gonad weight and thus fecundity increased faster than body weight, underlining the benefits of increasing mesh sizes and thus postponing the size at first capture past the size of 90% maturity. Peak spawning season was 1-2 months earlier in all species compared to historical records. Condition (body weight at a given length) has decreased in all commercial species, presumably because of decreased oxygen in the water.

Introduction

Since 2020 GEOMAR has been working with a group of local fishers to better understand the reasons behind the decline and later collapse of the cod (*Gadus morhua*) and herring (*Clupea harengus*) stocks in the western Baltic Sea (Froese et al. 2020, 2022). For that purpose, from December to May each year, fishers were paid to do a variety of measurements and examinations (Figure 1) on fishes in their commercial catch before marketing.

The main purpose of the investigation was the following:

- Better understanding of the strong difference in resilience against climate change of cod and herring (low) and all flatfish (high).
- Better understanding of natural strategies to deal with (=adapt to) warming waters and increased environmental variability.
- Finding signs of impact of environmental change on individual fish.
- Identifying management options for helping fish adapt to climate change.

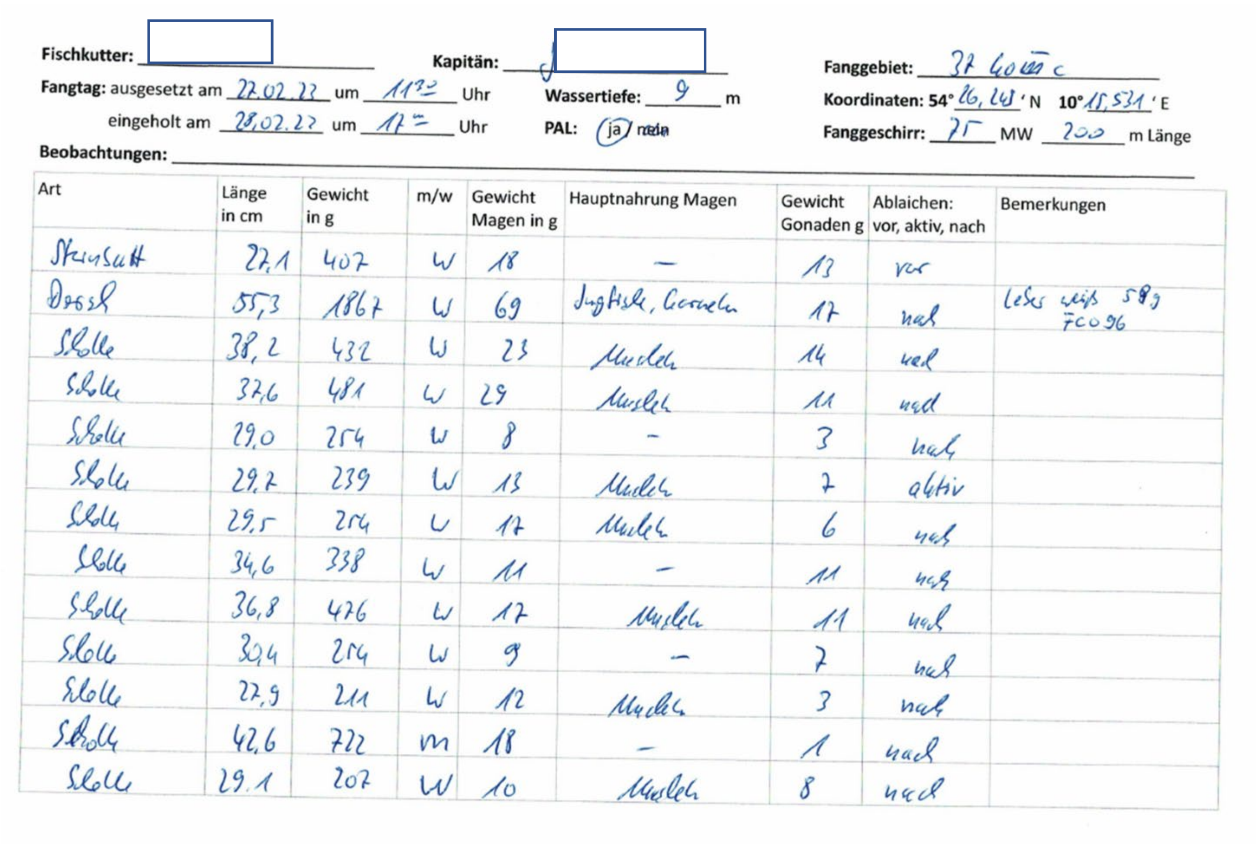
Material and Methods

Data from Kiel Bight

The data from Kiel Bight were collected by commercial fishers who examined the main commercial species before sale and reported the results together with station data. The following was reported:

- Date, time, depth, locality and coordinates of gear deployment.
- Type of gear (gillnet, fyke net or trawl) with mesh size (knot to knot) and length or width of gear.
- Deployment of harbour porpoise alert (PAL) devices.
- Species (cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), flounder (*Platichthys flesus*), dab (*Limanda limanda*), turbot (*Scophthalmus maximus*), herring (*Clupea harengus*)) and occasionally brill (*Scophthalmus rhombus*), lemon sole (*Microstomus kitt*), lump fish (*Cyclopterus lumpus*) and eel (*Anguilla anguilla*), the latter group not being treated in this report.
- Total length (cm), wet weight (g), stomach (or gut in flatfish) weight (g), coarse description of stomach content, sex (male, female, juvenile), gonad weight (g), visual assessment of gonad status as before spawning, active spawning, and after spawning.

These observations were encoded in a paper form (see example in Fig. 1) and later transferred into a spreadsheet file for analysis. Submission of the paper forms was done by taking cellphone photos of the forms and sending them as Email attachments, or by sending the paper forms by regular mail. Names of boats or fishers were present on the paper forms but were not encoded in the spreadsheet and not used for analyses.



Fischkutter: ____ **Kapitän:** ____ **Fanggebiet:** 37 G0 [illegible]

Fangtag: ausgesetzt am 27.02.22 um 11³⁰ Uhr **Wassertiefe:** 9 m **Koordinaten:** 54° 26,48 ' N 10° 15,531 ' E

eingeholt am 28.02.22 um 17⁰⁰ Uhr **PAL:** ja / nein **Fanggeschirr:** 75 MW 200 m Länge

Beobachtungen:

Art	Länge in cm	Gewicht in g	m/w	Gewicht Magen in g	Hauptnahrung Magen	Gewicht Gonaden g	Ablaichen: vor, aktiv, nach	Bemerkungen
Steinbutt	27,1	407	w	18	–	13	vor	
Dorsch	55,3	1867	w	69	Jungfische, Garnelen	17	nach	Leber weiß 58g FC096
Scholle	38,2	432	w	23	Muscheln	14	nach	
Scholle	37,6	481	w	29	Muscheln	11	nach	
Scholle	29,0	254	w	8	–	3	nach	
Scholle	29,7	239	w	13	Muscheln	7	aktiv	
Scholle	29,5	254	w	17	Muscheln	6	nach	
Scholle	34,6	338	w	11	–	11	nach	
Scholle	36,8	476	w	17	Muscheln	11	nach	
Scholle	30,4	254	w	9	–	7	nach	
Scholle	27,9	211	w	12	Muscheln	3	nach	
Scholle	42,6	722	m	18	–	1	nach	
Scholle	29,1	207	w	10	Muscheln	8	nach	

Figure 1. Example of a paper form filled in by one of the participating fishers. Names of boat and captain have been hidden and were not stored or used for analysis.

The file with all data from Kiel Bight is available from https://oceanrep.geomar.de/id/eprint/61451/

Data from Surveys

The International Council for the Exploration of the Sea (ICES) provides an online database of trawl surveys, including data from the Baltic International Trawl Survey (BITS) which conducts regular standardized surveys in Febuary-March in the Western Baltic Sea with data from 1991 to 2023. The survey results are reported in different formats and levels of aggregation. For the purpose of this study, the Sex, Maturity, Age, Length Key (SMALK) format was used for maximum length and weight, length and age structure, condition, and maturity at length and age. Data as submitted (Exchange format xchCA) were used for determining maximum length and weight, maximum age, and sex ratio.

The DATRAS database is accessible from https://www.ices.dk/data/data-portals/Pages/DATRAS.aspx.

Methods

Length-weight relationship and condition

Body weight and total length were plotted in log-log graphs for all species. The parameters *a* and *b* of the length-weight relationship were estimated from a linear regression of $\log_{10}$ weight (W) in grams as a function of $\log_{10}$ length (L) in cm, to fit Equation 1 (Froese 2006).

$$log_{10}(W) = a + b\ log_{10}(L) \qquad \text{Equation 1}$$

Parameters were estimated for females, males and juveniles, and all combined.

Points that were more than three standard deviations away from the predicted mean weight for the respective length were considered outliers and were excluded from parameter estimation (Froese 2006) as well as from all other analyses. The lm(), resid() and confint() functions of R (R Core Team 2021) were used for estimation of parameters, plausible 95% confidence intervals, and coefficient of determination r^2.

Individual condition was calculated as the ratio of observed body weight (W) relative to the cube of the corresponding body length according to Equation 2. The multiplication with 100 only serves to scale results around 1.0 (Froese 2006).

$$C = \frac{W}{L^3}\,100 \qquad \text{Equation 2}$$

Data were analyzed by box plots and as annual trends where condition in Kiel Bight (2020-2023) was compared to condition derived from SMALK data for the Western Baltic Sea in 1991-2023.

Maximum and optimum length, weight and age

Maximum length (L_{max}) and weight (W_{max}) for a species were determined as the maximum value reported in the BITS surveys for the Western Baltic Sea (ICES areas 22 and 24) in 1991-2023 or observed in Kiel Bight in 2020-2023. Maximum age (t_{max}) was derived from the BITS Exchange data.

There is an optimal length (L_{opt}) for catching fish, where the increase in body weight has reached a maximum, and where most individuals have already reproduced 1-3 times. This is also the length where catches will be highest for a given effort or where for a given catch the least number of fish will be killed (Froese et al. 2016). L_{opt} was approximated as 2/3 L_{max} (Froese et al. 2016) and optimum weight at capture W_{opt} was determined by calculating the weight corresponding to L_{opt} as $W_{opt} = a\, L_{opt}^b$, where a and b are parameters estimated in Equation 1.

The length at first capture resulting in a mean length of L_{opt} in the catch was approximated as L_{c_opt} = 0.56 L_{max} (Froese et al. 2016) and the corresponding weight was calculated as $W_{c\_opt} = a\, L_{c\_opt}^b$.

Length at first maturity

Length at first maturity was derived from the SMALK database by taking the following maturity codes as indication of subsequent, active or recent participation in spawning: 3, 4, 5, 63, 64, 65, C, E, III, IV, V. Proportion of juvenile versus mature individuals was then presented in histograms of age and length.

The lengths with 50% and 90% mature females were derived with a rearranged ogive function such that L_{m50} and L_{m90} show up as parameters. That equation was fitted to observed proportions of mature females at increasing length classes (S_L) (Equation 3).

$$S_L = \frac{1}{1 + e^{\frac{2.2\,(L - L_{m50})}{L_{m50} - L_{m90}}}} \qquad \text{Equation 3}$$

The fitting was done with the nls() function of R (R Core Team 2021), using the coef() and confint() functions for extraction of parameters and plausible 95% confidence intervals.

Similarly, Equation 3 was used to derive L_{m50} and L_{m90} estimates by fitting it to observed proportions of mature females in samples obtained from Kiel Bight.

Gonadosomatic index and scaling of ovary weight with body weight

Ovary weight of females was divided by body weight to obtain the fraction of body weight contributed by ovary weight, which is referred to as the gonadosomatic index. A log-log linear regression of gonad weight as a function of body weight provided an estimate of the scaling (=slope). The fitting was done with the lm() function of R (R Core Team 2021), using the coef() functions for extraction of the slope parameter with 95% confidence limits. Also, the 95th percentile of the gonadosomatic index was derived to approximate the maximum fraction of gonad weight in relation to body weight.

Spawning season

The proportion of spawning females per month from 2020 to 2023 was derived from the sampled months from December to May. Spawning females were taken as those where the ovaries represented more than 7.5% (15% in herring and turbot) of body weight. The peak of spawning was the month with the highest proportion of spawning females, start and end of the spawning season were taken as months with just over 10% of spawning females.

Abundance trends

Abundance of species in the shallow waters of Kiel Bight during January to May was determined as catch per unit of effort (CPUE) by standardizing reported catches as median catch per day (24 hours) in 250 m of gillnets with 65-75 mm mesh size (knot to knot) for the years 2020-2023. The respective trends were compared to spawning stock biomass trends or stock sizes indices reported in the cited ICES Advice documents.

Diet composition

Stomach content as reported by the Kiel fishers was standardized into 35 food items and their relative frequency of occurrence was calculated and displayed in a table as well as in pie-charts. For cod the analysis was done for juveniles (<= 35 cm length) and adults (> 35 cm length).

Gear selectivity

Length frequencies caught by different gears were analyzed for gillnets with mesh sizes from 55-80 mm (knot to knot) (all species) and for trawls with 110 mm mesh size (stretched mesh) (only cod and plaice). Box plots were used to compare the length composition with the target length L_{opt} and the optimum length for first capture (L_{c_opt}).

Somatic growth

For the estimation of somatic growth, length and age data were derived for the years 2020-2023 from the SMALK database and fitted with a von Bertalanffy (1938) growth curve (Equation 4).

$$L_t = L_{inf}(1 - e^{-K\,(t-t_0)}) \qquad \text{Equation 4}$$

Where L_t is the length at age t, L_{inf} is the asymptotic length, K is a parameter indicating how fast L_{inf} is approached per year, and t_0 corrects for the fact that hatching fish (at t=0) already have a length and that growth of embryos or larvae is not represented well by the von Bertalanffy growth equation.

The corresponding equation for weight at age (W_t) is Equation 5, applied here only to weight and age data for cod from Kiel Bight.

$$W_t = W_{inf}\left(1 - e^{-K\,(t-t_0)}\right)^3 \qquad \text{Equation 5}$$

The fitting was done with the nls() function in R (R Core Team 2021) and the functions coef() for parameters and confint() for plausible 95% confidence intervals.

In addition, for cod, data from Kiel Bight could be used to fit equation 4 to observed length-at-age data from the median length of one year old cod plus the median lengths of the outstanding 2016 year class in the years 2020-2023 (ages 4, 5, 6), which could be identified because recruitment of year classes 2015, 2017 and 2018 was negligible.

For the other species, a second growth curve was fitted based on the assumption that the maximum length is a plausible proxy for L_{inf} and that a plausible value for t_0 can be derived from published growth equations. An estimate of K can then be derived from the median length of one- or two-year old fishes with an equation based on Pütter (1920) (Equation 6).

$$K = \frac{\frac{L_t}{t - t_0}}{L_{max} - 0.5\, L_t} \qquad \text{Equation 6}$$

Where L_t is the median length of fish at age t. L_t was derived as median length of individuals of t = 1 year of age (t = 2 in turbot) in SMALK. This preliminary estimation of growth parameters was done because of the very wide variability in SMALK age readings for ages larger than one or two.

The R-code written and used for the analyses presented in this study is available from https://oceanrep.geomar.de/id/eprint/61451/

Results and Discussion

Results for Cod (*Gadus morhua*)

Status: The status and history of exploitation of the western Baltic cod are given in the ICES Advice document of May 2023 (ICES-cod 2023), with time series of catch, recruitment, harvest rate as an index of fishing pressure, and spawning stock biomass (SSB) relative to the border of safe biological limits (Bpa), from 1985 to 2022/23. To put things in perspective, the highest landings on record in 1996 were 38,505 tonnes, which together with 6,868 tonnes of estimated discards (mostly undersized cod discarded on sea) and estimated recreational catch of 3,420 tonnes gives a total catch of 48,793 tonnes. In comparison, the total catch reported for 2022 was 403 tonnes (out of an allowed catch of 489 tonnes). In other words, less than 1% of the previous maximum catch was found and caught by the fishers, who were unable to exhaust the allowed catches. Similarly, the highest spawning stock biomass was 49,784 in 1997, of which only 5,661 tonnes (11%) remained in 2022 (ICES-cod 2022). To put the remaining stock size even more into perspective, it is helpful to compare it to the natural stock size that would be present without fishing, the so-called carrying capacity of the Western Baltic Sea for cod. A proxy for that can be derived by combining the highest catch taken from the system (48,793 tonnes) with the biomass that was still present after that catch was taken (49,784 tonnes at the beginning of 1997, ICES-cod 2022), suggesting a natural maximum stock size of about 98,577 tonnes. In comparison, only 6% of that carrying capacity remains, a stock size where effects other than fishing make a recovery difficult (Hutchings 2015), and where the stock is much too small to fulfil its natural role as top predator in the Western Baltic Sea (Scotti et al. 2022). The decline and collapse of the stock is reflected in the catch-per-unit-of-effort data from 2020-2023 of the fishers in Kiel Bight (Figure 2), however, the strong increase in SSB predicted for 2022 and 2023 (ICES-cod 2022, their Fig. 1) is not confirmed by the Kiel Bight data and is probably too high.

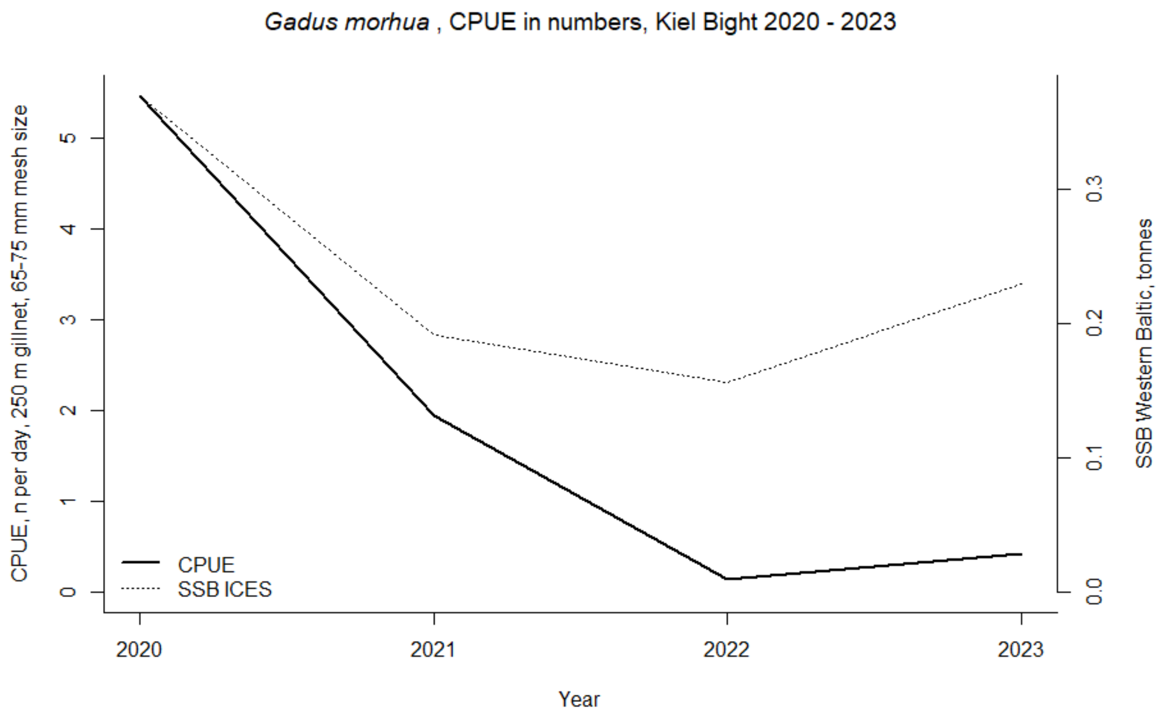


Figure 2. Average number of cod caught per day in Kiel Bight by commercial fishers with 250 m of gill nets with 65-75 mm mesh size (knot to knot), from December/January to May in 2020 – 2023 (bold curve). Note the 10-fold decrease in local CPUE to less than 1, meaning that in 2022 and 2023, many hauls did not contain a single cod. The dotted curve shows the spawning stock biomass (SSB) estimates of ICES for the western Baltic for comparison.

Fishing pressure: The ICES Advice document of 2023 (ICES-cod 2023) is helpful in that it presents fishing pressure as harvest rate, i.e., the catch relative to the spawning stock biomass that was present at the beginning of the year. From 1985 to about 2015, that harvest rate fluctuated around 1.0, i.e., the catches took 100% of the adult cod present at the beginning of the year. Even higher catches were possible because juvenile cod made up a substantial proportion of the catch, and growth of adult cod throughout the year increased biomass. But there could never have been any doubt that such fishing pressure would collapse the stock, as it did. The decline in abundance caused by losses (catch plus natural mortality) exceeding production (somatic growth plus recruitment) is reflected in the decline of catch-per-unit-of-effort data from 2020-2023 of the fishers in Kiel Bight (Figure 2).

Healthy age and size structure: A healthy age and size structure of commercial fish stocks is a requirement for good environmental status in the Marine Strategy Framework Directive (MSFD 2008) of the European Union. Figure 3 shows that most mature year classes are practically missing from the cod stock because excessive fishing mortality (ICES-cod 2023) and early onset of legal fishing (Marine Conservation Reference Length MCRL = 35 cm; 38 cm in SH) increase total mortality such that very few fish survive to more than 3-4 years, although observed maximum age in surveys is 13 years (Table 4). This is confirmed by the length data collected in Kiel Bight in 2020-2023 (Figure 4), where length frequencies between MCRL and 60 cm, which should be higher than those above 60 cm, are actually serrated and much lower, indicative of recruitment failures and missing year classes.

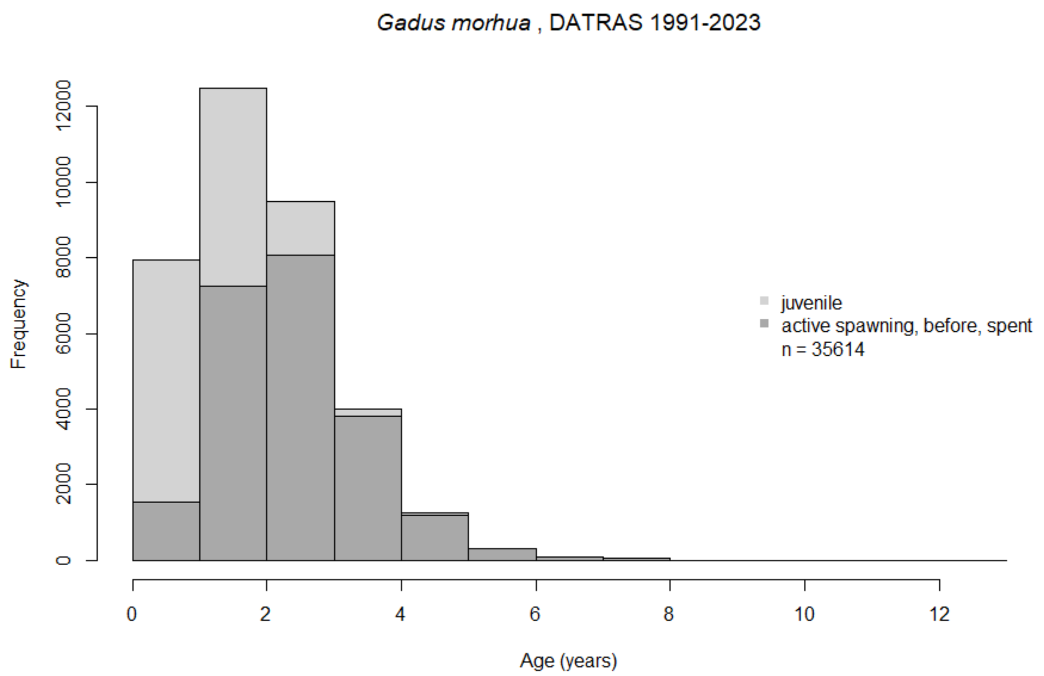


Figure 3. Age frequency of juveniles and adults based on the SMALK database (1st quarter 1991-2023, area 22 and 24). Note that only above age 3 more than 90% are mature. Active spawning of one year old cod seems doubtful.

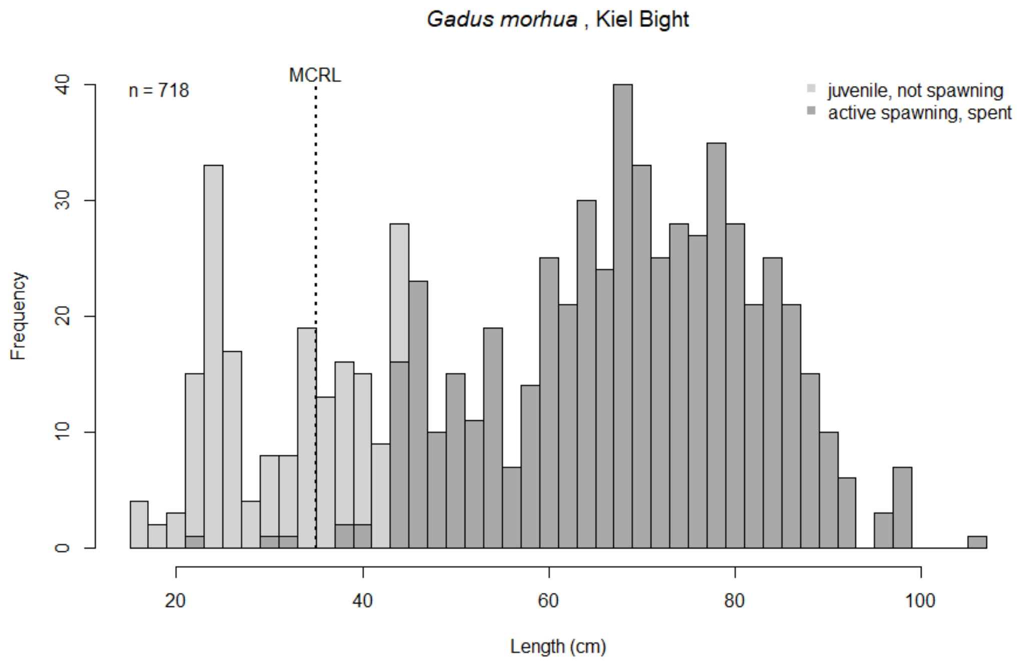


Figure 4. Length frequency of juveniles and adults based on gonad examination (before, active, after spawning) by commercial fishers from December/January to May in 2020-2023 in Kiel Bight. MCRL indicates the EU legal minimum conservation reference length. Note that according to these data, only fish >= 46 cm length are more than 90% mature.

Length-weight relationship and condition

The parameters of the length-weight relationship of cod (Table 4, Figure 5) describe cod as a fusiform species, indicated by *a* = 0.009 being close to the typical fusiform value of *a* = 0.01 (Froese 2006). Also, cod do not change body shape or proportions as they grow through late juvenile and adult life stages, indicated by *b* = 3.0 (Froese 2006). Nearly all of the variability in the data is accounted for by the high coefficient of determination (r^2 = 0.99) of the log-log linear relation between body weight and length, with only a few outlying specimens (erroneous measurements or starving or obese fish) which were excluded from this and other analyses.

Median body weight for a given length (condition) dropped from 0.98 to 0.91 (7%) in catches from Kiel Bight from 2020 to 2023 (Figure 6), confirming reports from fishers that cod and commercial fish in general were getting thinner. A comparison with DATRAS survey data for the Western Baltic from 1991 to 2023 confirmed this observation, showing a total decline of 16.3% during that period (Figure 7).

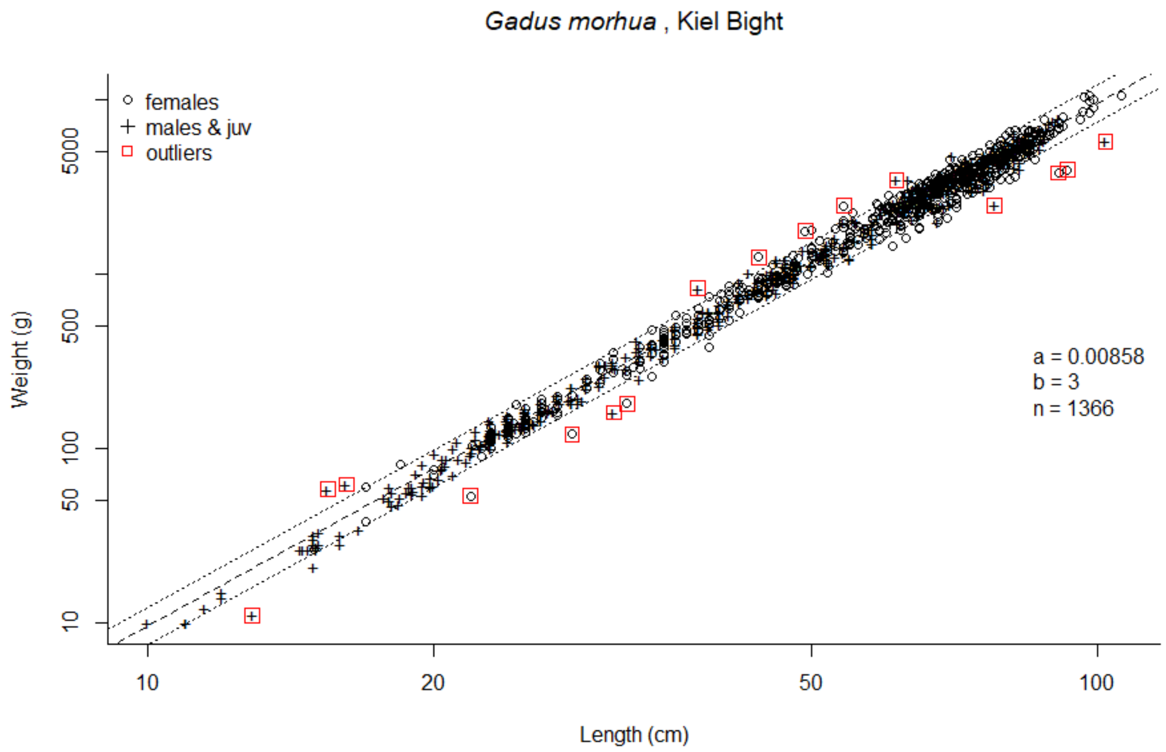


Figure 5. Length-weight relationship for cod in Kiel Bight, based on catches of commercial fishers from December/January to May in 2020-2023 in gill net and trawl fisheries. The dashed line indicates the overall fit and the dotted lines indicated the 95% confidence limits. Red squares indicate outliers beyond 3 standard deviations from the predicted mean; these were excluded from the analyses in this study.

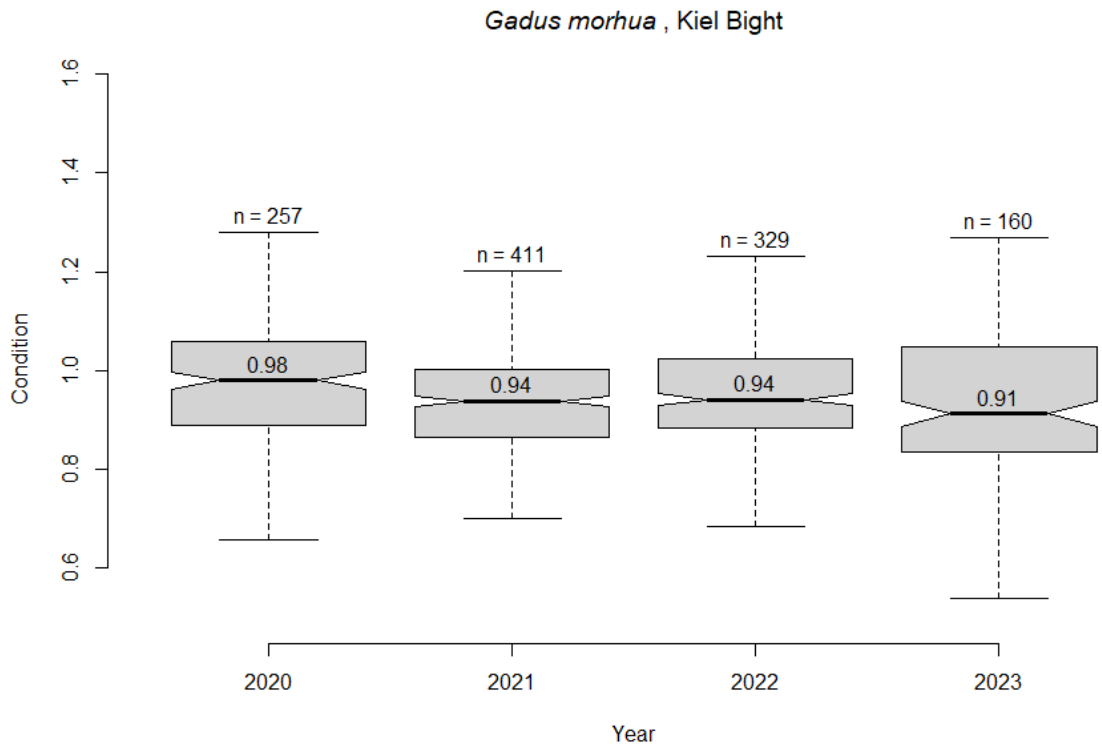


Figure 6. Comparison of Condition C = 100 Weight/Length^3 in December/January to May 2020 to 2023, based on commercial catches in Kiel Bight.*

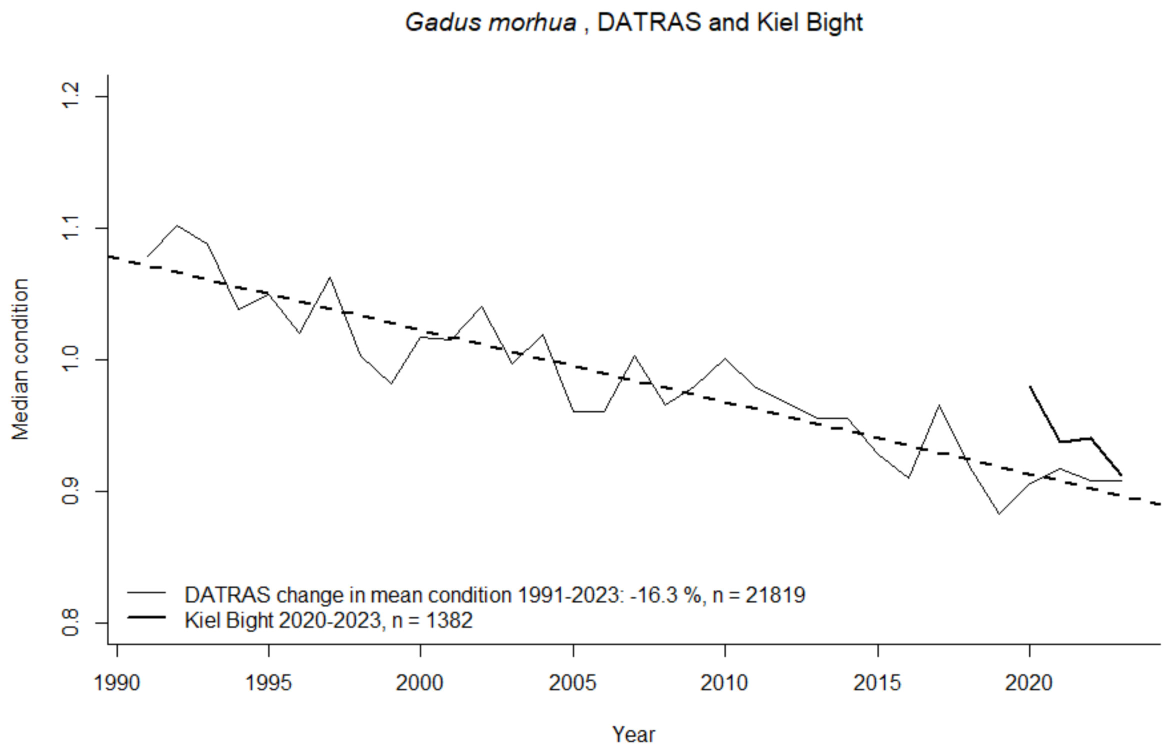


Figure 7. Change in median condition based on DATRAS (with dashed regression line, 1st quarter 1991-2023, area 22 and 24) and 2020-2023 data from commercial fishers in Kiel Bight (bold curve).

Length and age at maturation: The size and age where 50% or 90% of individuals have reached sexual maturity and participate in spawning is typically derived from an ogive curve fitted to the proportion of mature females over length or age class (see Material and Methods). However, using ovary weight relative to whole body weight (the gonadosomatic index) leads to higher length and age estimates than the visual evaluation of ovaries done during surveys, where apparently half-developed ovaries were counted as indication of participation in spawning of females of 18-28 cm of length (Figure 3, Figure 8, Figure 9), resulting in a mean length at 50% maturity of L_{m50} = 29.8 cm (Table 4). Instead, in this study the first fully developed ovaries were only found at about 33 cm of female body length (Figure 10, Figure 11, Figure 12) or above about 250 g of body weight (Figure 13). An ogive curve fitted to data derived in this study suggests L_{m50} = 43 cm (Table 4), which however seems a bit too high because of missing age and length classes (Figure 4, Figure 10). There is less uncertainty and disagreement between data sets if instead the length at 90% maturity is selected as reference point with L_{m90} = 44.6 cm based on the survey data and L_{m90} = 43.3 cm based on the data from Kiel Bight.

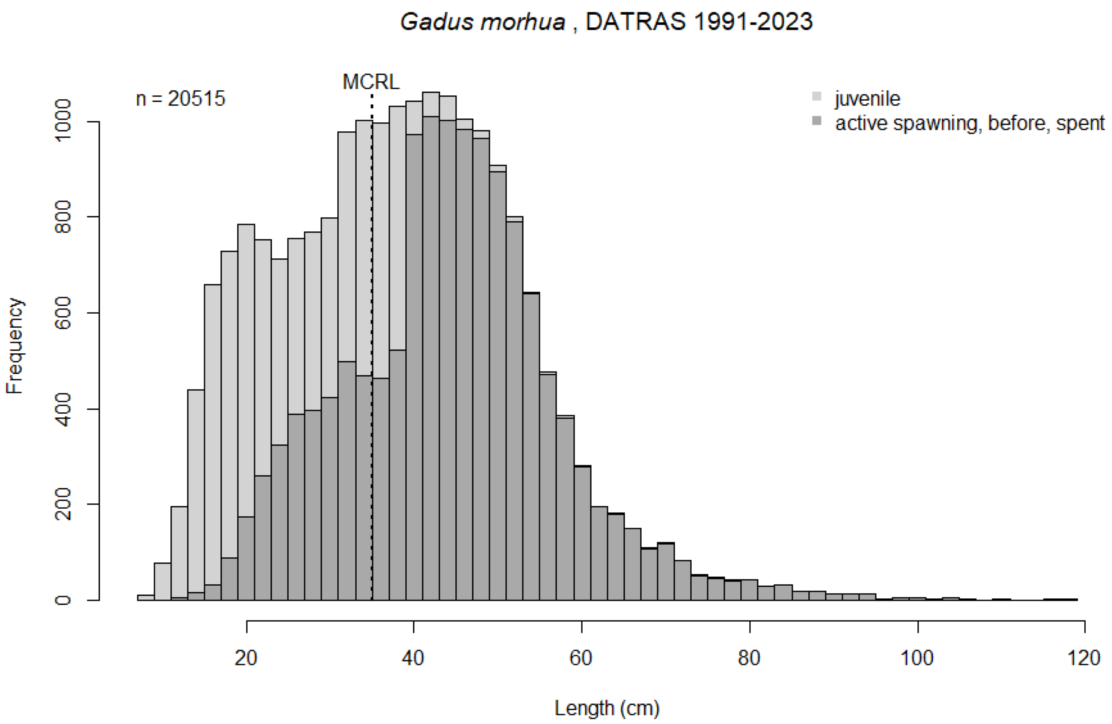


Figure 8. Length frequency of juveniles and adults based on the SMALK database in DATRAS (1st quarter 1991-2022, area 22 and 24). MCRL indicates the EU legal minimum conservation reference length for cod in the Baltic Sea. Note that about 50% of the individuals are still immature at MCRL. Also, active spawning below 20 cm seems doubtful.

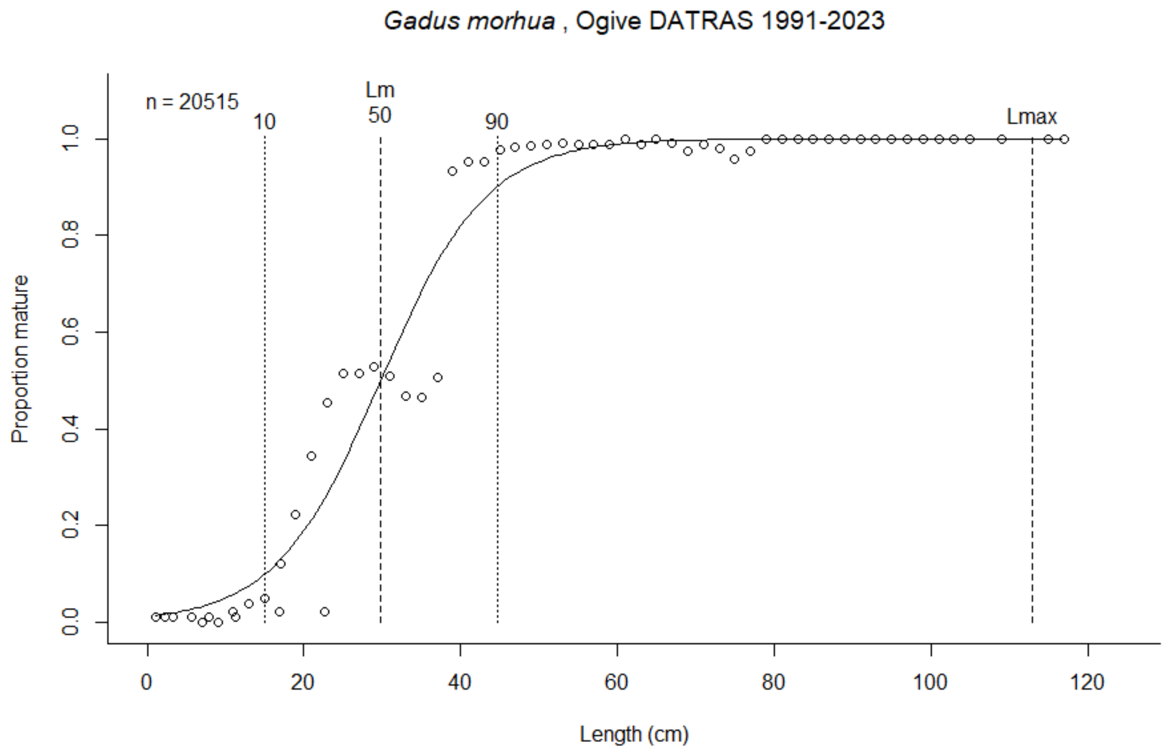


Figure 9. Proportion of mature females based on the SMALK database in DATRAS (1st quarter 1991-2023, area 22 and 24). There is some doubt that females below 30 cm length with enlarged ovaries would really fully develop their ovaries and participated in spawning.

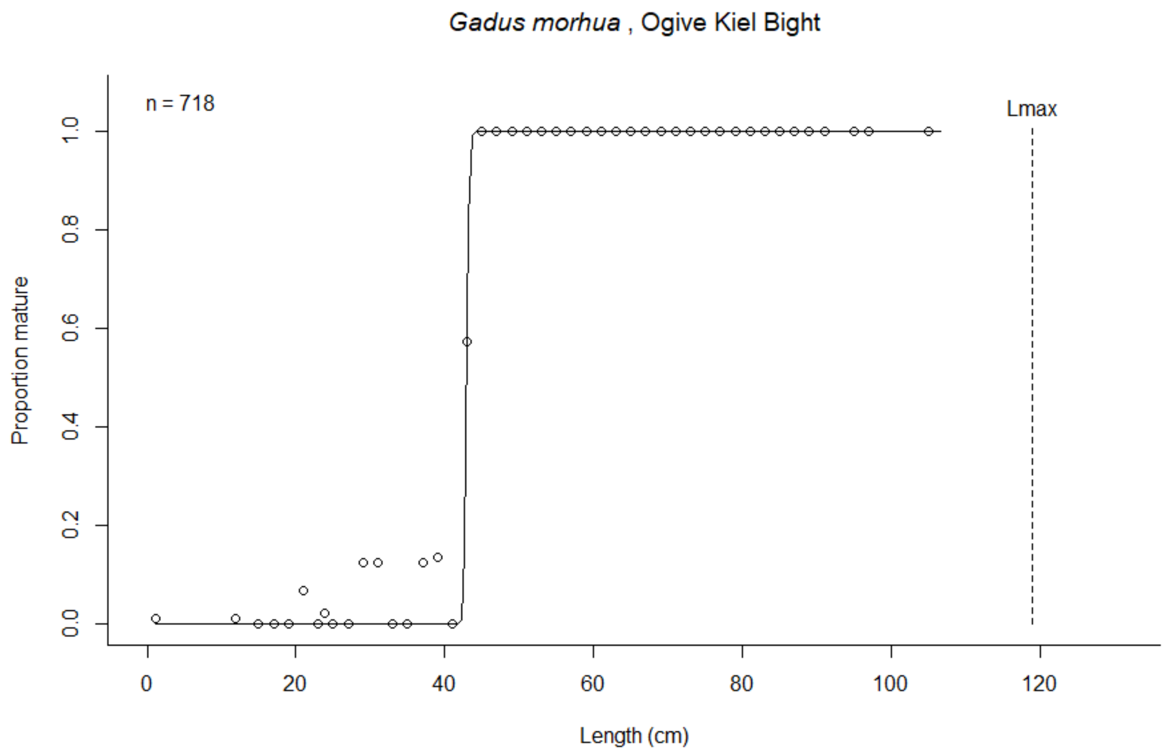


Figure 10. Proportion of mature females based on gonad examination (before, active, after spawning) by commercial fishers from December/January to May in 2020-2023 in Kiel Bight. The steep slope stems from few juveniles being present in 2020-2023 because of repeated recruitment failure. Also, Kiel fishers avoided catching of juveniles.

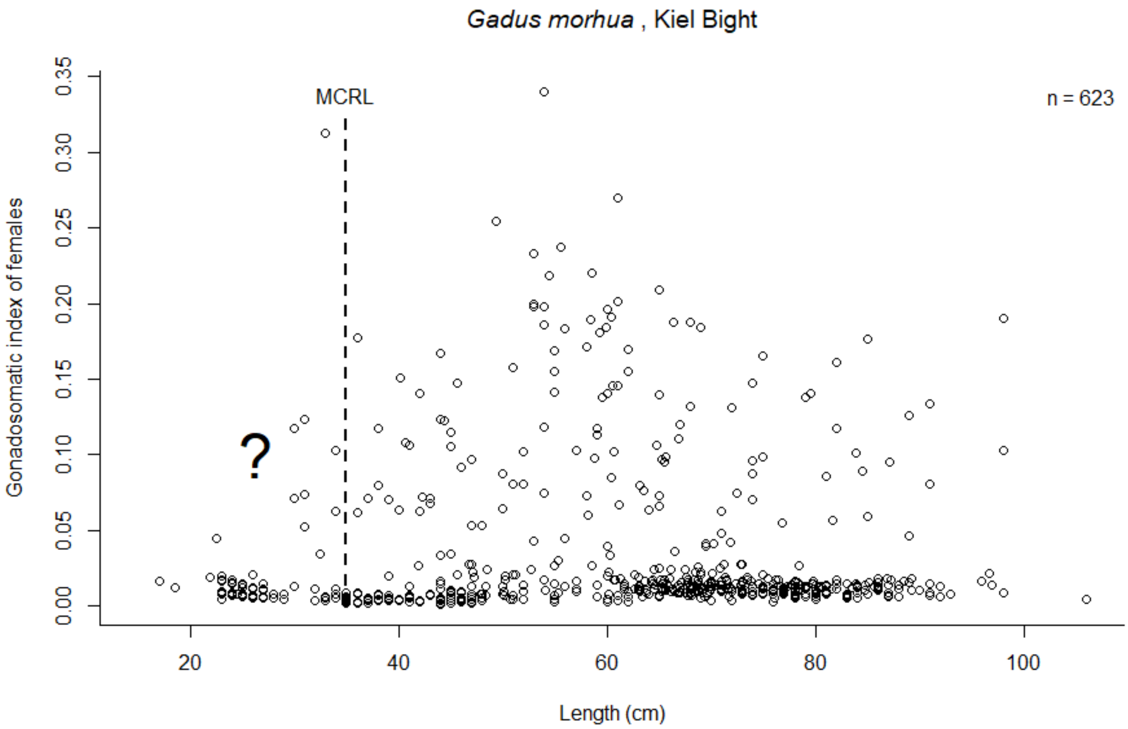


Figure 11. Relative weight of ovaries (GSI) plotted over body length for 623 female cod in Kiel Bight, 2020-2023. There is no indication that females below about 36 cm developed ovaries beyond 0.075 GSI and participated in spawning.

Figure 12. Ripe and partly spent ovaries of the smallest female cod in Kiel Bight considered mature at 33 cm total length, caught in spring 2023.

Fecundity as a function of body weight: The base assumption of the relation between fecundity and body weight is that the number of eggs of a female or the maximum weight of the gonads increase about proportionally with body weight. Overall, the fully developed ovaries of cod females examined in Kiel Bight took up about 24% of total body weight (Table 4). The available data on relative weight of ovaries (gonado-somatic index) collected in this study also suggest that the increase in fecundity was even slightly higher (slope = 1.16) than predicted by a directly proportional increase in body weight (Figure 13).

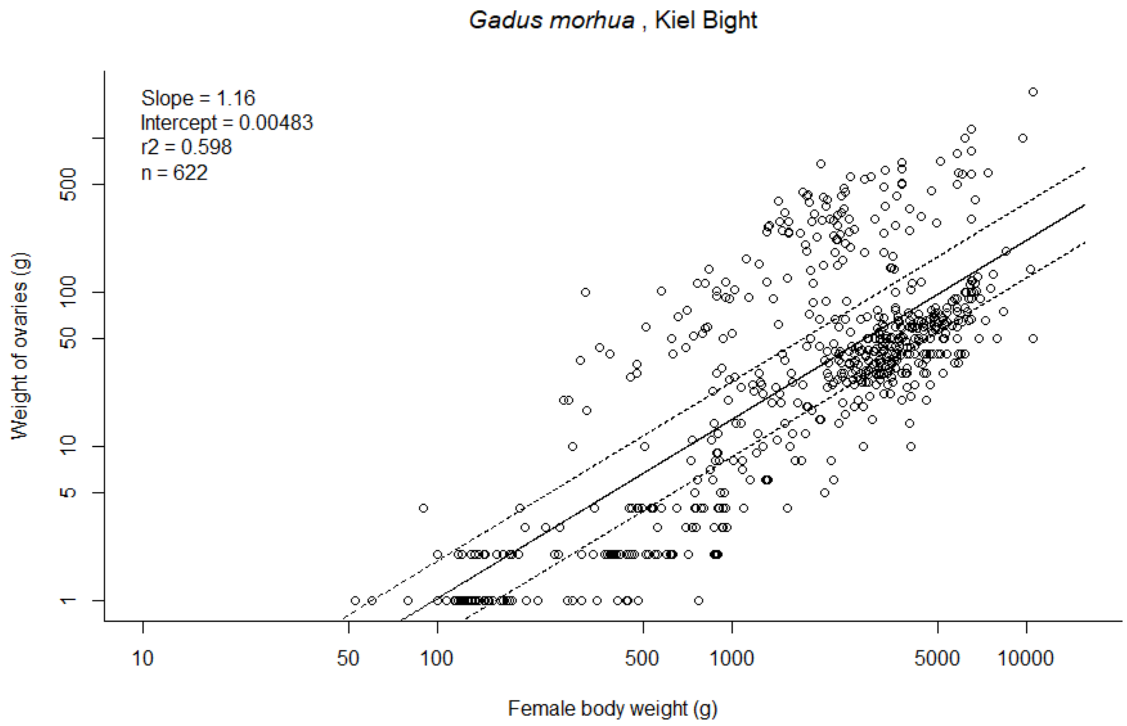


Figure 13. Weight of ovaries in different stages plotted over body weight, based on data from commercial fishers in Kiel Bight (December/January-May 2020-2023). Note that the slope > 1.0 suggests that the weight of ovaries and thus fecundity increases faster than body weight. Note also that no fully developed gonads were observed in females below 200 g or about 30 cm body length.

Sex ratio: Cod females are determinate spawners where the number of eggs in the ovary are fixed before the onset of spawning, during which a female releases 15-20 egg batches over a period of 5-6 weeks (Kjesbu 1989, Murua & Saborido-Rey 2003). Whereas the sex ratio of cod fluctuated around the expected 1:1 ratio in survey data taken from throughout the Western Baltic Sea, there were only about half as many male cod present in the shallow waters of Kiel Bight during the spawning seasons of 2020-2023 (Table 4, Figure 14). A working hypothesis is that male cod stay longer in the spawning grounds (as found by Grabowski et al. 2014 for Icelandic cod) whereas female cod visit shallow waters for feeding (and maybe relief from pursuing males) during their breaks from active spawning.

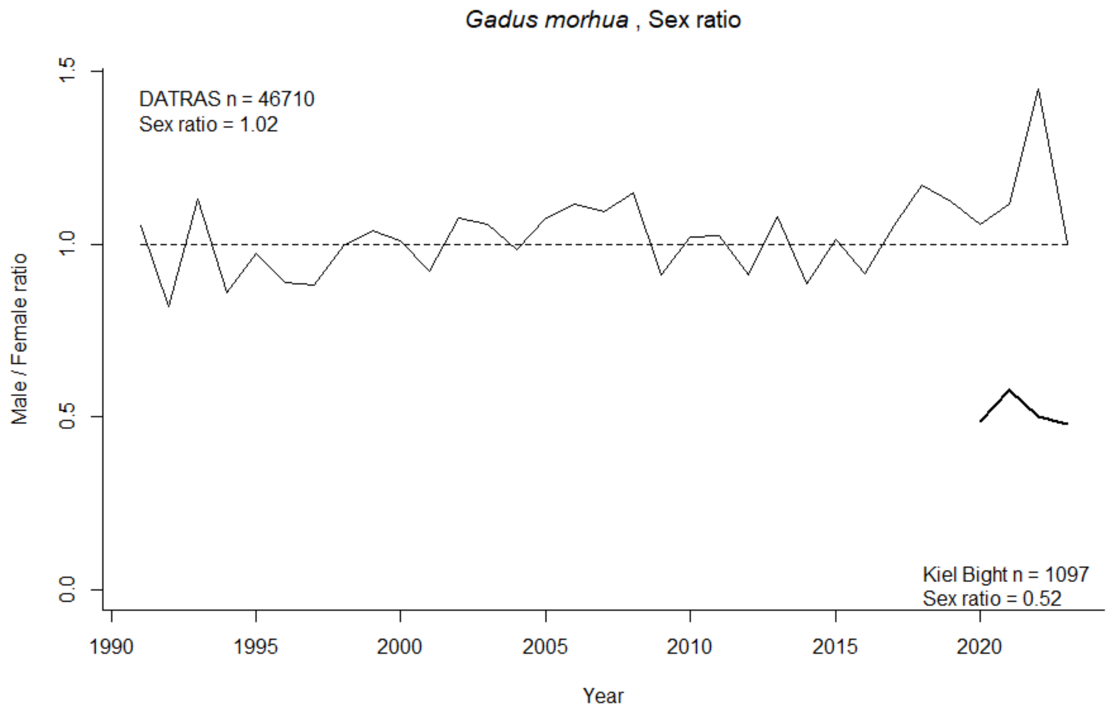


Figure 14. Time series of annual sex ratios for the western Baltic Sea based on DATRAS and for Kiel Bight based on reports by commercial fishers (bold curve). The dashed line indicates the expected 1:1 ratio. During January to May spawning season mostly females enter the shallow waters of Kiel Bight, resulting in the local sex ratio of about 0.5 in 2020-2023.

Spawning season: Relative size of ovaries was used to determine the cod spawning season in 2020-2023 as from December to March, with a clear peak in January (Figure 15, Figure 16). This is clearly earlier than the traditional peak of spawning in March (Bagge et al. 1994). Note also that the range and peak of cod spawning cannot be derived from the few standard surveys undertaken in the Western Baltic during that period.

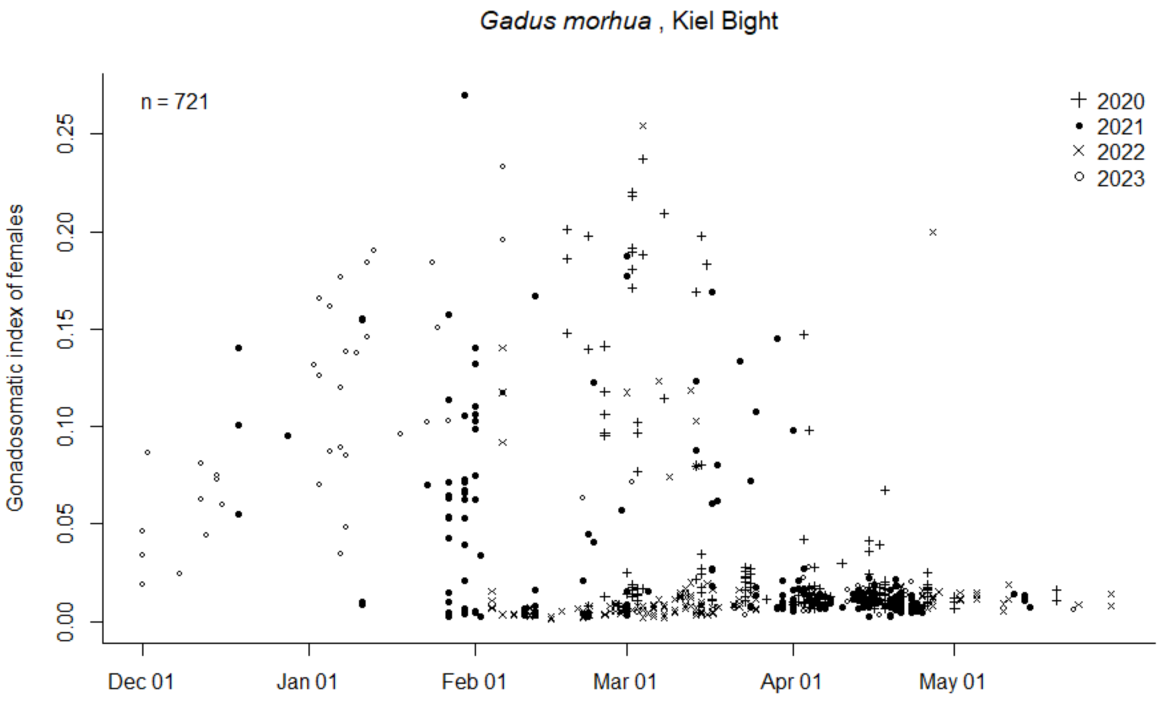


Figure 15. Timing of spawning as indicated by the gonadosomatic index of females in Kiel Bight, based on samples taken from December/January to May in 2020-2023 in commercial gill net and trawl fisheries. Note that no samples were taken in December-January 2020 and 2022.

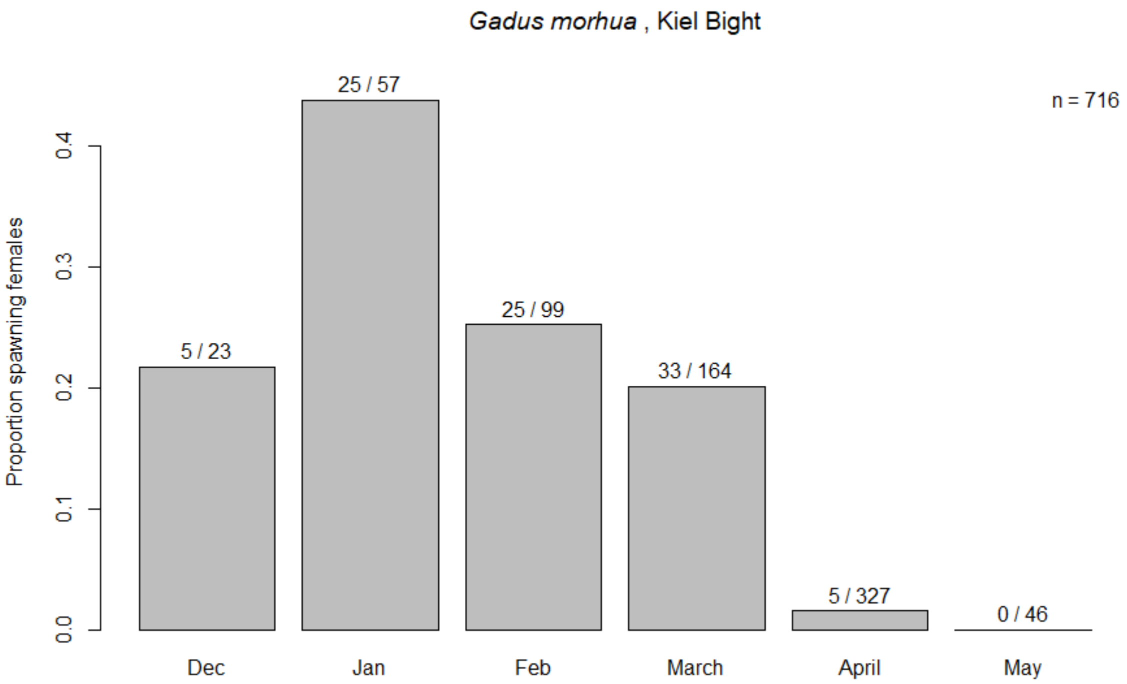


Figure 16. Monthly number of actively spawning females ($L > L_{m90}$ and GSI > 0.075) relative to the number of females examined (numbers on top of bars), for years 2020 to 2023 in Kiel Bight.

Diet composition

The fishers in Kiel Bight weighed stomachs and identified the most prominent food items for altogether 1382 juvenile and adult cod (Table 1). The most common food items were a broad variety of other fish reported from 69% of the stomachs (Figure 18, Figure 19) and a variety of benthic organisms (Figure 19) reported from 53% of the stomachs and dominated by green crabs (*Carcinus maenas*) (Figure 17).

Table 1. Frequency of occurrence of food items found in altogether 1382 juvenile and adult cod stomachs of commercial fish in Kiel Bight, examined in December/January – May 2020-2023. Altogether 923 (67%) of the stomachs contained food. Percentages in the last column are calculated as frequency of occurrence divided by number of stomachs with food, times 100. Note that the sum of percentages exceeds 100 because stomachs can contain more than one food item. Food items are presented additionally by functional groups (columns 1 and 2). Main contributing groups are highlighted in orange and main contributing food items are highlighted in yellow.

Food I	**Food II**	**Names** (German, English)	**Scientific name**	**n**	**%**
zoobenthos				**491**	**53.2**
	worms			**36**	**3.9**
		Ringelwürmer, Seeringelwürmer, ragworms	*Hediste diversicolor*	11	1.2
		Wattwürmer, lugworms	*Arenicola marina*	6	0.7
		Würmer, worms		19	2.1
	mollusks			**8**	**0.9**
		Muscheln, mussels		6	0.7
		Schnecken, snails		2	0.2
	benthic crustaceans			**447**	**48.4**
		Flohkrebse, amphipods	*Gammarus sp.*	1	0.1
		Garnelen, shrimp	*Palaemon sp.*	93	10.1
		Strandkrabben, green crab	*Carcinus maenas*	353	38.2
		Krebse, crustaceans		2	0.2
zooplankton				**8**	**0.9**
	jellyfish			**1**	**0.1**
		Qualle, jellyfish	*Aurelia aurita*	1	0.1
	fish eggs/larvae			**7**	**0.8**
		Fischlaich, Fischrogen, Rogen, roe		5	0.5
		Heringseier, herrings eggs	*Clupea harengus*	2	0.2
nekton				**639**	**69.2**
	finfish			**639**	**69.2**
		Aalmutter, eelpout	*Zoarces viviparous*	9	1.0
		Aalquappe, burbot	*Lota lota*	1	0.1
		Butterfisch, rock gunnel	*Pholis gunnellus*	8	0.9
		Dorsch, cod	*Gadus morhua*	3	0.3
		Grundel, gobies	*Gobius niger, Neogobius melanostomus, Aphia minuta*	31	3.4
		Hering, herring	*Clupea harengus*	93	10.1
		Kliesche, dab	*Limanda limanda*	11	1.2
		Lippfisch, lipfish	*Ctenolabrus*	5	0.5

		Neunauge, lamprey	*Petromyzon marinus, Lampetra sp.*	3	0.3
		Sandaal, sandeel	*Ammodytes sp.*	26	2.8
		Sardelle, anchovy	*Engraulis encrasicolus*	6	0.7
		Scholle, plaice	*Pleuronectes platessa*	15	1.6
		Seenadel, pipefish	*Sygnathus sp.*	1	0.1
		Seeskorpion, sculpin	*Myoxocephalus scorpius*	4	0.4
		Sprotte, sprat	*Sprattus sprattus*	60	6.5
		Steinpicker, hooknose	*Agonus cataphractus*	8	0.9
		Stichling, stickleback	*Gasterosteus aculeatus*	2	0.2
		Wittling, whiting	*Merlangius merlangus*	5	0.5
		Plattfisch, flatfish		176	19.1
		Fische, Jungfische, unspecified fish		172	18.6

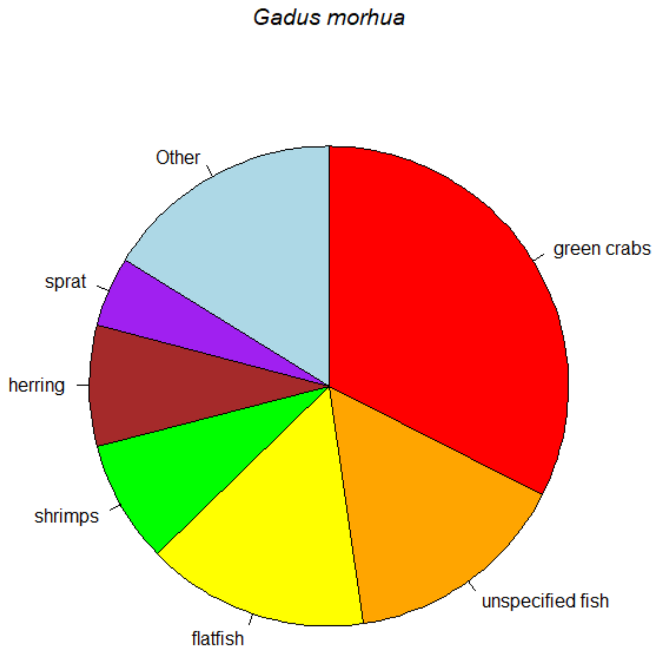


Figure 17. Six most frequently encountered food items in cod stomachs, based on commercial catches from December/January to May 2020 to 2023 in Kiel Bight.

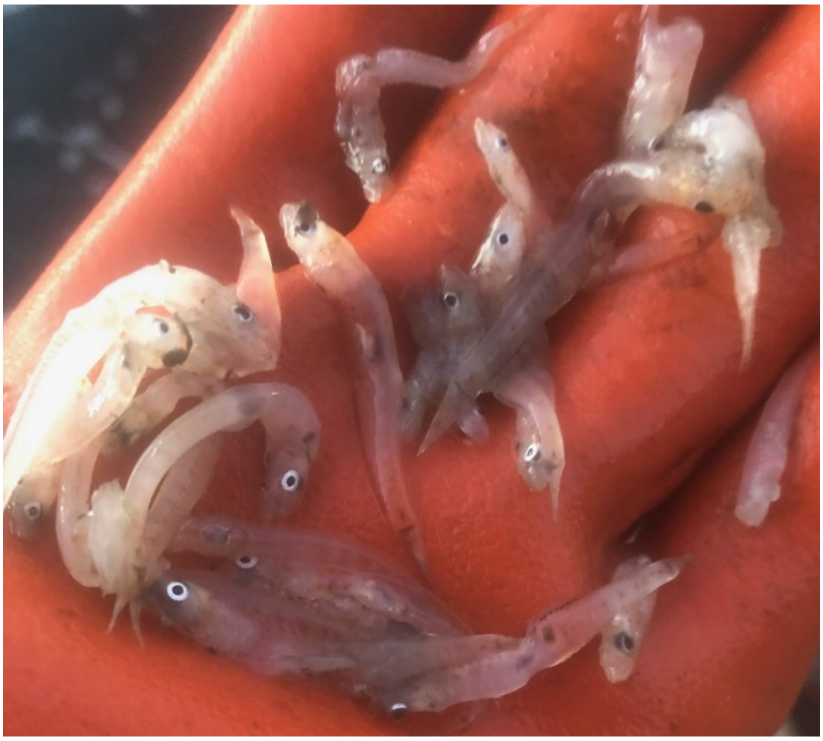


Figure 18. Mass occurrence of 'Glasfische', presumably Transparent goby Aphia minuta. Some reported from cod stomachs.

Figure 19. Stomach content of an adult cod in Kiel Bight in March 2023, including the skeleton and some tissue of an unidentified fish of about 15 cm length, an unidentified goby, 5 Baltic prawn (Palaemon adspersus), and other unidentified food items. Photo Erik Meyer.

The most common food items found in the stomachs of juvenile cod (<= 35 cm) (Table 2) were other fish (mostly herring and young fish) reported from 56% of the stomachs and a variety of benthic organisms reported from 33% of the stomachs and dominated by shrimps and worms (Figure 20).

Table 2. Frequency of occurrence of food items found in altogether 439 stomachs of juvenile cod (<= 35 cm) of which 121 (28%) contained food or were analyzed for food (undersized cod were sometimes released, often only measured and not dissected). Note that the sum of percentages exceeds 100 because stomachs can contain more than one food item. Food items are presented by functional groups. Main contributing groups are highlighted in orange and main contributing food items are highlighted in yellow.

Food I	**Food II**	**Food III** (German)	**Scientific**	**n**	**%**
zoobenthos				**40**	**33.1**
	worms			**14**	**11.6**
		Würmer, worms		14	11.6
	mollusks			**4**	**3.3**
		Muscheln, mussels		3	2.5
		Schnecken, snails		1	0.8
	benthic crustaceans			**22**	**18.2**
		Flohkrebse, amphipods	*Gammarus sp.*	1	0.8
		Garnelen, shrimps	*Palaemon sp.*	14	11.6
		Strandkrabben, green crab	*Carcinus maenas*	7	5.8
zooplankton				**4**	**3.3**
	fish eggs/larvae			**4**	**3.3**
		Fischlaich, Fischrogen, Rogen, roe		4	3.3
nekton				**68**	**56.2**
	finfish			**68**	**56.2**
		Grundel, gobies	*Gobius niger, Neogobius melanostomus, Aphia minuta*	7	5.8
		Hering, herring	*Clupea harengus*	29	24.0
		Lippfisch, lipfish	*Ctenolabrus*	1	0.8
		Sardelle, anchovy	*Engraulis encrasicolus*	3	2.5
		Sprotte, sprat	*Sprattus sprattus*	4	3.3
		Fische, Jungfische, fish		24	19.8

The most common food items found in the stomachs of adult cod (> 35 cm) (Table 3) were other fish (mostly flatfish and juveniles of other fish) reported from 71% of the stomachs and a variety of benthic organisms reported from 56% of the stomachs and dominated by green crab (Figure 20).

Table 3. Frequency of occurrence of food items found in altogether 943 stomachs of adult cod (> 35 cm) of which 802 (85%) contained food. Note that the sum of percentages exceeds 100 because stomachs can contain more than one food item. Food items are presented by functional groups. Main contributing groups are highlighted in orange and main contributing food items are highlighted in yellow.

Food I	**Food II**	**Food III** (German, English)	**Scientific**	**n**	**%**
zoobenthos				**453**	**56.5**
	worms			**22**	**2.7**
		Ringelwürmer, Seeringelwürmer, ragworms	*Hediste diversicolor*	11	1.4
		Wattwürmer, lugworms	*Arenicola marina*	6	0.7
		Würmer, worms		5	0.6
	mollusks			**4**	**0.5**
		Muscheln, mussels		3	0.4
		Schnecken, snails		1	0.1
	benthic crustaceans			**427**	**53.2**
		Garnelen, shrimp	*Palaemon sp.*	79	9.9
		Strandkrabben, green crab	*Carcinus maenas*	346	43.1
		Krebse, crustaceans		2	0.2
zooplankton				**4**	**0.5**
	jellyfish			**1**	**0.1**
		Qualle, jellyfish	*Aurelia aurita*	1	0.1
	fish eggs/larvae			**3**	**0.4**
		Fischlaich, Fischrogen, Rogen, roe		1	0.1
		Heringseier, herring eggs	*Clupea harengus*	2	0.2
nekton				**571**	**71.2**
	finfish			**571**	**71.2**
		Aalmutter, eelpout	*Zoarces viviparous*	9	1.1
		Aalquappe, burbot	*Lota lota*	1	0.1
		Butterfisch, rock gunnel	*Pholis gunnellus*	8	1.0
		Dorsch, cod	*Gadus morhua*	3	0.4
		Grundel, goby	*Gobius niger, Neogobius melanostomus, Aphia minuta*	24	3.0
		Hering, herring	*Clupea harengus*	64	8.0
		Kliesche, dab	*Limanda limanda*	11	1.4
		Lippfisch, lipfish	*Ctenolabrus*	4	0.5
		Neunauge, lamprey	*Petromyzon marinus, Lampetra sp.*	3	0.4
		Sandaal, sandeel	*Ammodytes sp.*	26	3.2
		Sardelle, anchovy	*Engraulis encrasicolus*	3	0.4

		Scholle, plaice	*Pleuronectes platessa*	15	1.9
		Seenadel, pipefish	*Sygnathus sp.*	1	0.1
		Seeskorpion, sculpin	*Myoxocephalus scorpius*	4	0.5
		Sprotte, sprat	*Sprattus sprattus*	56	6.9
		Steinpicker, hooknose	*Agonus cataphractus*	8	1.0
		Stichling, stickleback	*Gasterosteus aculeatus*	2	0.2
		Wittling, whiting	*Merlangius merlangus*	5	0.6
		Plattfisch, flatfish		176	21.9
		Fische, Jungfische, fish		148	18.5

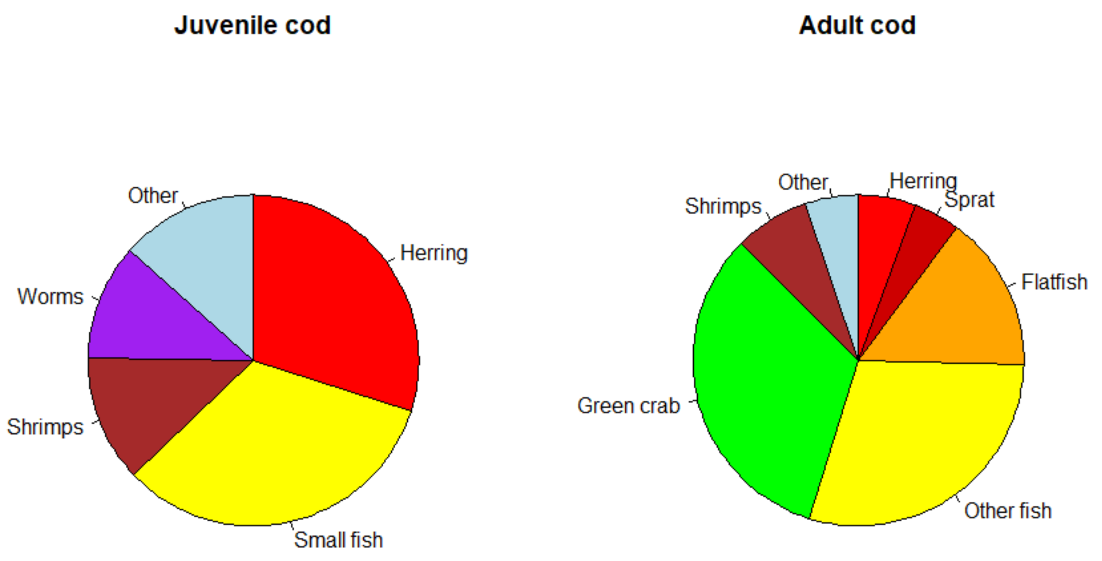


Figure 20. Food items found in stomachs of juvenile (<=35 cm) and adult (>35 cm) cod caught by commercial fishers in Kiel Bight in December/January – May, 2020-2023. Note the shift in diet of adult cod towards larger prey.

Note that these stomach analyses were conducted during the spawning season, confirming that cod continue to feed during that time. This is also confirmed by a slight increase in condition from January to May, with condition here measured as body weight of females without ovaries and stomach weight relative to length cubed (Figure 21).

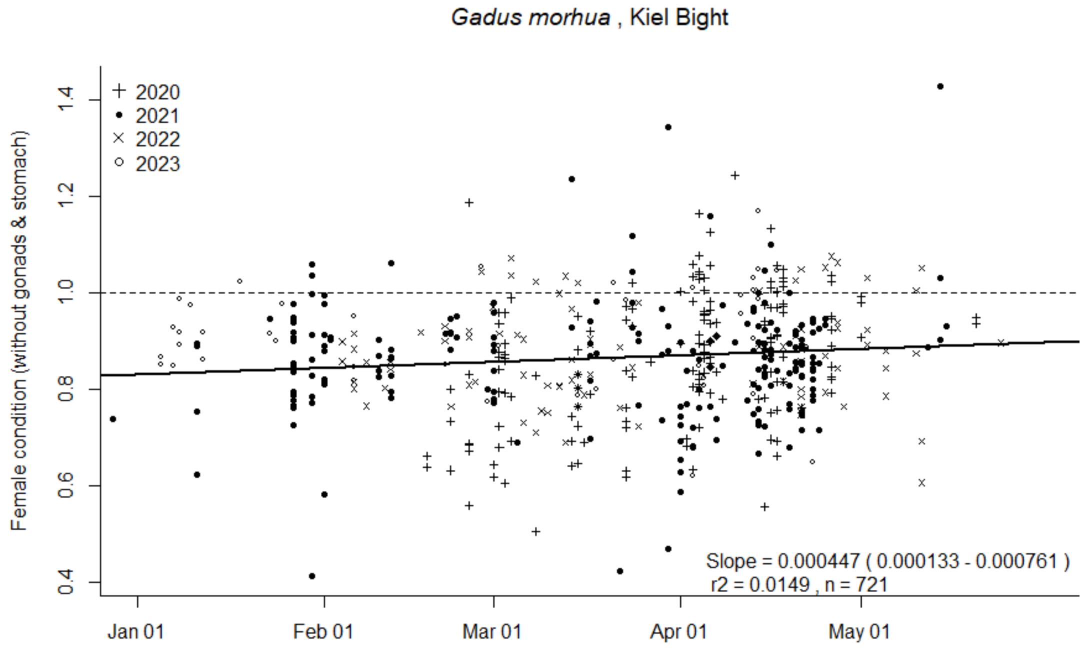


*Figure 21. Condition (C = 100 * W/L³) of female cod in Kiel Bight, based on samples taken from December/January to May in 2020-2023 in commercial gill net and trawl fisheries. Note that weight of stomach and gonads was excluded, i.e., the bold regression line suggests a weight increase in muscles and bones, but it accounts for only 1.5% of the variability.*

Somatic growth

Thousands of cod caught in standard scientific surveys have been aged for stock assessment purposes, however, the uncertainty of these age readings is very wide, suggesting e.g. that two year old cod can be between 10 to 70 cm long or weigh between 10 and over 1000 gram (Figure 22). These ranges seem highly unrealistic and have led, among other reasons, to the abandonment of age-based assessments in Eastern Baltic cod because of a declared "inability to determine age" (ICES-cod 2018, page 3). Also, fitting a growth curve to these length-at-age data strongly underestimates asymptotic length (L_{inf}) when compared with observed lengths (Figure 22). Instead, the median length of young-of-the year cod and the median length of the outstanding year class of 2016 were used to construct more convincing growth curves (Figure 22, Figure 23).

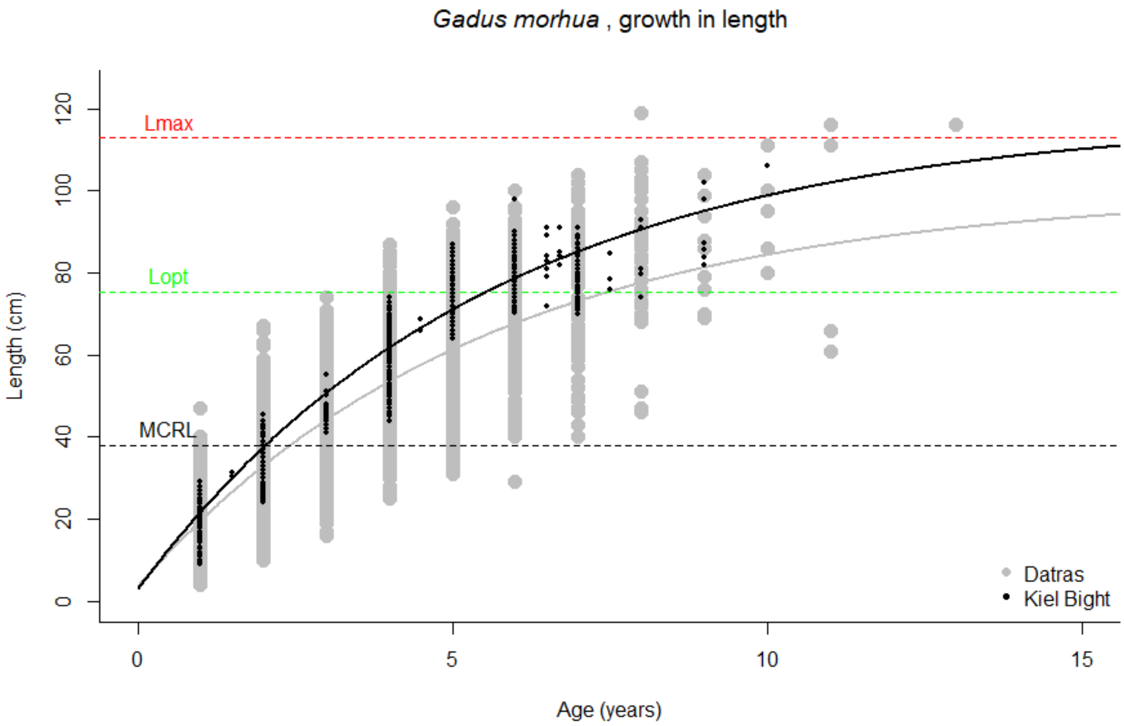


Figure 22. Growth in length, based on age readings in DATRAS (grey, 1st quarter 1990-2023, area 22 and 24), and on following the peak of the 2016 year class in Kiel Bight (black, 2020-2023). The horizontal dashed lines indicate the observed maximum length (L_{max}), the length at maximum increase in weight (Lopt), and the legal Minimum Conservation Reference Length (MCRL). DATRAS (grey dots and curve) seems to have a bias in overestimating age and underestimating asymptotic length L_∞.

Figure 23. Growth in weight, based on 2020-2023 data from Kiel Bight, with indication of the weight corresponding to the legal Minimum Conservation Reference Length (MCRL, dotted horizontal line). The red circle indicates the inflection point of the growth curve where increase in body weight is maximum. Note cod with low condition beyond age 7.

Fisheries management considerations

There is an optimal length (L_{opt}) for catching fish, where the increase in body weight has reached a maximum, and where most individuals have already reproduced 1-3 times. This is also the length where catches will be highest for a given effort or where for a given catch the least number of fish will be killed (Froese et al. 2016). A proxy for L_{opt} can be derived as 2/3 of maximum length (see Material and Methods), which for cod in the Western Baltic gives L_{opt} = 2/3 L_{max} = 2/3 133 = 75.3 cm. Similarly, an optimum length at first capture can be derived as L_{c_opt} = 0.56 L_{max} = 63.3 cm (Table 4). Finally, there is the Minimum Conservation Reference Length (MCRL) which is the minimum length for selling fish, which for cod in Schleswig-Holstein is 38 cm and 35 cm for the Baltic Sea in general. These reference lengths can be used to determine the appropriateness of the selectivity of the most common fishing gears (gill nets and trawls) in the western Baltic and Kiel Bight.

Fishers in Kiel Bight use gill nets with mesh sizes from the legal minimum size of 55 mm up to voluntarily used 80 mm or more (all measured knot to knot). A comparison of the size selectivity of mesh sizes of 55, 70, 75 and 80 mm shows that the legal mesh size of 55 mm catches cod below MCRL with a median length well below L_{c_opt} and L_{opt} and with about 25% of the caught fish being below the length of 90% maturity (L_{m90}). Only the mesh size of 80 mm gives a median length in the catch that is well above MCRL, and L_{c_opt} and even slightly above L_{opt}.

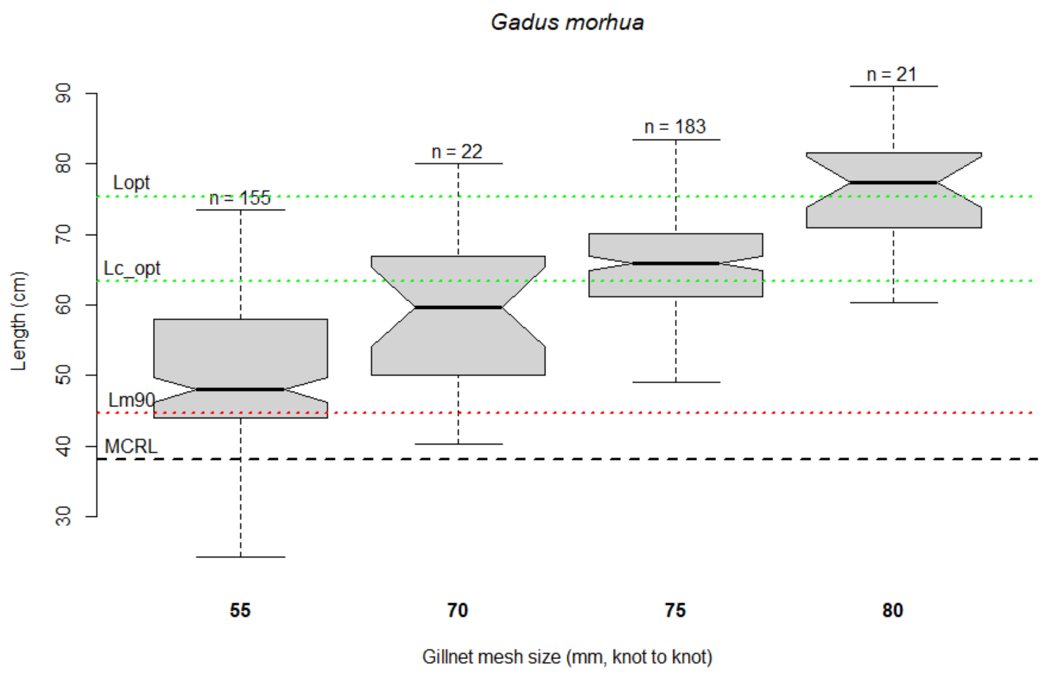


Figure 24. Boxplot of length distribution in gill nets from 55 mm (knot to knot), which is the legal minimum mesh size, to 70 – 80 mm, which are preferred by fishers who do not want to catch juveniles. The red horizontal line indicates the length L_{m90} at which 90% of the females have reached maturity. The green horizontal line indicates the length L_{opt}. Data from commercial fishing in Kiel Bight, December to May 2020-2023.

The selectivity of trawls with 110 to 120 mm stretched mesh size catches cod well below MCRL, L_{m90}, L_{c_opt} and L_{opt}, although the analysis is distorted by the lack of year classes after 2016, leading to a peak in catches around 80 cm cause by the remaining individuals of the last successful 2016 year class (Figure 25). In summary, the legal minimum mesh sizes for gill nets and trawls are too small and should be increased by about 50% to avoid capture of undersized and immature cod and to approach the optimum length of capture.

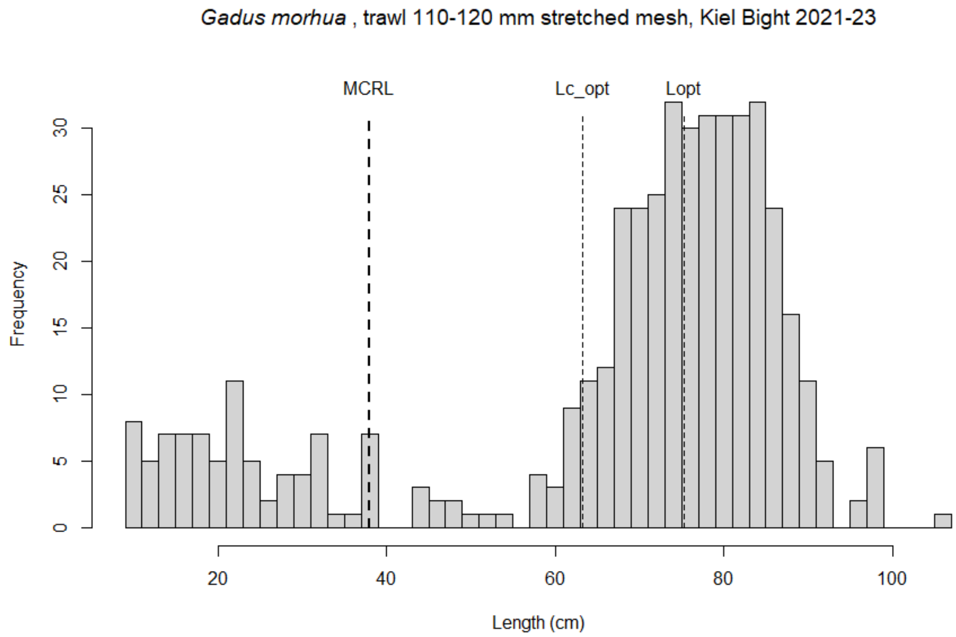


Figure 25. Selectivity of commercial trawl with 120 mm stretched mesh size. Note that only cod year class 2016 is present in large numbers, with lengths around optimum size L_{opt} .

Another standard management measure is to protect fish from capture during the spawning season, in order to maximize reproductive output and the probability of successful recruitment. For the Western Baltic cod, that is implemented with a prohibition to catch cod with bottom trawls below 20 m of water depth. However, as shown by the data collected in Kiel Bight for this study, mature cod regularly enter shallower waters during the spawning season where they are subject to legally ongoing fishing. Thus, in effect there is no protection of spawning cod in the Western Baltic Sea.

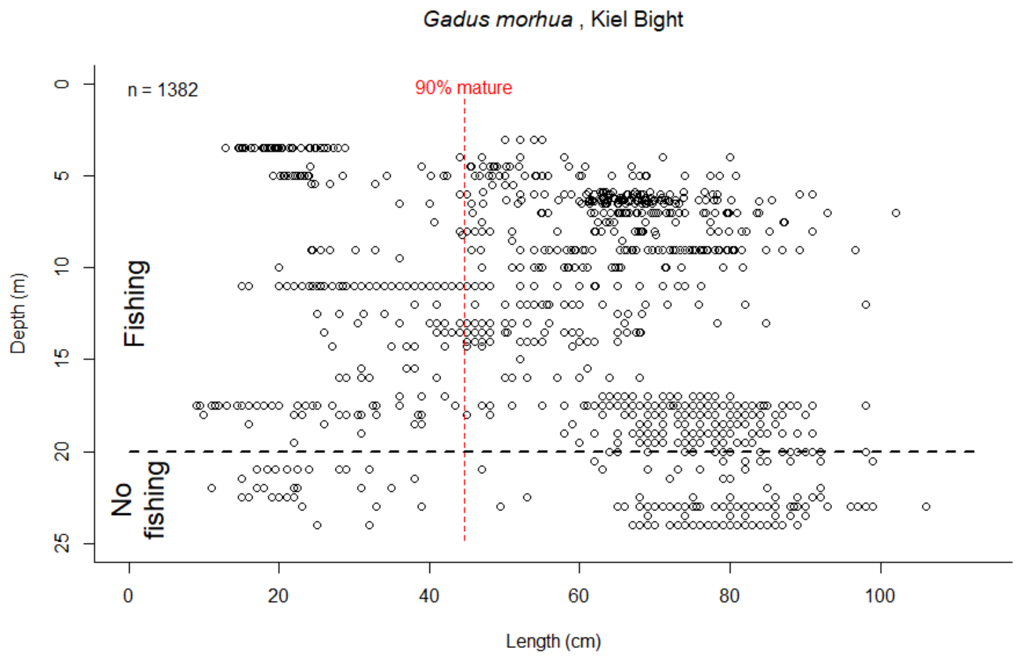


Figure 26. Length-distribution of cod over depth of capture by commercial fishers in Kiel Bight, December/January to May 2020-2023. The vertical dashed line indicates the 20 m depth below which fishing is not allowed from February 1 to March 31 for vessels longer than 15 m. The dashed red line indicates the length at which 90% of the females have reached maturity.

Table 4. Key life history reference points, with plausible 95% confidence limits (LCL, UCL) and/ or coefficient of determination (r^2), where applicable, derived from catches of commercial fishers in Kiel Bight (KB) in 2020-2023, December/January and May, and from scientific surveys in the Western Baltic Sea as documented in DATRAS for the first quarter of the years 2000-2022 in areas 22 and 24. Doubtful estimates have footnotes.

Species	Cod	*Gadus morhua*				Gadidae	
Parameter		estimate	LCL	UCL	n r^2	Unit	Method
Lmax KB	Maximum length	106				cm	largest on record
Lmax datras	Maximum length	113				cm	largest on record
Lmax used	Maximum length	113				cm	chosen for study
a.f KB	$W=aL^b$, females	0.0095	0.0085	0.0106	n=666	g/cm^b	log-log regression
b.f KB	$W=aL^b$, females	3.00	2.97	3.02	r^2=0.99		log-log regression
a.m KB	$W=aL^b$, males	0.0081	0.0074	0.0088	n=489	g/cm^b	log-log regression
b.m KB	$W=aL^b$, males	3.04	3.02	3.06	r^2=0.99		log-log regression
a.c KB	$W=aL^b$, combined	0.0086	0.0081	0.0091	n=1366	g/cm^b	log-log regression
b.c KB	$W=aL^b$, combined	3.02	3.01	3.04	r^2=0.99		log-log regression
Wmax KB	Maximum weight	10500				g	largest on record
Wmax DATRAS	Maximum weight	25220				g	largest on record
Wmax LWR	Maximum weight	13847				g	$Wmax=a.c\ Lmax^{b.c}$
Wmax	Maximum weight	13847				g	chosen for study
tmax DATRAS	Maximum age	13				years	oldest on record
L_opt	Optimum length	75.3				cm	2/3 Lmax
Lc_opt	Optimum capture	63.3				cm	0.56 Lmax
Wopt	Optimum weight	4064				g	$a.c\ Lopt^{b.c}$
Wc_opt	Optimum capture	2399				g	$a.c\ Lopt^{b.c}$
MCRL	Minimum length	35				cm	EU law; 38 cm SH
Lm50 KB	50% mature fem.	43.0[1]			n=718	cm	ogive
Lm90 KB	90% mature fem.	43.3[1]			n=718	cm	ogive
Lm50 DATRAS	50% mature fem.	29.8[2]	28.4[2]	31.1[2]	n=20514	cm	ogive
Lm90 DATRAS	90% mature fem.	44.6	41.7	47.2	n=20514	cm	ogive
tm50 DATRAS	50% mature fem.	2[2]			n=20514	years	first age > 0.5 mature
tm90 DATRAS	90% mature fem.	4			n=20514	years	first age > 0.9 mature
sex ratio KB	males / females	0.52[3] : 1			n=1097		n (sex=m) / n (sex=f)
sex ratio DATRAS	males / females	1.02 : 1			n=2462		n (sex=m) / n (sex=f)
gsi.95 KB	Gonad/Body weight	0.24			n=622		95th percentile of GSI
gsi.slope KB	Gonad/Body slope	1.16	1.09	1.24	r^2=0.60		gonads ~ body weight
spawning season	peak, range	Jan	Dec	March	n=537	month	L>Lm90, mat > 10%
Linf DATRAS	Asymptotic length	104	90.8	124	n=2578	cm	VBGF fit
K DATRAS	Growth parameter	0.15	0.12	0.19		$year^{-1}$	VBGF fit
t0 DATRAS	Growth parameter	-0.14				years	VBGF fit
SE DATRAS	SE of residuals	7.62				cm	VBGF fit
Linf KB	Asymptotic length	118	112	126	n=1026	cm	VBGF fit, 2016 class
K KB	Growth parameter	0.18	0.16	0.20		$year^{-1}$	VBGF fit, 2016 class
t0 KB	Growth parameter	-0.132				years	VBGF fit, 2016 class
SE KB	SE of residuals	6.42				cm	VBGF fit, 2016 class

1) values are overestimated because smaller year classes are missing

2) values are underestimated because enlarged gonads in small fish are counted as mature

3) apparently females but not males come to feed in shallow Kiel Bight waters during the spawning season

Results for Plaice (*Pleuronectes platessa*)

Status: The status and history of exploitation of the two recognized stocks of plaice in the western Baltic Sea are given in the ICES Advice documents of May/June 2023 (ICES-ple 2023a, ICES-ple 2023b). Both assessments show stock status as very good with biomass clearly above the level that can produce MSY, and with good recruitment despite highly variable environmental conditions and warming waters caused by climate change (Froese et al. 2022). This is helped by catches from both stocks in 2022 being the lowest of the past 20 years. The recent several-fold increase in abundance of plaice is reflected in the catch-per-unit-of-effort (CPUE) data from Kiel Bight (Figure 27).

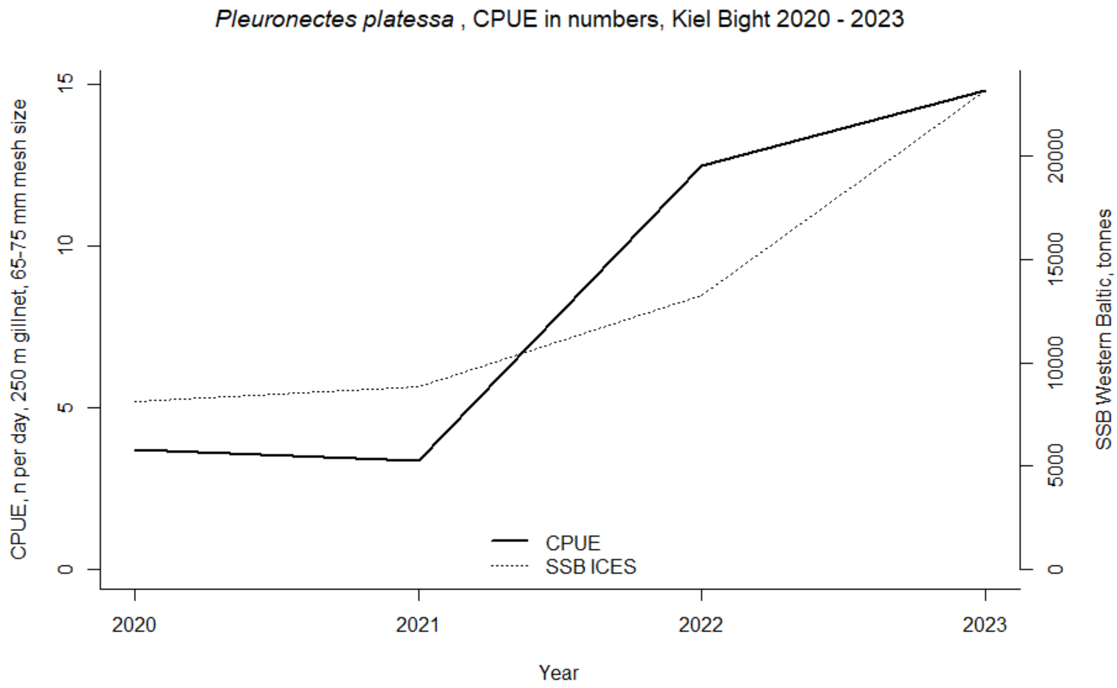


Figure 27. Average number of plaice caught per day in Kiel Bight by commercial fishers with 250 m of gill nets with 70-75 mm mesh size (knot to knot), from December to May in 2020 – 2023 (bold curve). The dotted curve shows the spawning stock biomass (SSB) estimates of ICES for the western Baltic in good agreement of local trends in abundance.

Fishing pressure: Given the high biomass and low catches in 2022, fishing pressure in both stocks is well below the MSY-level. This restraint in catches is apparently continuing in 2023 and 2024, as total allowed catch (TAC) levels have been set close to previous levels to keep the bycatch of the severely depleted cod stock low.

Healthy age and size structure: A healthy age and size structure of commercial fish stocks is a requirement for good environmental status in the Marine Strategy Framework Directive (MSFD 2008) of the European Union. The maximum age of plaice found in surveys in the western Baltic is 18 years (Table 6). Figure 28 shows the frequency distribution of a reasonably healthy stock, with all year classes present, albeit with a strong decline in numbers after being fully selected by fishing at 3 years of age. The decline is caused by past overfishing (before 2021, ICES-ple 2023a) but is cushioned by a mean length of capture above MCRL and above length at maturation (Figure 29 and see respective sections below). These results are confirmed by data collected in Kiel Bight from 2020 to 2023 (Figure 30).

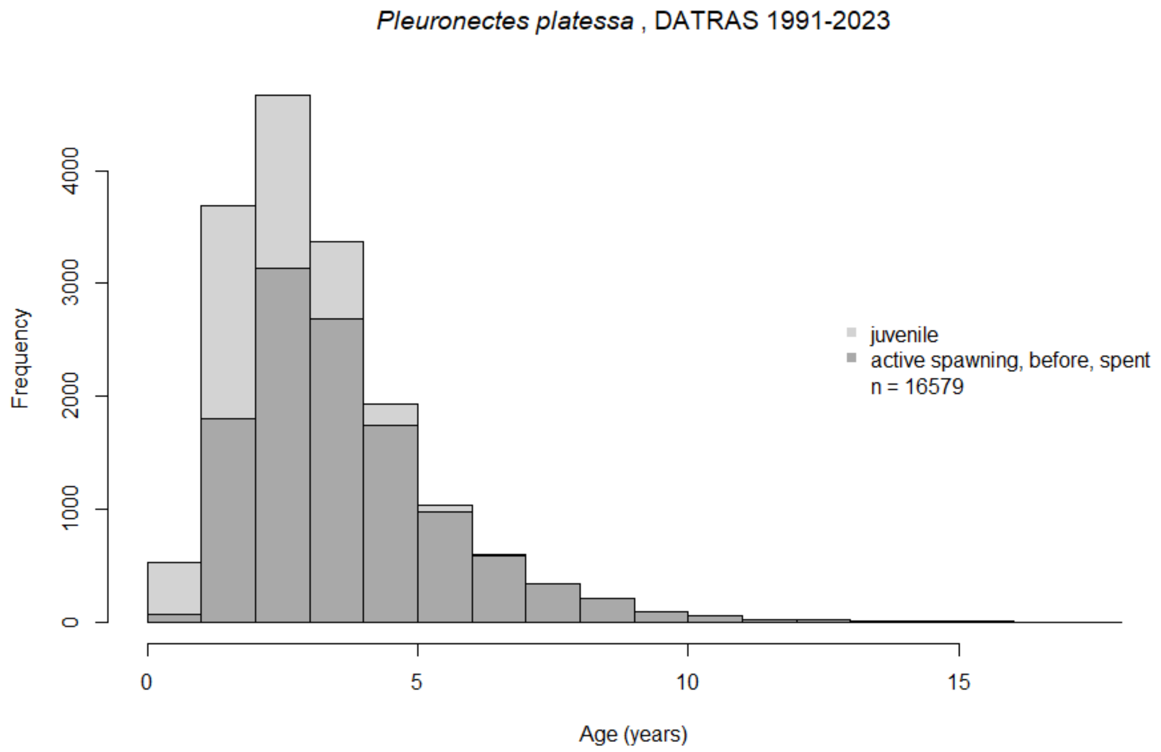


Figure 28. Age frequency of juveniles and adults based on the SMALK database (1st quarter, area 22 and 24). Note that only above age 4 more than 90% are mature.

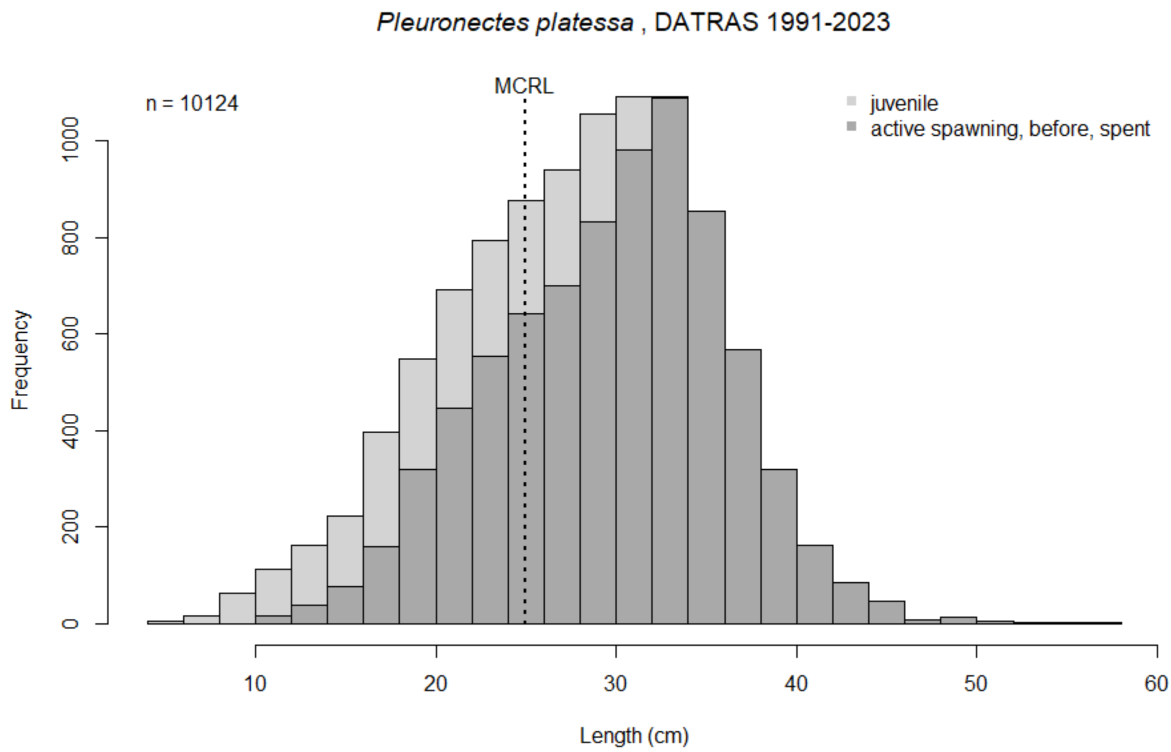


Figure 29. Length frequency of juveniles and adults based on the SMALK database (1st quarter, area 22 and 24). MCRL indicates the legal minimum conservation reference length. Note that about 30% of the individuals are still immature at MCRL.

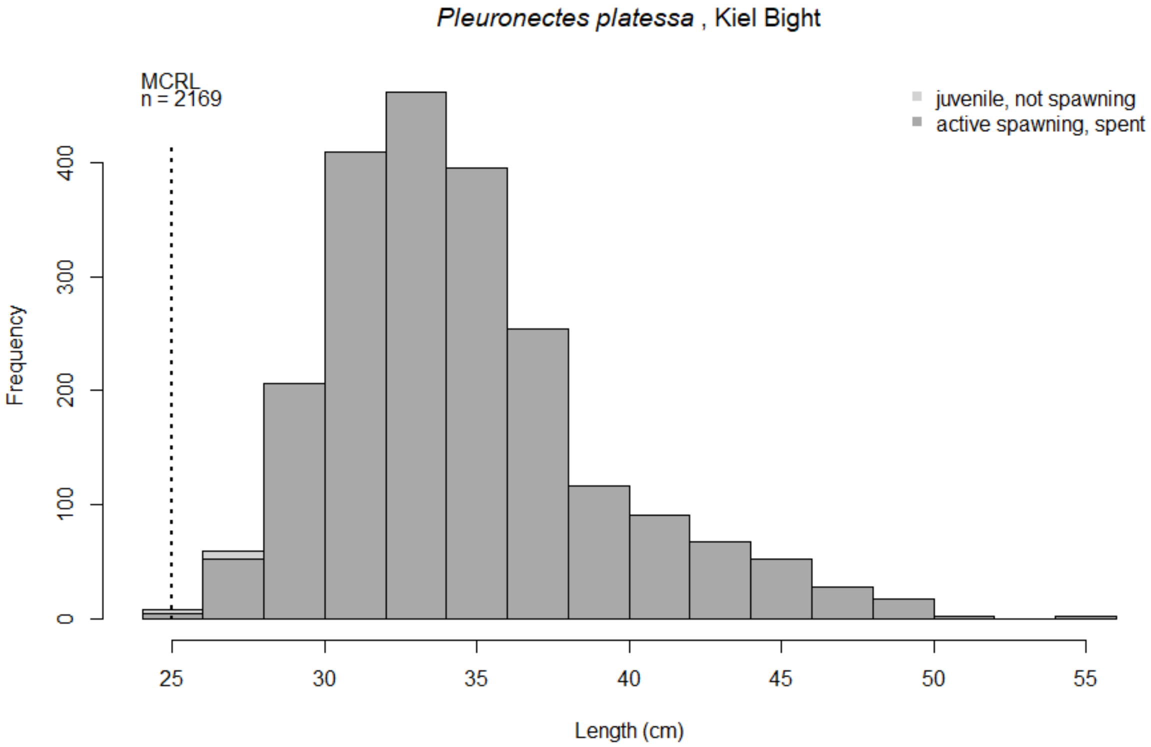


Figure 30. Length frequency of juveniles and adults based on data from commercial fishers (2020-2023). MCRL indicates the legal minimum conservation reference length. Note that commercial fishers avoided capture of juvenile plaice.

Length-weight relationship and condition: The parameters of the length-weight relationship of plaice (Table 6, Figure 31) describe plaice correctly as a more roundish than fusiform species, indicated by *a* = 0.028 being well above the typical fusiform value of *a* = 0.01 (Froese 2006). Also, plaice change their body shape or proportions to a slightly more elongated form as they grow through late juvenile and adult life stages, indicated by *b* = 2.7 instead of the symmetric value of *b* = 3.0 (Froese 2006). Much but not all of the variability in the data is accounted for by the coefficient of determination (r^2 = 0.86, Table 6) of the log-log linear relation between body weight and length, with the decrease in condition (see next paragraph) possibly playing an additional role. There are only a few outlying specimens (erroneous measurements or starving or obese fish) which were excluded from this and other analyses.

Median body weight for a given length (condition) dropped from 1.05 to 0.92 (13%) in catches from Kiel Bight from 2020 to 2023 (Figure 32), confirming reports from fishers that plaice and commercial fish in general were getting thinner. A comparison with DATRAS survey data for the western Baltic from 1991 to 2023 confirmed this observation, showing a general decline of 13.5% during that period (Figure 33).

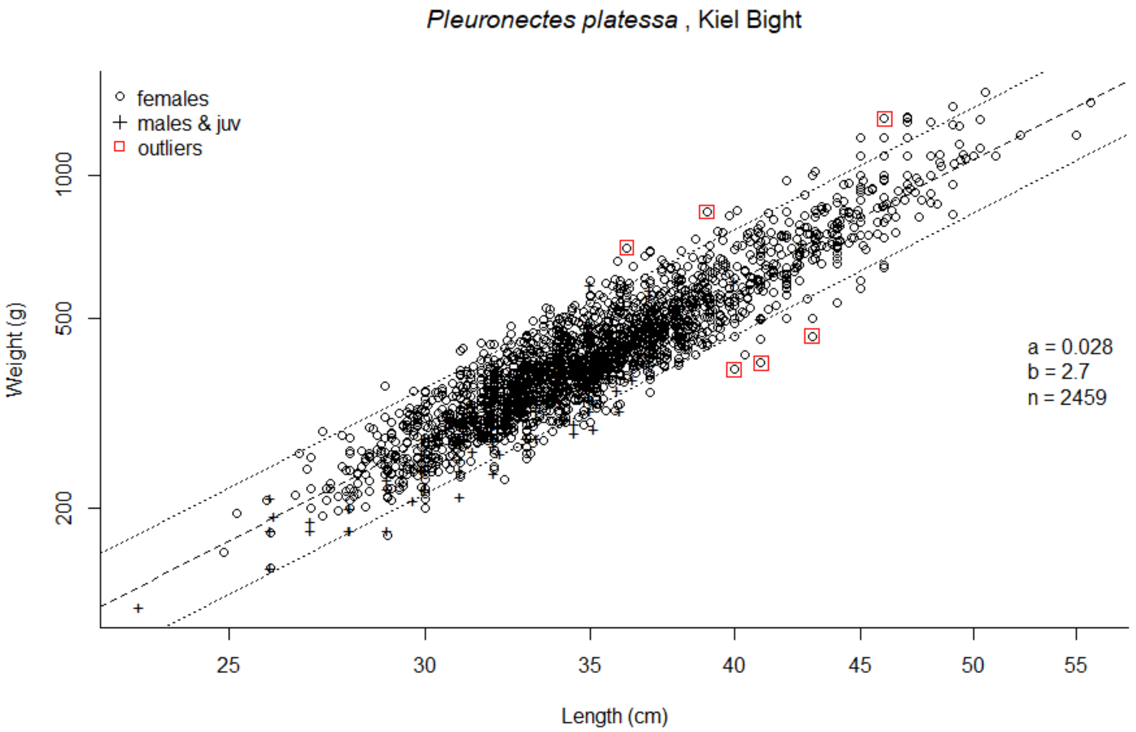


Figure 31. Length-weight relationship for plaice (Pleuronectes platessa) in Kiel Bight, based on samples taken from December to May in 2020-2023 in commercial gill net and trawl fisheries. The dashed line indicates the overall fit and the dotted lines indicated the 95% confidence limits.

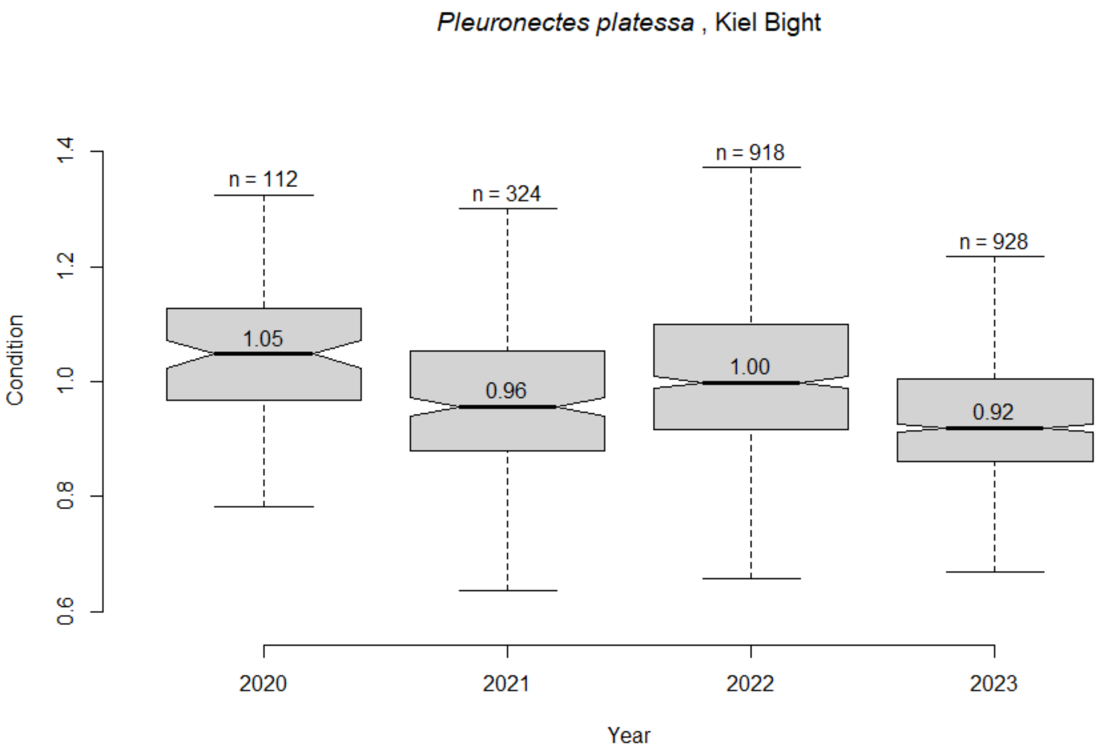


Figure 32. Comparison of Condition C = 100 Weight/Length^3 from 2020 to 2023, based on commercial catches from January to May in Kiel Bight. Note clear decline in condition, with lowest values in 2023.*

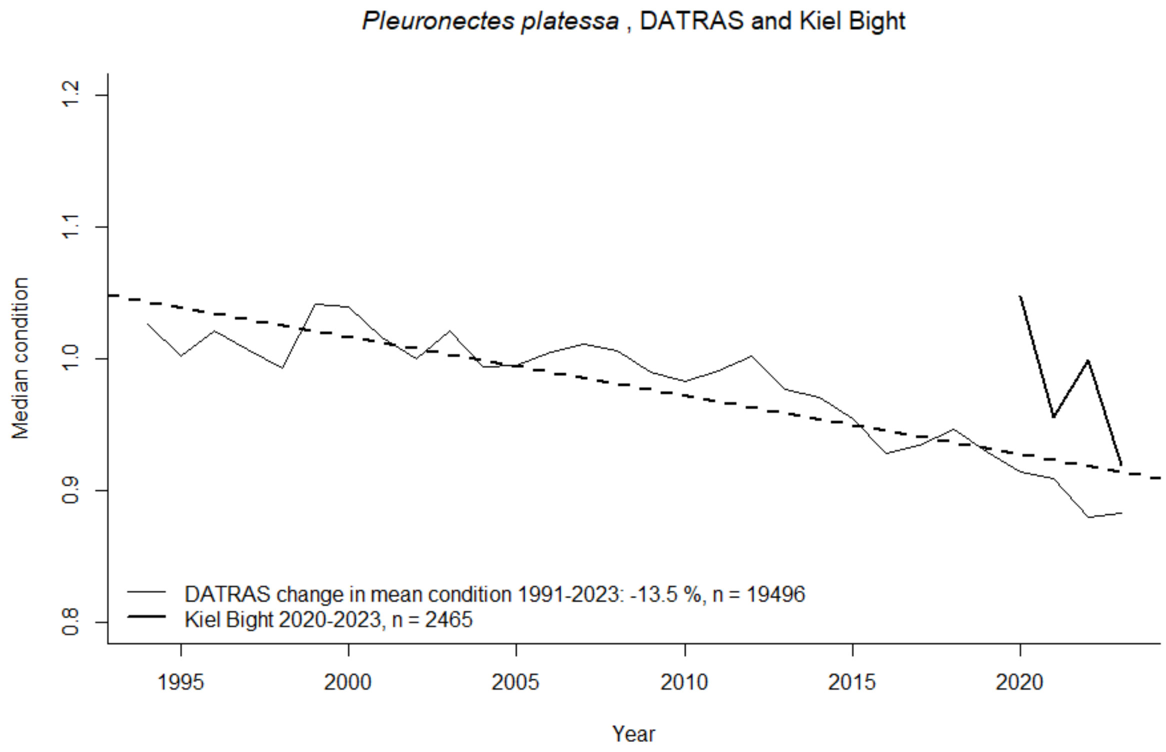


Figure 33. Change in median condition based on DATRAS (black curve and blue line, 1st quarter, area 22 and 24) and 2020-2023 data from commercial fishers in Kiel Bight (bold curve). Note strong decline in condition (-12.3%) between 2000 and 2023.

Length and age at maturation: The size and age where 50% or 90% of individuals have reached sexual maturity and participate in spawning is typically derived from an ogive curve fitted to the proportion of mature females over length or age class (see Material and Methods). However, using ovary weight relative to whole body weight (the gonadosomatic index) leads to higher length and age estimates than the visual evaluation of ovaries done during surveys, where apparently half-developed ovaries were counted as indication of participation in spawning of females of 10 - 18 cm of length (Figure 29, Figure 34), resulting in a mean length at 50% maturity of L_{m50} = 18.4 cm (Table 6). Instead, in this study the first fully developed ovaries were only found at about 25 cm of female body length (Figure 35, Figure 36). An ogive curve fitted to data derived in this study suggests L_{m50} = 24 cm (Table 6), which however seems a bit too high because fishers in Kiel Bight used larger mesh size to avoid capture of small plaice (Figure 35). There is less uncertainty and disagreement between data sets if instead the length at 90% maturity is selected as reference point with L_{m90} = 28.6 cm based on the survey data and L_{m90} = 26.1 cm based on the data from Kiel Bight (Table 6).

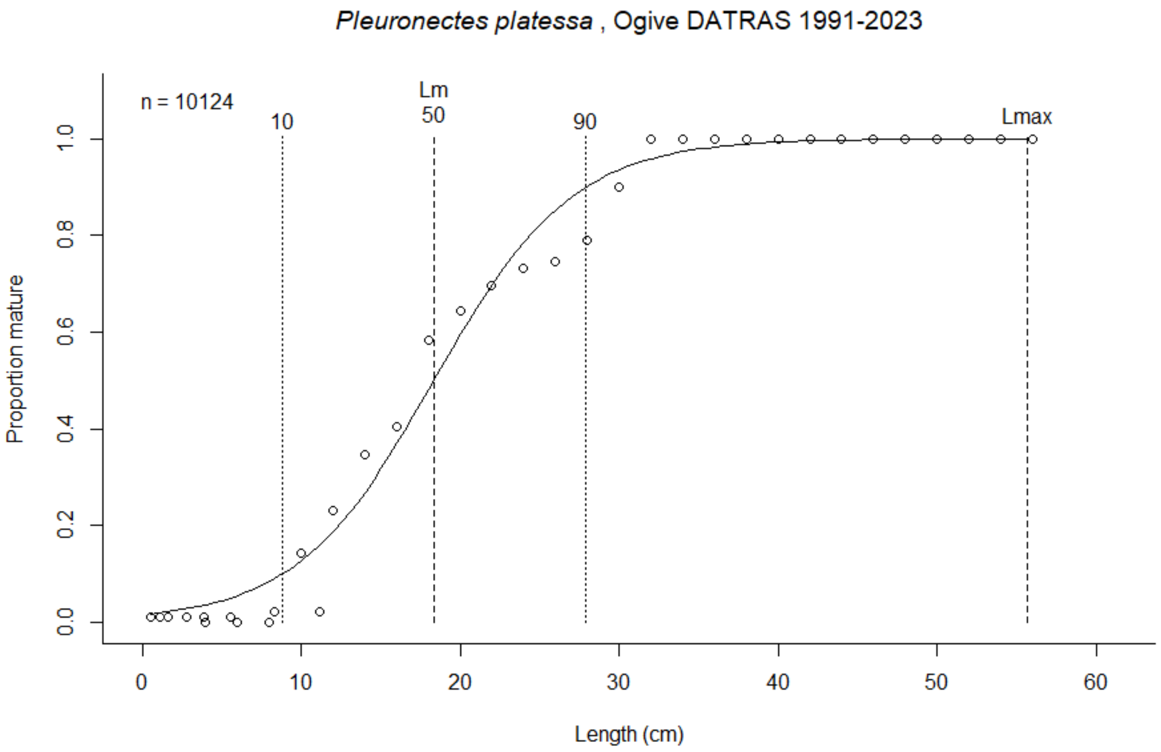


Figure 34. Proportion of mature females based on the SMALK database (1st quarter, area 22 and 24). There is some doubt that females below 20 cm length would really fully develop their ovaries and participated in spawning (see Figure 33).

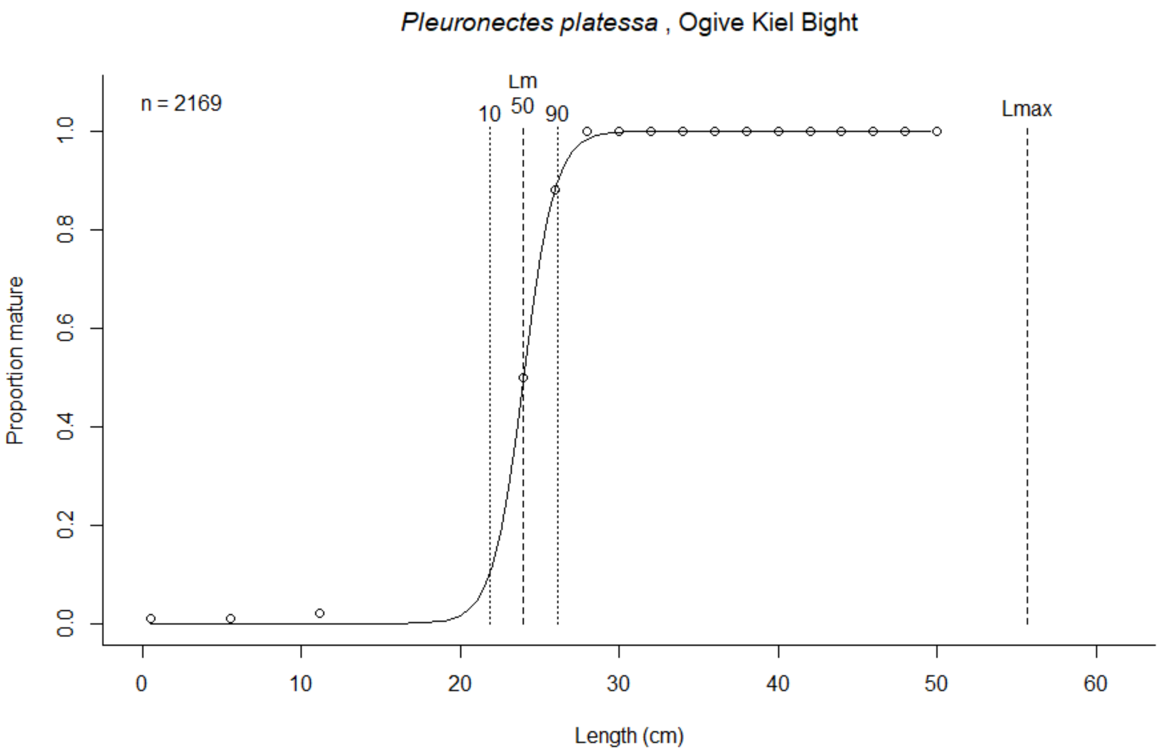


Figure 35. Proportion of mature females based on data from commercial fishers in Kiel Bight (2020-2023). Note that commercial fishers avoided capture of juvenile plaice.

Fecundity as a function of body weight: The base assumption of the relation between fecundity and body weight is that the number of eggs of a female or the maximum weight of the gonads grows about proportionally with body weight. Overall, the fully developed ovaries of plaice females examined in Kiel Bight took up about 24% of total body weight (Table 6, Figure 36). The available data on relative weight of ovaries (gonado-somatic index) collected in this study also suggest that the increase in fecundity was even higher (slope = 1.51) than predicted by a directly proportional increase in body weight (Table 6, Figure 37).

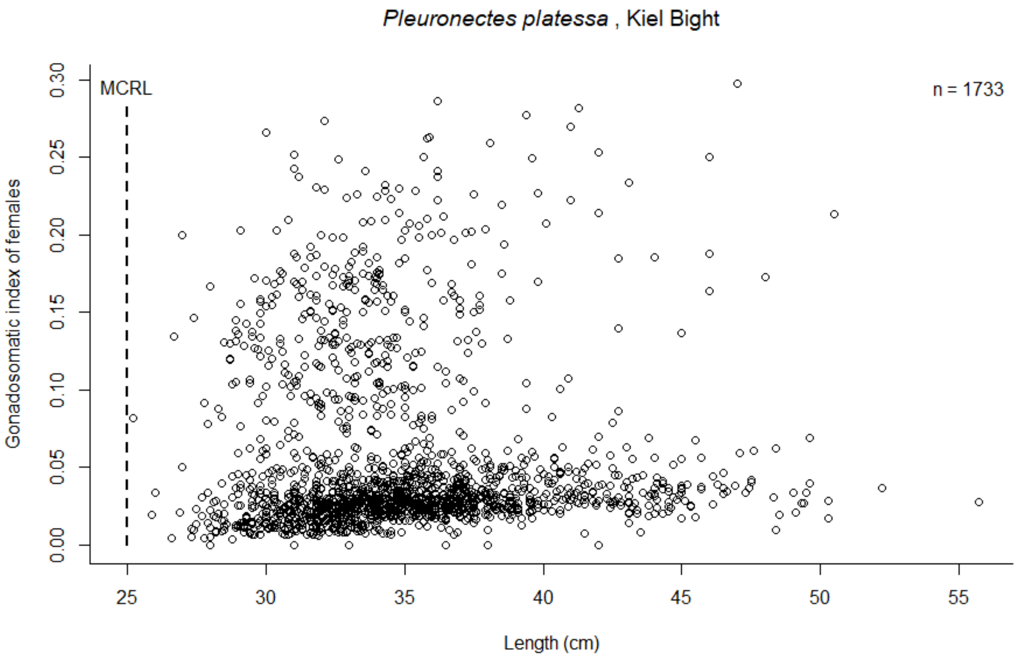


Figure 36. Relative weight of ovaries (GSI) plotted over body length of females in Kiel Bight, 2020-2023. There is no indication that females below 25 cm (dashed vertical line) developed ovaries beyond 0.15 GSI and participated in spawning. But note that commercial fishers avoided capture of juvenile plaice.

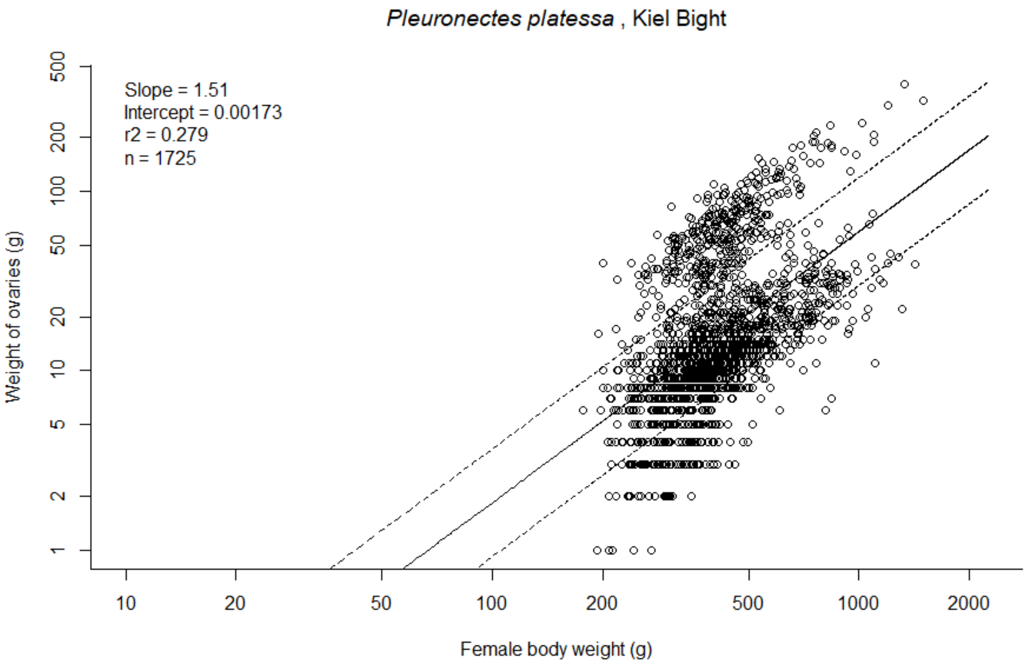


Figure 37. Weight of ovaries in different stages over body weight based on data from commercial fishers in Kiel Bight (2020-2023). Note that a slope > 1 suggests that the weight of ovaries and thus fecundity increases faster than body weight.

Sex ratio: Whereas the sex ratio of plaice fluctuated around the expected 1:1 ratio in survey data taken from throughout the western Baltic Sea, there were only very few male plaice present in the shallow waters of Kiel Bight during the spawning seasons of 2020-2023 (Table 6, Figure 38). Female plaice are determinate spawners where the number of eggs in the ovary is fixed before the onset of spawning, and eggs are released in batches every 3-5 days for about a month (Murua & Saborido-Rey 2003). Similar as for cod, a working hypothesis for the strongly distorted sex ratio of plaice in shallow waters is that male plaice stay in the spawning grounds whereas female plaice visit shallow waters for feeding (and maybe relief from pursuing males) during breaks from active spawning. A problem with this hypothesis is the ongoing lack of males in the catches in March to May when spawning was completed (Figure 40).

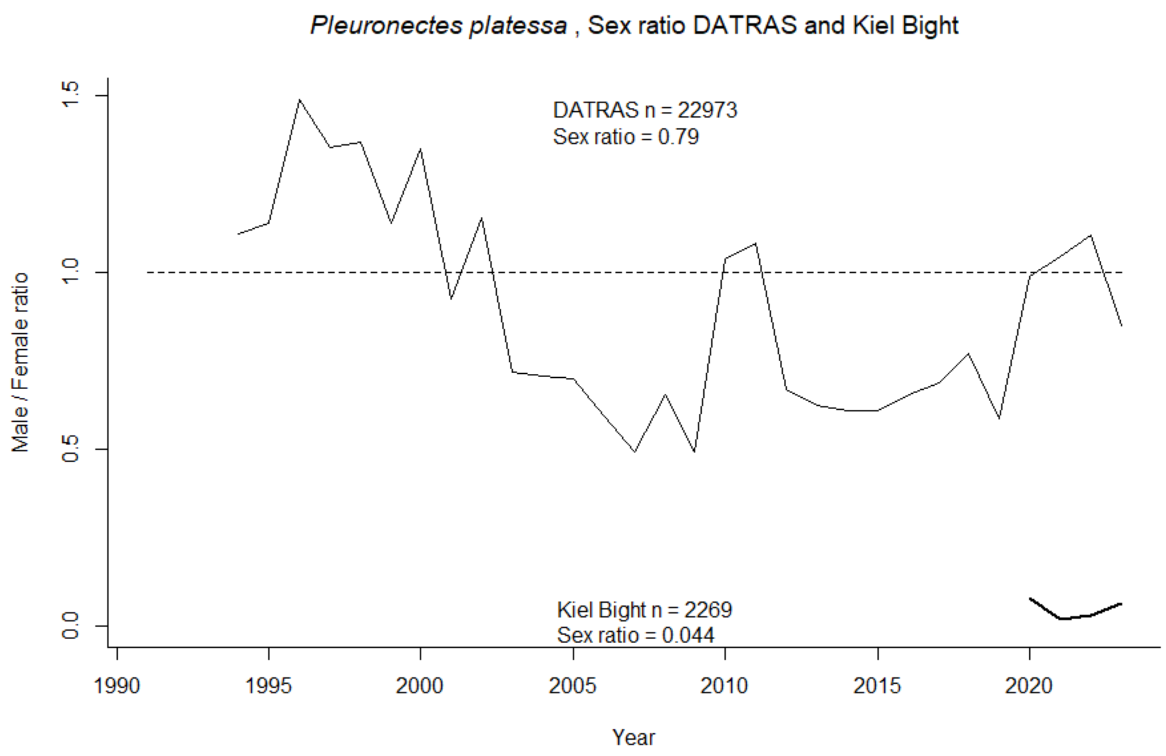


Figure 38. Time series of annual sex ratios, based on DATRAS (upper curve) and Kiel Bight (lower bold curve). While the sex ratio in the wider Western Baltic Sea covered by DATRAS includes the dashed 1:1 line, the sex ratio in the shallower Kiel Bight is strongly dominated by females.

Spawning season: Relative size of ovaries was used to determine the plaice spawning season in 2021-2023 as from before December (no data were available for October/November) to February, with a peak in December (Figure 39, Figure 40). This is about one month earlier than the traditional spawning season indicated as November to March in the Baltic Sea (Muus & Nielsen 1999).

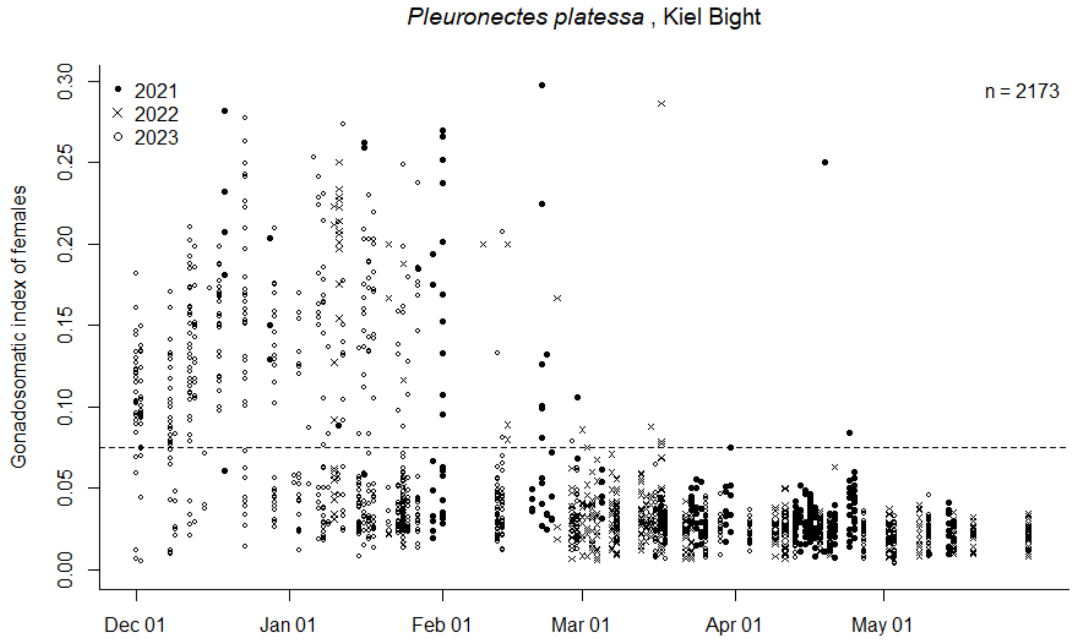


Figure 39. Timing of spawning as indicated by the gonadosomatic index of females in Kiel Bight, based on samples taken from December to May in 2021-2023 in commercial gill net fisheries. Note that no samples were taken in December-January 2022.

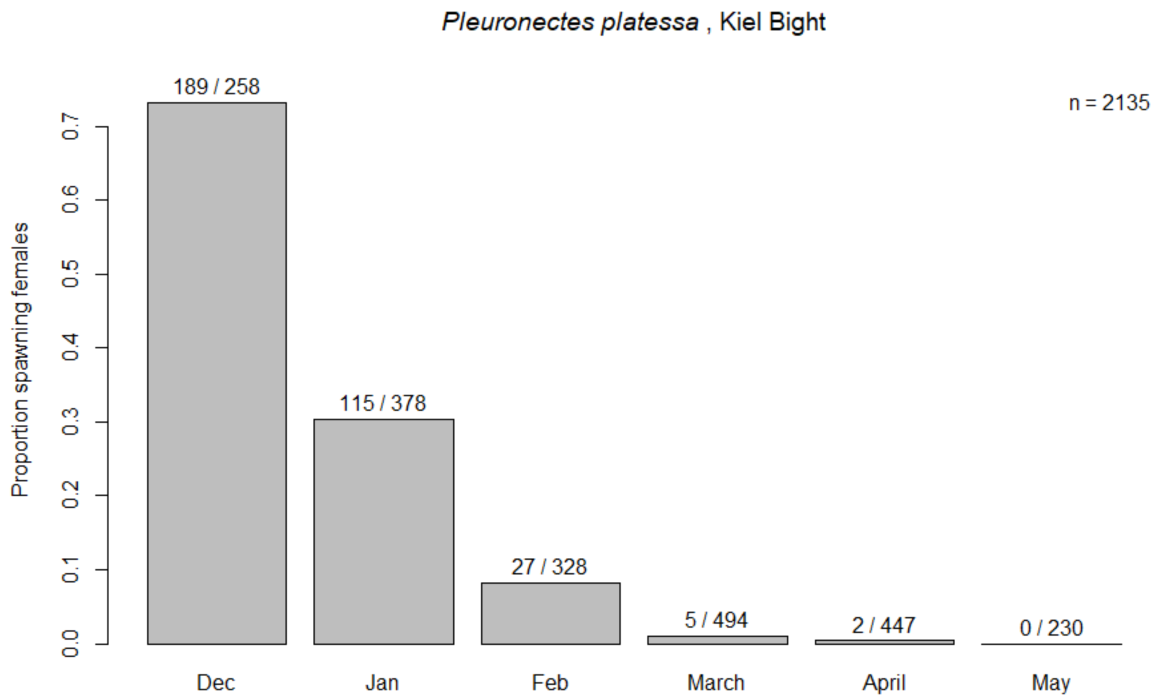


Figure 40. Monthly number of actively spawning females (L > Lm90 and gsi > 0.05) relative to the total number of females examined (numbers on top of bars), for years 2021 to 2023 in Kiel Bight. Spawning peaks in December, but data from October and November are needed to confirm the peak.

Diet composition: The fishers in Kiel Bight weighed stomachs and identified the most prominent food items for altogether 2465 plaice (Table 5, Figure 41). Plaice clearly are benthic feeders, with the most common food item being small mussels (German: Muschelgrus, see Figure 42) reported from most non-empty stomachs.

Table 5. Frequency of occurrence of food items found in altogether 2465 plaice stomachs of which 1433 (58%) contained food. Note that the sum of percentages in the last column exceeds 100 because stomachs can contain more than one food item. Food items are presented by functional groups. Main contributing groups are highlighted in orange and main contributing food items are highlighted in yellow.

Food I	**Food II**	**Names** (German, English)	**Scientific name**	**n**	**%**
zoobenthos					108
	worms				24.7
		Ringelwürmer, Seeringelwürmer, ragworms	*Hediste diversicolor*	150	10.5
		Wattwürmer, lugworms	*Arenicola marina*	55	3.8
		Würmer, worms		149	10.4
	mollusks				73.5
		Muscheln, mussels		1051	73.3
		Schnecken		3	0.2
	benthic crustaceans				10.0
		Garnelen, shrimp	*Palaemon sp.*	13	0.9
		Strandkrabben, green crab	*Carcinus maenas*	1	0.14
		Krebse, crustaceans			
	echinoderms				0.2
		Seeigel, sea urchins	*Psammechinus miliaris*	2	0.1
		Seestern, starfish		1	0.07
zooplankton					0.21
	jellyfish				0.14
		Qualle, jellyfish	*Aurelia aurita*	2	0.14
	fish eggs/larvae				0.07
		Fischlaich, Fischrogen, Rogen, roe		1	0.07
nekton					0.9
	finfish				0.9
		Fische, Jungfische, unspecified fish		13	0.9

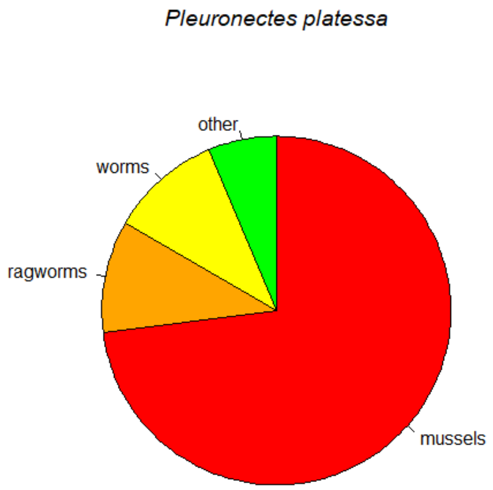


Figure 41. Four most frequently encountered food items in plaice stomachs, based on commercial catches from January to May 2021 to 2023 in Kiel Bight.

Figure 42. Stomach content of an adult plaice in Kiel Bight in March 2023, including predominantly early life stages of blue mussel (Mytilus edulis) and unidentified other early life stage mussels and snails. Photo Erik Meyer.

Note that most of these stomach analyses were done during the spawning season, confirming that at least female plaice feed during breaks in active spawning. This observation is confirmed by a slight increase in condition from January to May, with condition here measured as body weight of females without ovaries and stomach weight relative to length cubed (Figure 43).

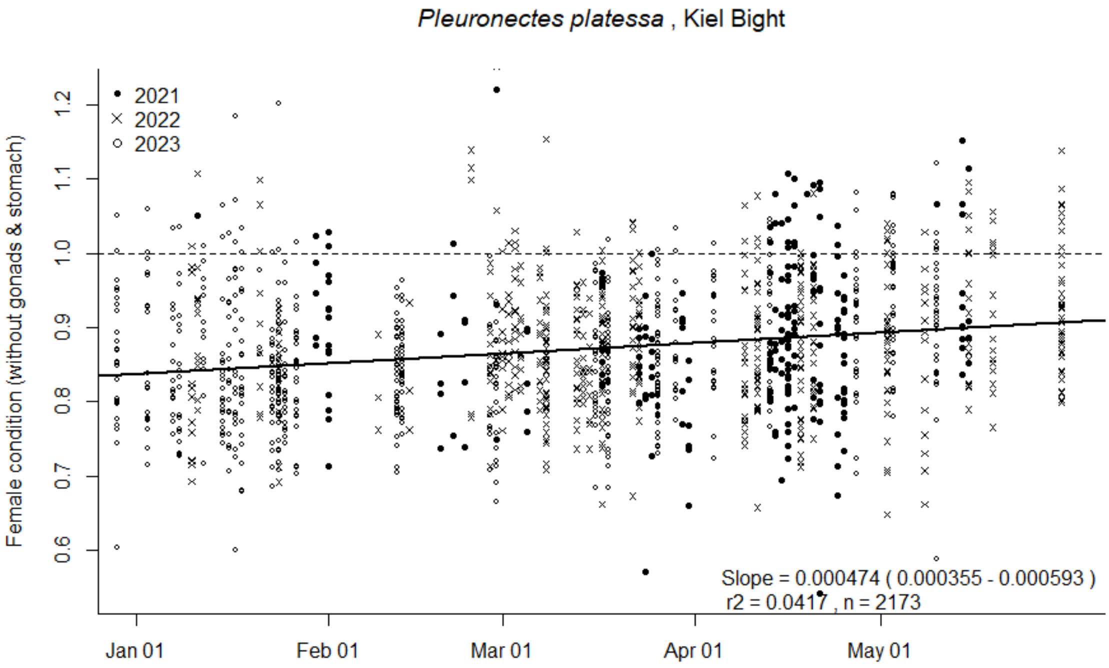


*Figure 43. Condition (C = 100 * W/L3) of female plaice in Kiel Bight, based on samples taken from December to May in 2021-2023 in commercial gill net and trawl fisheries. Note that weight of stomach and gonads was excluded, i.e., the bold line suggests a weight increase in muscles and bones, but it accounts for only 4% of the variability.*

Somatic growth: Thousands of plaice caught in standard scientific surveys have been aged for stock assessment purposes, however, the uncertainty of these age readings is very wide, suggesting e.g. that four year old plaice can be between 10 to 45 cm long (Figure 44). Fitting a growth curve to these length-at-age data strongly underestimates asymptotic length (L_{inf}) when compared with observed lengths (Figure 44). Instead, a more convincing growth curve was obtained by setting L_{inf} equal to the maximum observed length L_{max} = 55.7 cm (Table 6) and using the median length of one year old plaice according to DATRAS to anchor the growth curve.

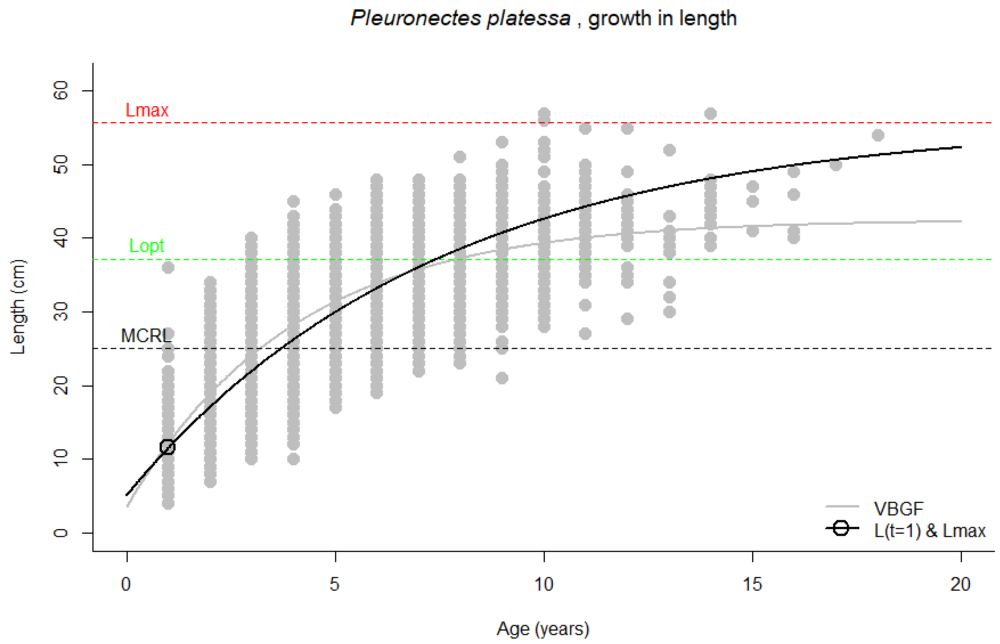


Figure 44. Growth in length based on DATRAS age readings from 2020-2022, first quarter, area 22 and 24. Note highly variable length-at-age readings in older fish and the underestimation of L_{max} by the fitted asymptotic length (L_{inf}), making the derived growth parameters doubtful. The black curve uses instead L_{max} as a proxy for L_{inf} and the most common length of one year old fish and a user-provided estimate of t_0, resulting a more plausible growth curve (Froese 2022).

Fisheries management considerations: There is an optimal length (L_{opt}) for catching fish, where the increase in body weight has reached a maximum, and where most individuals have already reproduced 1-3 times. This is also the length where catches will be highest for a given effort or where for a given catch the least number of fish will be killed (Froese et al. 2016). A proxy for L_{opt} can be derived as 2/3 of maximum length (see Material and Methods), which for plaice in the western Baltic gives L_{opt} = 37.1 cm with an optimum length at first capture as L_{c_opt} = 0.56 L_{max} = 31.2 cm (Table 6). The Minimum Conservation Reference Length (MCRL) for plaice in the Baltic Sea is 25 cm. These reference lengths can be used to determine the appropriateness of the selectivity of the most common fishing gears (gill nets and trawls) in the western Baltic and Kiel Bight.

Fishers in Kiel Bight use gill nets with mesh sizes from the legal minimum size of 55 mm up to voluntarily used 80 mm or more (all measured knot to knot). A comparison of the size selectivity of mesh sizes of 55, 70, 75 and 80 mm for plaice shows that the legal mesh size of 55 mm catches individuals below MCRL and below the length where 90% have reached maturity. Only the mesh size of 80 mm gives a size distribution in the catch that includes L_{opt} within the length range that contains 50% of the caught fish (Figure 45).

The selectivity of commercial trawls with 110 to 120 mm stretched mesh size has a peak for catches of plaice well below MCRL, L_{m90}, L_{c_opt} and L_{opt} (Figure 46). Thus, the legal minimum mesh sizes for gill nets and trawls are too small and should be increased by about 50% to avoid capture of undersized and immature plaice and to approach the optimum length of capture.

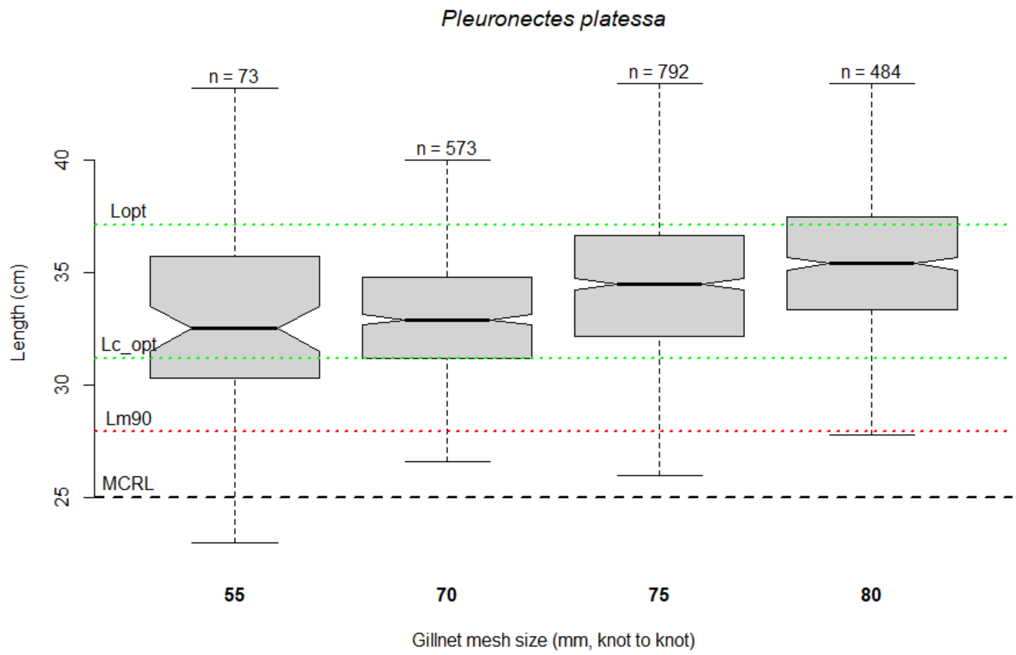


Figure 45. Boxplot of length distribution in gill nets from 55 mm (knot to knot), which is the legal minimum mesh size, to 70 – 80 mm, which are preferred by fishers who do not want to catch juveniles. The red horizontal line indicates the length L_{m90} at which 90% of the females have reached maturity. The green horizontal line indicates the length L_{opt} at which the catch for a given fishing pressure is maximized and number of fish killed for the allowed catch in weight is minimized. Note that with the legal minimum mesh size, close to half of the caught fish are below the length Lc_opt, which is the lower bound of optimum selectivity, which is achieved with 70, 75 and 80 mm. Data from commercial fishing in Kiel Bight, December to May 2020-2023.

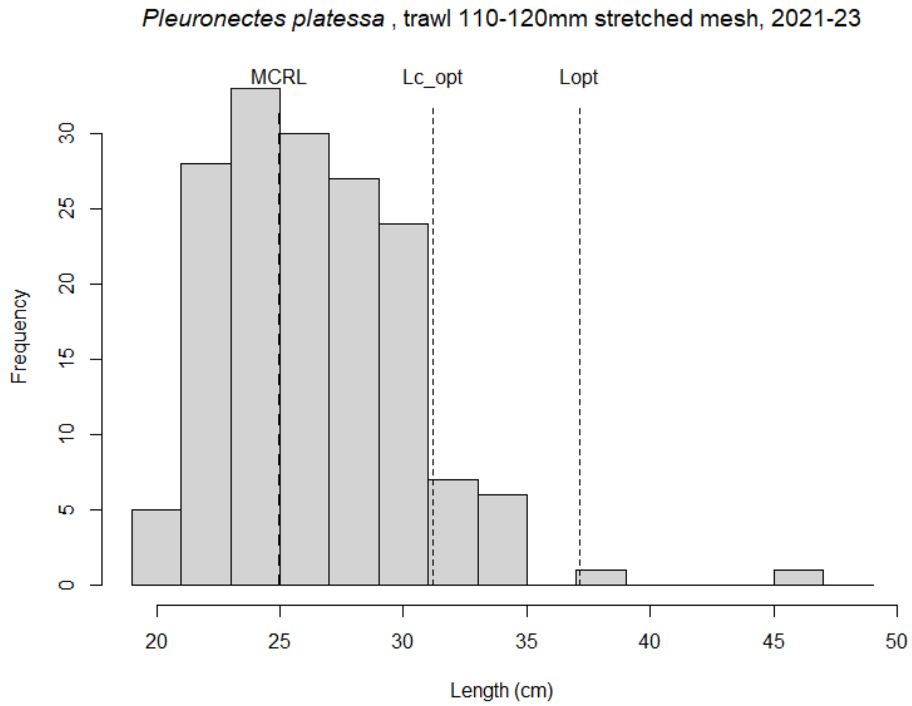


Figure 46. Selectivity of commercial trawl with 110 mm stretched mesh size, the legal minimum mesh size is 90 mm. Even this voluntarily enlarged mesh size is too narrow for plaice, with a peak in numbers caught below the minimum conservation reference length (MCRL). If the suitable gill net mesh sizes of 75 and 80 mm (knot to knot) are taken as guidance, then about 150 – 160 mm stretched mesh size would have the correct selectivity for plaice and cod.

Another standard management measure is to protect fish from capture during the spawning season, in order to maximize reproductive output and the probability of successful recruitment. For plaice in the Baltic Sea, no protection during the spawning season exists. Spawning plaice do also not benefit from the prohibition to catch cod with trawls below 20 m of water depth from February 1 to March 31 for vessels longer than 15 m. As can be seen from the data collected in Kiel Bight for this study (Figure 47), mature plaice regularly enter shallower waters during that period where they are subject to legally ongoing fishing. Thus, there is no protection of spawning plaice in the western Baltic Sea.

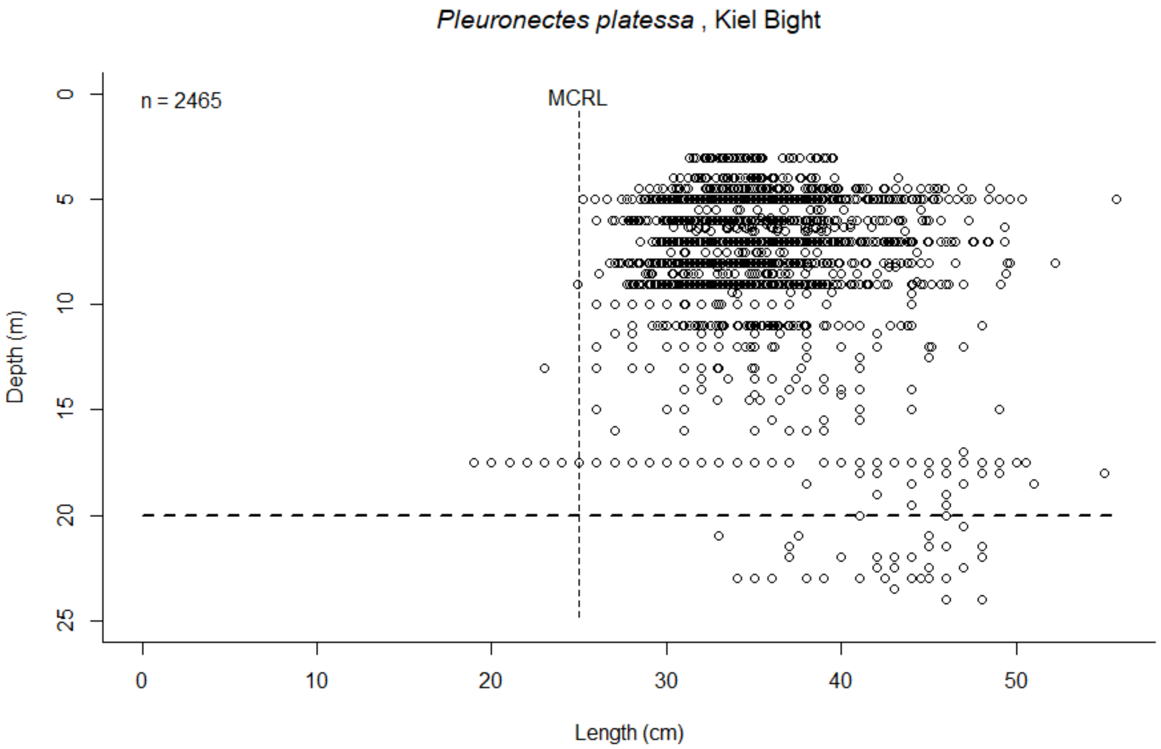


Figure 47. Length-distribution by depth of capture by commercial fishers from December to May 2021-2023 in Kiel Bight. Note that while fewer small plaice are found below 20 m (dashed line), large mature/spawning plaice occur at all depths.

Table 6 contains a summary of relevant reference points extracted from DATRAS for the western Baltic Sea or established in this study.

Table 6. Key life history reference points, with plausible 95% confidence limits (LCL, UCL) or coefficient of determination (r^2), where applicable, derived from catches of commercial fishers in Kiel Bight (KB) in 2020-2023, December/January and May, and from scientific surveys in the Western Baltic Sea as documented in DATRAS for the first quarter of the years 2000-2022 in areas 22 and 24. Doubtful estimates are marked with ***??***

Species	Plaice	*Pleuronectes platessa*				Pleuronectidae	
Parameter		estimate	LCL	UCL	n r^2	Unit	Method
Lmax KB	Maximum length	55.7				cm	largest on record
Lmax datras	Maximum length	49				cm	largest on record
Lmax	Maximum length	55.7				cm	chosen for study
a.f KB	W=**a**L^b, females	0.0314	0.0266	0.037	n=2152	g/cm^b	log-log regression
b.f KB	W=a$L^{\mathbf{b}}$, females	2.67	2.62	2.72	r^2=0.86		log-log regression
a.m KB	W=**a**L^b, males	0.0151	0.00754	0.0301	n=128	g/cm^b	log-log regression
b.m KB	W=a$L^{\mathbf{b}}$, males	2.85	2.66	3.05	r^2=0.866		log-log regression
a.c KB	W=**a**L^b, combined	0.028	0.0239	0.0329	n=2459	g/cm^b	log-log regression
b.c KB	W=a$L^{\mathbf{b}}$, combined	2.7	2.66	2.75	r^2=0.858		log-log regression
Wmax KB	Maximum weight	1500				g	largest on record
Wmax DATRAS	Maximum weight	2590				g	largest on record
Wmax LWR	Maximum weight	1456				g	Wmax=a.c $Lmax^{b.c}$
Wmax	Maximum weight	1500				g	chosen for study
tmax DATRAS	Maximum age	18				years	largest on record
L_opt	Optimum length	37.1				cm	2/3 Lmax
Lc_opt	Optimum capture	31.2				cm	0.56 Lmax
Wopt	Optimum weight	487				g	a.c $Lopt^{b.c}$
Wc_opt	Optimum capture	304				g	a.c $Lopt^{b.c}$
MCRL	Minimum length	25				cm	EU law
Lm50 KB	50% mature fem.	24.0	23.9	24.1	n=2169	cm	ogive
Lm90 KB	90% mature fem.	26.1	26.0	26.3		cm	ogive
Lm50 DATRAS	50% mature fem.	18.4 **??**	17.6 **??**	19.2 **??**	n=10123	cm	ogive, SMALK
Lm90 DATRAS	90% mature fem.	28.6	27.0	30.4		cm	ogive, SMALK
tm50 DATRAS	50% mature fem.	3				years	first age > 0.5 mature
tm90 DATRAS	90% mature fem.	5				years	first age > 0.9 mature
sex ratio KB	males / females	0.044 : 1			n=2269		n (sex=m) / n (sex=f)
sex ratio DATRAS	males / females	0.79 : 1			n=22973		n (sex=m) / n (sex=f) Exchange 1991-2023
gsi.95 KB	Gonad/Body weight	0.24			n=1725		95th percentile of GSI
gsi.slope KB	Gonad/Body slope	1.51	1.40	1.63	r^2=0.279		gonads ~ body weight
spawning season	peak, range	Dec	Dec	Feb	n=2147	month	L>Lm90, mat > 10%
Linf DATRAS	Asymptotic length	42.5 **??**	42.0 **??**	43.0 **??**	n=21031	cm	VBGF fit
K DATRAS	Growth parameter	0.251 **??**	0.242 **??**	0.26 **??**		$year^{-1}$	VBGF fit
t0 DATRAS	Growth parameter	-0.33 **??**				years	VBGF fit
SE DATRAS	SE of residuals	4.21 **??**				cm	VBGF fit
Linf KB	Asymptotic length	55.7				cm	Linf=Lmax
K KB	Growth parameter	0.155				$year^{-1}$	from median L(t=1)
t0 KB	Growth parameter	-0.7				years	t0=t0.user

Flounder (*Platichthys flesus*)

Status: The status and history of exploitation of the two recognized stocks of flounder (*Platichthys flesus*) overlapping in part of their areas with the western Baltic Sea are given in the ICES Advice documents of May 2022 (ICES-fle 2022a, ICES-fle 2022b). Both assessments show a peak in the stock size indicator derived from catch per unit of effort (CPUE in kg/h) in survey data in 2016, with 2021 stock size at about half of that level. The 2020 to 2021 increase in abundance in the western stock is confirmed by the catch-per-unit-of-effort (CPUE) data from Kiel Bight (Figure 27). Overall and despite an increase in temperature in the western Baltic Sea of about 1.4°C over the past decades (Dutheil et al. 2022), both stocks of this cold-adapted species seem to be in reasonably good status with stock sizes likely to increase if catches remain low.

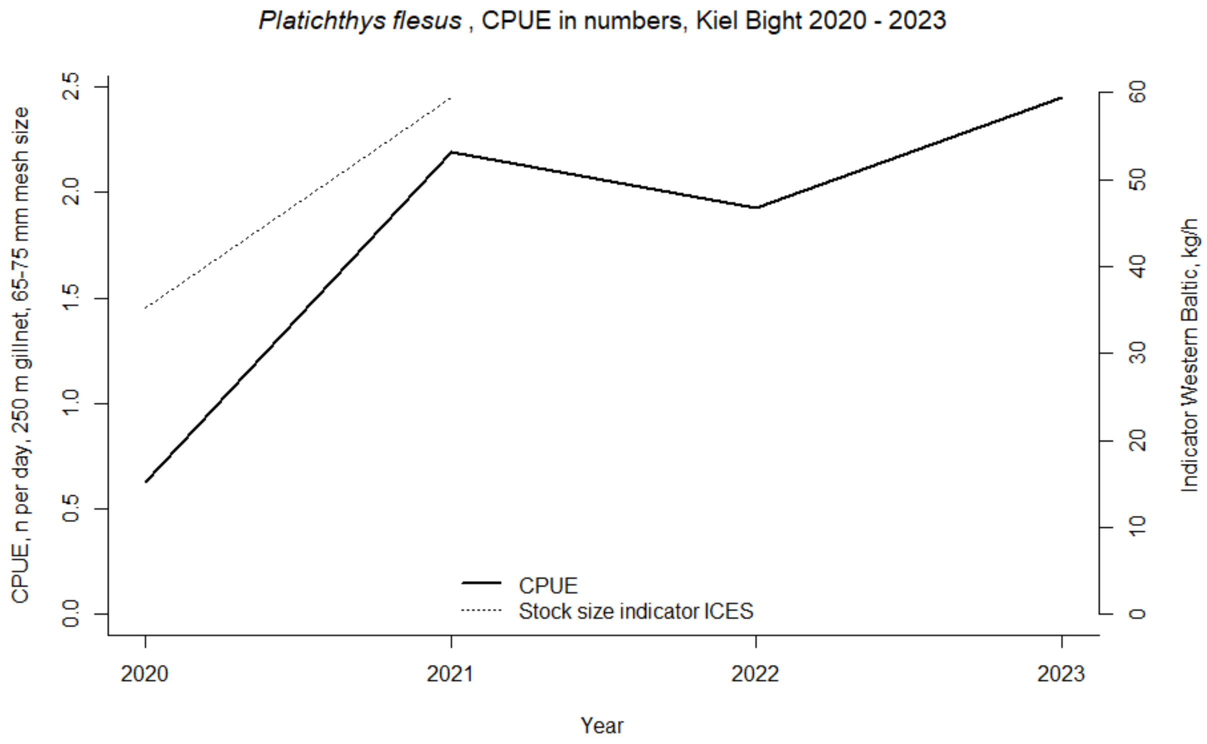


Figure 48. Average number of flounders caught per day in Kiel Bight by commercial fishers with 250 m of gill nets with 70-75 mm mesh size (knot to knot), from December to May in 2019 – 2023 (bold curve). The dotted curve shows the stock size indicator estimates of ICES-fle (2022a) for the western Baltic (no data for 2022 and 2023), in good agreement with the local trend in abundance.

Fishing pressure: A **l**ength-based indicator proposed by Froese and Sampang (2012) and adapted by ICES (ICES-fle 2022a,b) suggests that both flounder stocks are fished below the maximum sustainable level. This is confirmed by reported total catches from both stocks in 2021 being the lowest of the past 20 years. Note that both stocks are in reasonable shape and are not managed by catch limits or any other measures.

Healthy age and size structure: A healthy age and size structure of commercial fish stocks is a requirement for good environmental status in the Marine Strategy Framework Directive (MSFD 2008) of the European Union. The maximum age of flounder found surveys in the western Baltic is 20 years (Table 8). Figure 49 shows the frequency distribution of a reasonably healthy stock, with all year classes present, albeit with a strong decline in numbers after being fully selected by fishing at 3 years of age. The decline is caused by past higher catches (before 2020, ICES-fle 2023a) but is cushioned by a mean length of capture above MCRL and above length at maturation (Figure 50 and Figure 51, and see respective sections below).

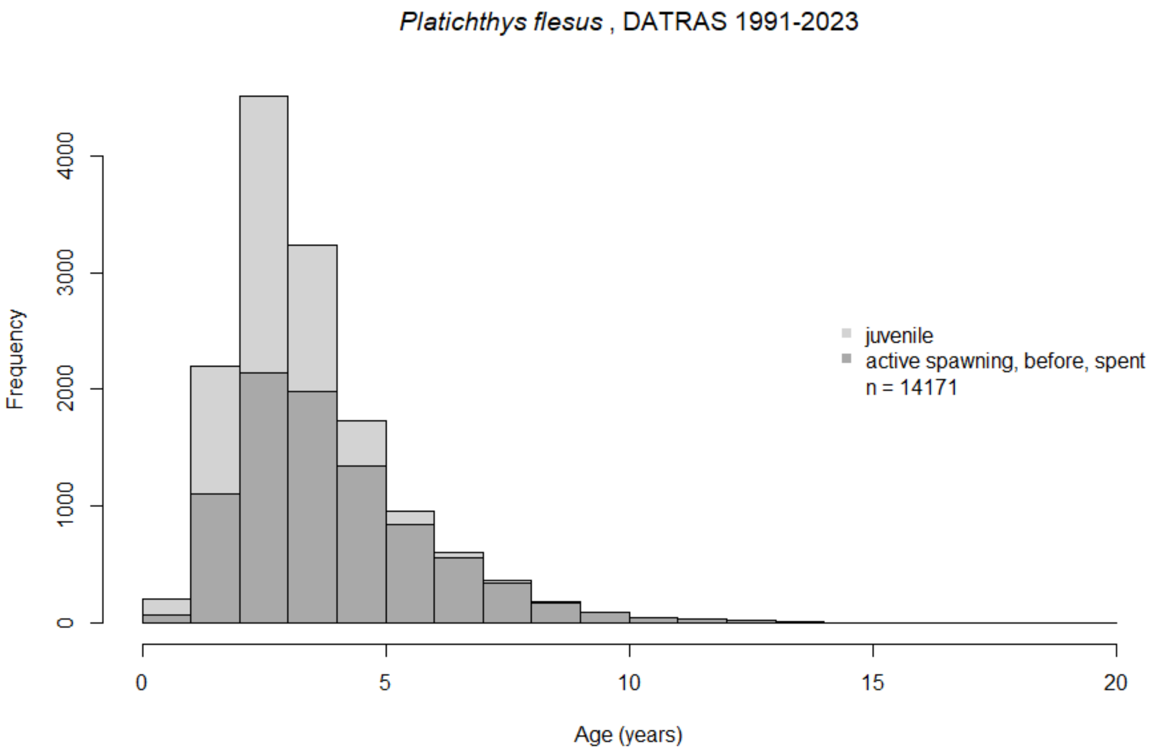


Figure 49. Age frequency of juveniles and adults based on the SMALK database (1st quarter, area 22 and 24). Note that only above age 5 more than 90% of the individuals are mature.

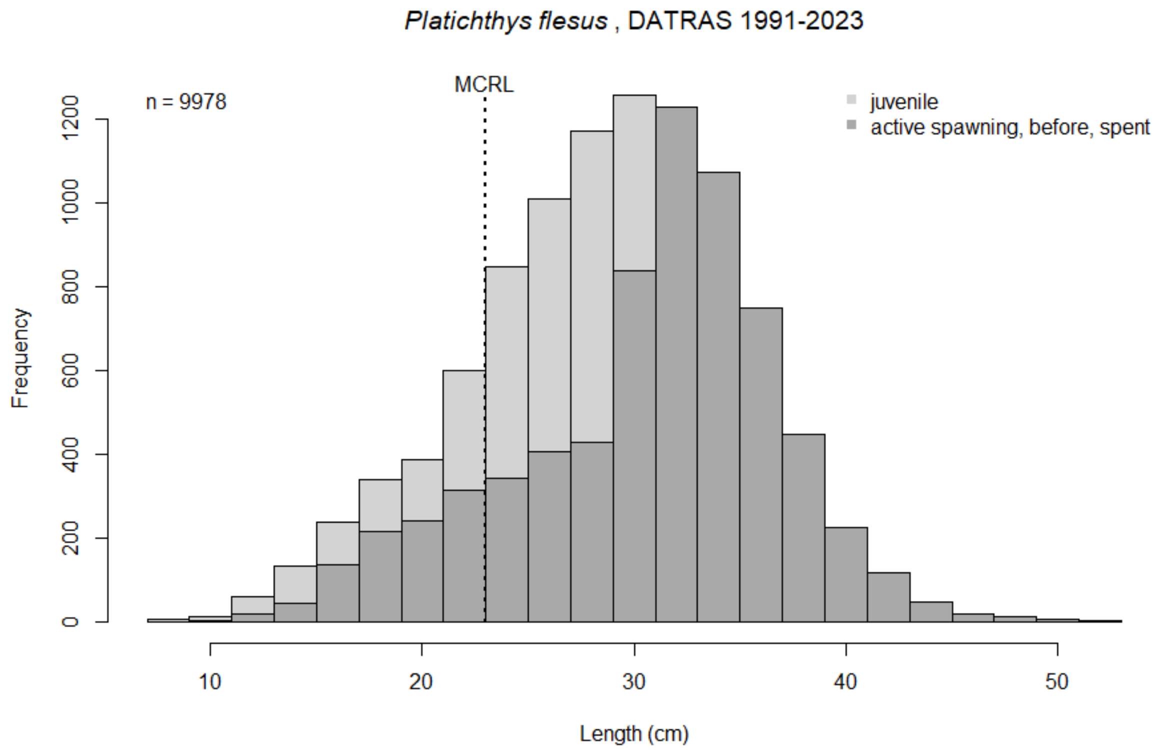


Figure 50. Length frequency of juveniles and adults based on the SMALK database (1st quarter, area 22 and 24). MCRL indicates the legal minimum conservation reference length. Note that about half of the individuals are still immature at MCRL, 90% are mature above 32 cm length. Effective maturity at and below 20 cm seems highly doubtful, see Figure 54.

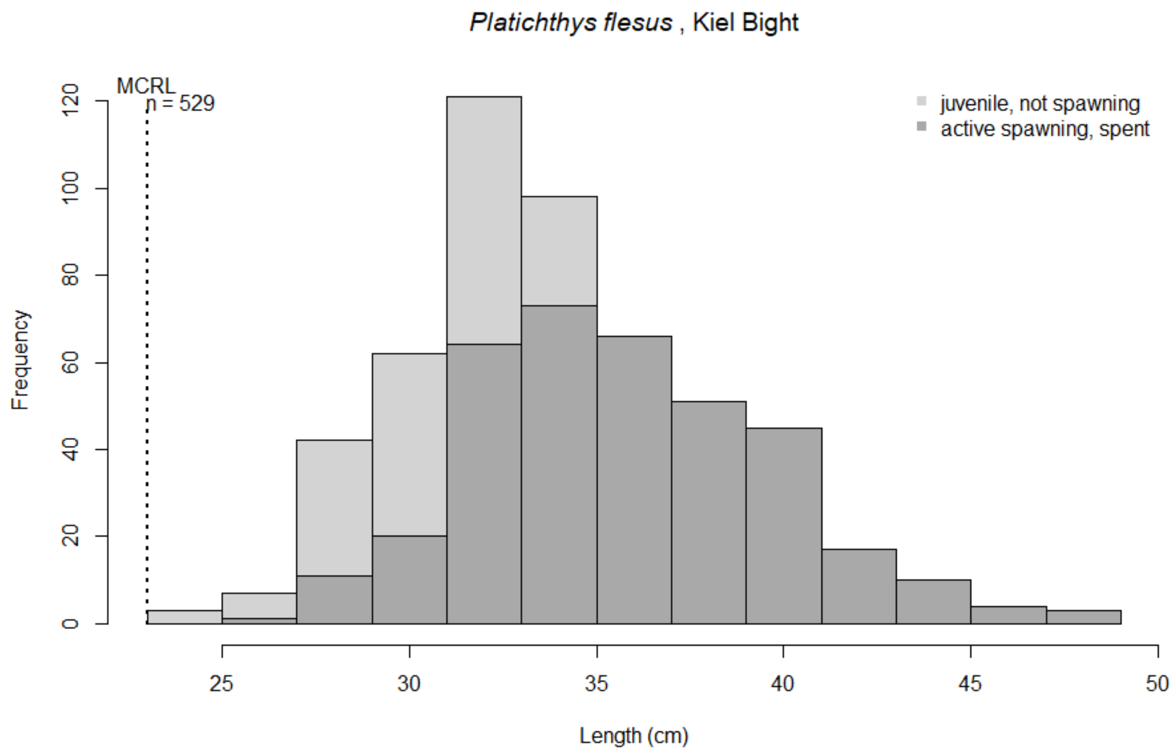


Figure 51. Length frequency of juveniles and adults based on data from commercial fishers (2020-2023). MCRL indicates the legal minimum conservation reference length. Note that commercial fishers avoided capture of juvenile flounders.

Length-weight relationship and condition: The parameters of the length-weight relationship (Table 8, Figure 52) describe flounder correctly as a more roundish than fusiform species, indicated by *a* = 0.043 being well above the typical fusiform value of *a* = 0.01 (Froese 2006). Also, flounder change their body shape or proportions to a slightly more elongated form as they grow through late juvenile and adult life stages, indicated by *b* = 2.6 instead of the symmetric value of *b* = 3.0 (Froese 2006). Much but not all of the variability in the data is accounted for by the coefficient of determination (r^2 = 0.79, Table 8) of the log-log linear relation between body weight and length, with the decrease in condition (see next paragraph) possibly playing an additional role. There are only three outlying specimens (erroneous measurements or starving or obese fish) which were excluded from this and other analyses.

Median body weight for a given length (condition) dropped from 1.15 to 1.07 (8%) in catches from Kiel Bight from 2020 to 2023 (Figure 53), confirming reports from fishers that flounder and commercial fish in general were getting thinner. A comparison with DATRAS survey data for the western Baltic from 1991 to 2023 confirmed this observation, showing a general decline of 16% during that period (Figure 54).

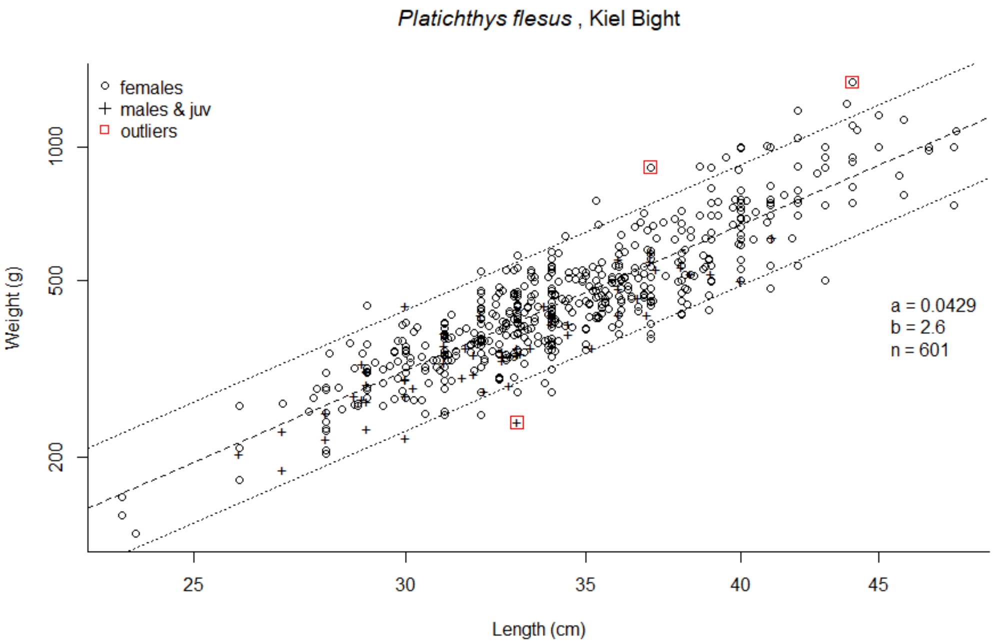


Figure 52. Length-weight relationship for flounder in Kiel Bight, based on samples taken from December to May in 2020-2023 in commercial gill net and trawl fisheries. The dashed line indicates the overall fit and the dotted lines indicated the 95% confidence limits.

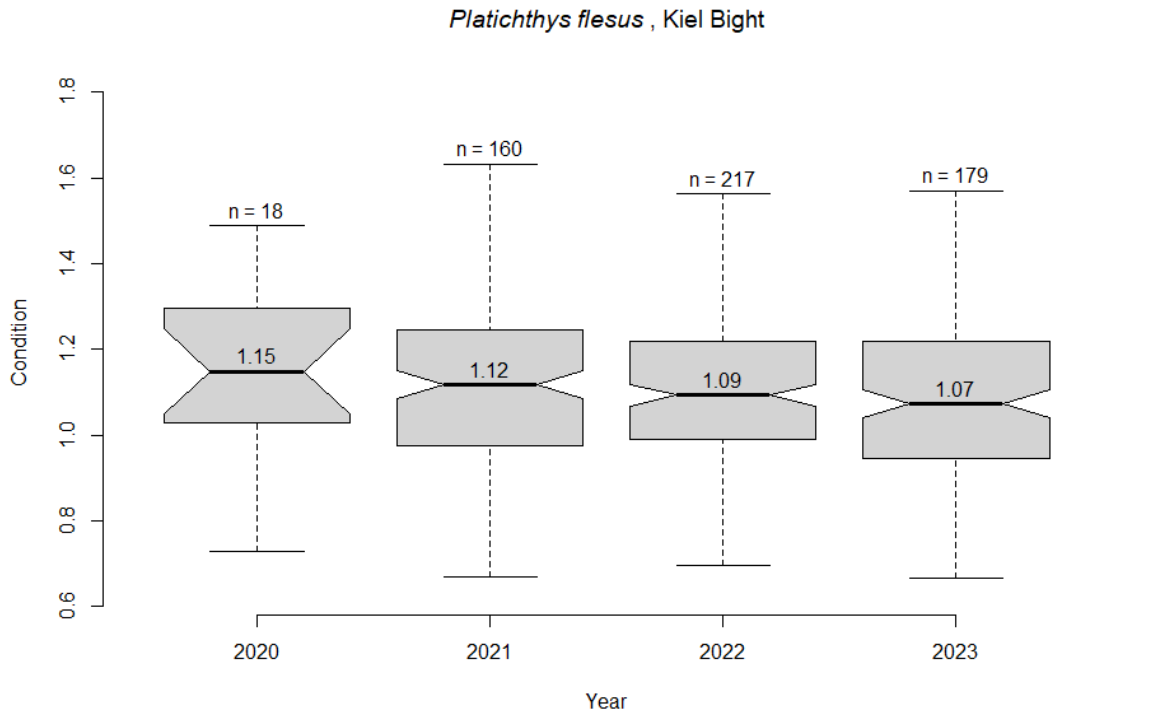


Figure 53. Comparison of Condition C = 100 Weight/Length^3 from 2020 to 2023, based on commercial catches from January to May in Kiel Bight.*

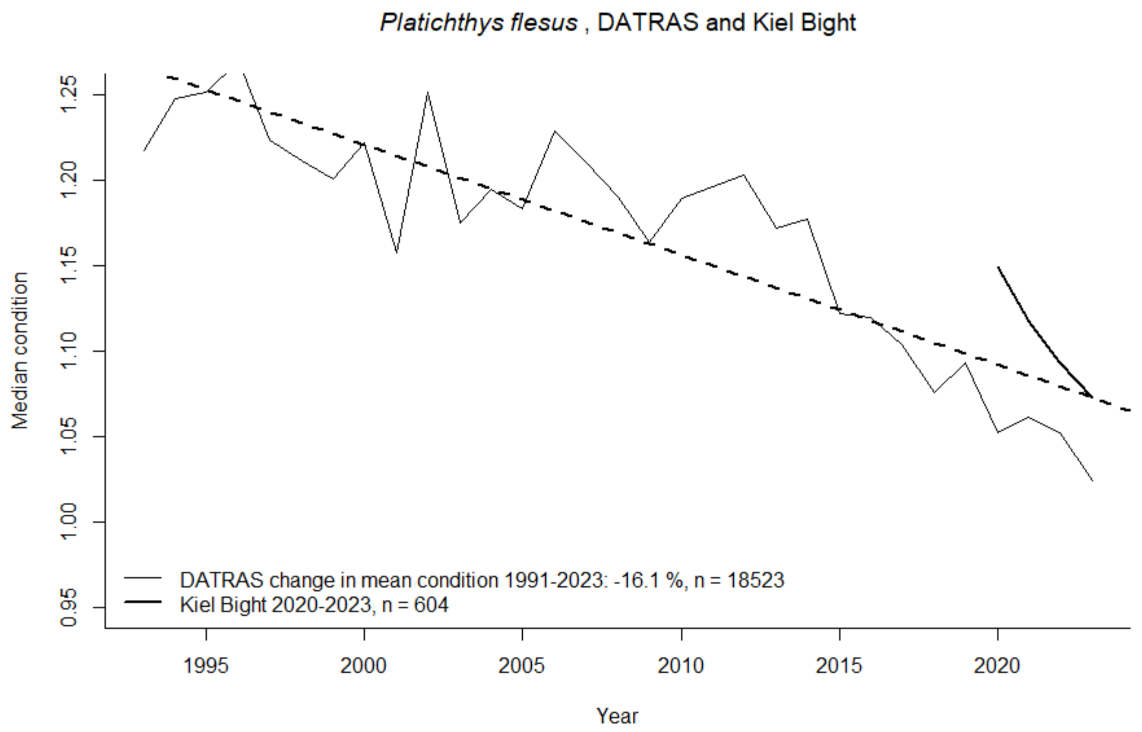


Figure 54. Change in median condition based on DATRAS (black curve and blue line, 1st quarter, area 22 and 24) and 2020-2023 data from commercial fishers in Kiel Bight (bold curve).

Length and age at maturation: The size and age where 50% or 90% of female flounders have reached sexual maturity and participate in spawning is L_{m50} = 20.1 cm and L_{m90} = 35.1 cm (Figure 55, Table 8), at ages 4 and 7 (Figure 49, Table 8), based on survey data, with L_{m90} = probably being a bit too high and caused by variability in the data (Figure 55). An ogive curve fitted to data derived in this study suggests L_{m50} = 30.3 cm (Figure 56), which however seems a bit too high because fishers in Kiel Bight used larger mesh sizes to avoid capture of small cod, plaice and flounders (Figure 35).

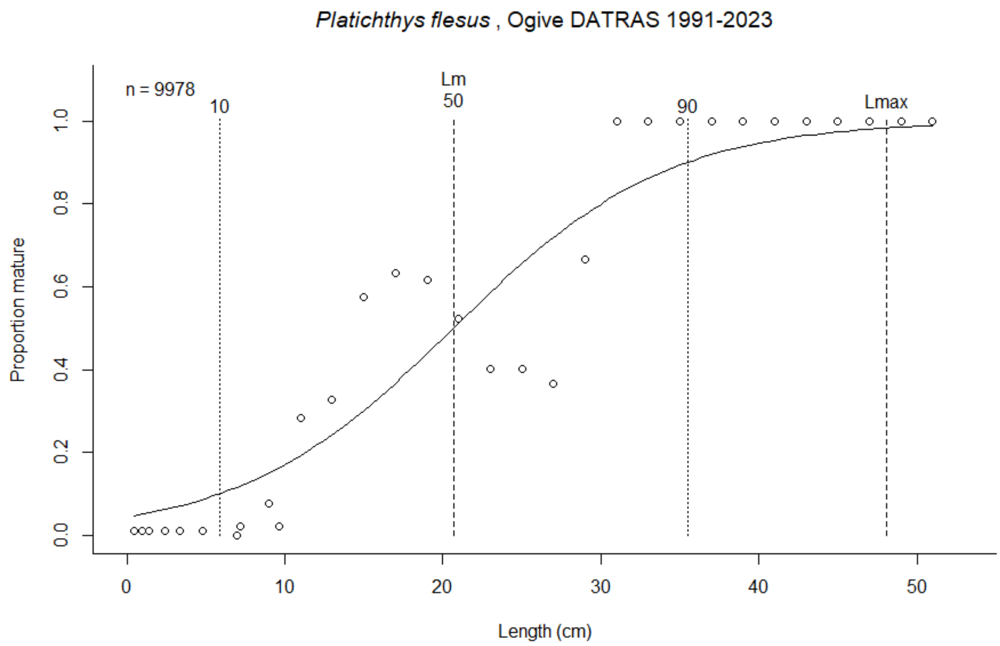


Figure 55. Proportion of mature females based on the SMALK database (1st quarter, area 22 and 24). It is doubtful that females at and below 20 cm length would really fully develop their ovaries and participated in spawning (see Figure 54), altogether there is high uncertainty in the data length at 50 or 90% maturity.

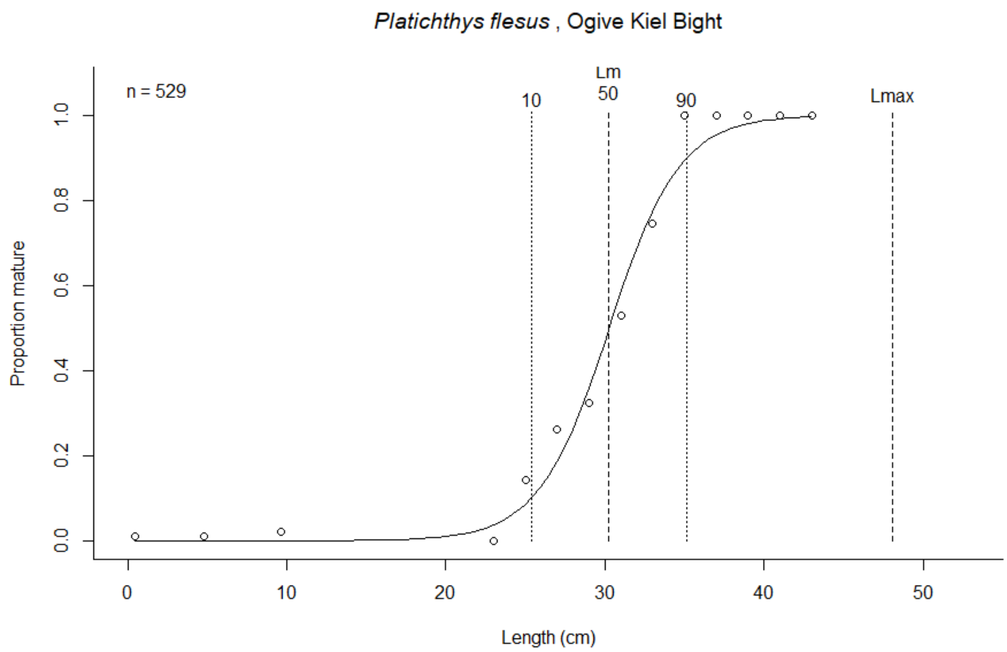


Figure 56. Proportion of mature females based on data from commercial fishers in Kiel Bight (2020-2023). The estimates of Lm50 at about 30 cm and Lm90 at about 35 cm seem too high for a maximum length of 48 cm. Juvenile flounders are missing from the fishers catch.

Fecundity as a function of body weight: The base assumption of the relation between fecundity and body weight is that the number of eggs of a female or the maximum weight of the gonads grows about proportionally with body weight. Overall, the fully developed ovaries of flounder females examined in Kiel Bight took up about 24% of total body weight (Table 8, Figure 57). The available data on relative weight of ovaries (gonado-somatic index) collected in this study suggest that the increase in fecundity was higher (slope = 1.3) than predicted by a directly proportional increase in body weight (Table 8, Figure 58).

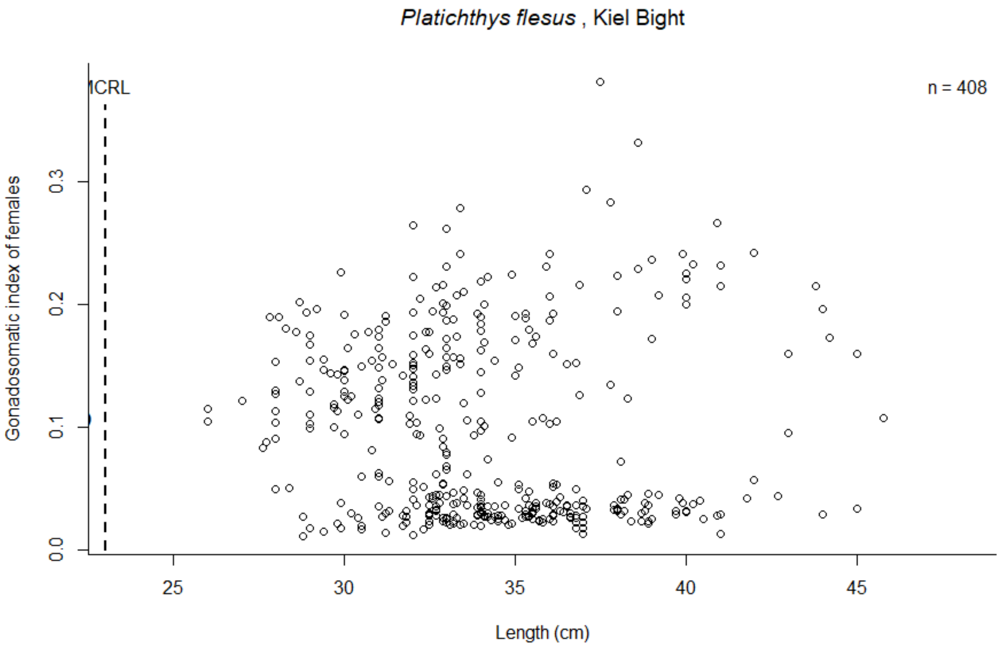


Figure 57. Relative weight of ovaries (GSI) plotted over body length of females in Kiel Bight, 2020-2023. There is no indication that females below 27 cm (dashed vertical line) developed ovaries beyond 0.15 GSI and participated in spawning.

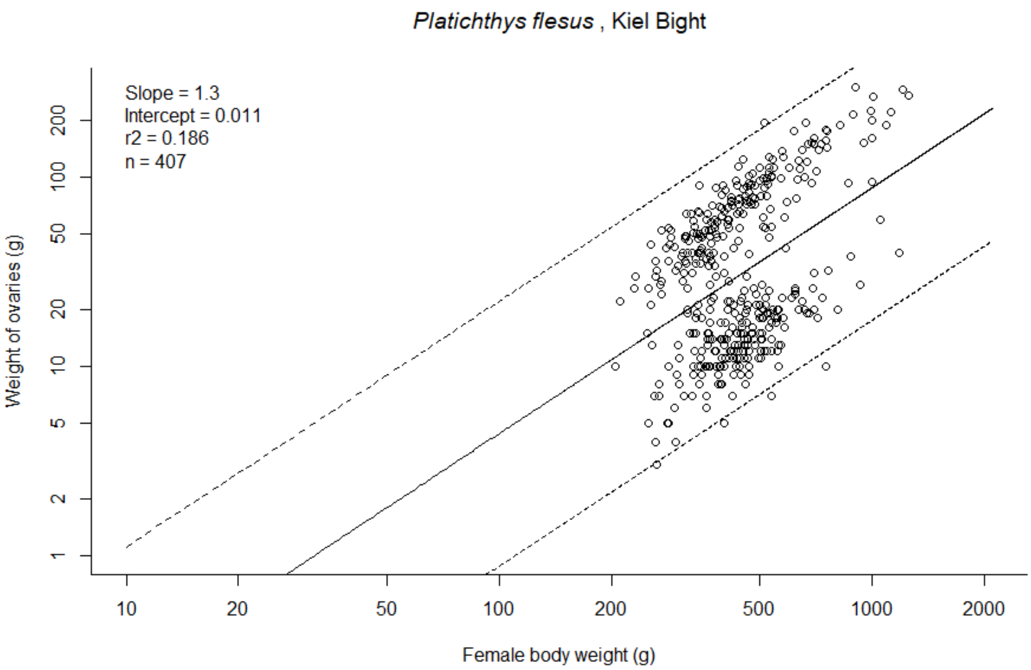


Figure 58. Weight of ovaries in different stages over body weight based on data from commercial fishers in Kiel Bight (2020-2023). Note that a slope > 1 suggests that the weight of ovaries and thus fecundity increase faster than body weight.

Sex ratio: Whereas the sex ratio of flounder fluctuated around the expected 1:1 ratio in survey data taken from throughout the western Baltic Sea, there were only very few male plaice present in the shallow waters of Kiel Bight during the spawning seasons of 2020-2023 (Table 8, Figure 59). Female flounders are determinate spawners where the number of eggs in the ovary is fixed before the onset of spawning (Murua & Saborido-Rey 2003). Similar as for cod and plaice, a working hypothesis for the strongly distorted sex ratio of flounders in shallow waters is that male flounders stay in the spawning grounds whereas female flounders visit shallow waters for feeding (and maybe relief from pursuing males) during breaks from active spawning. A problem with this hypothesis is the ongoing lack of males in the catches in March to May when spawning was completed (Figure 61).

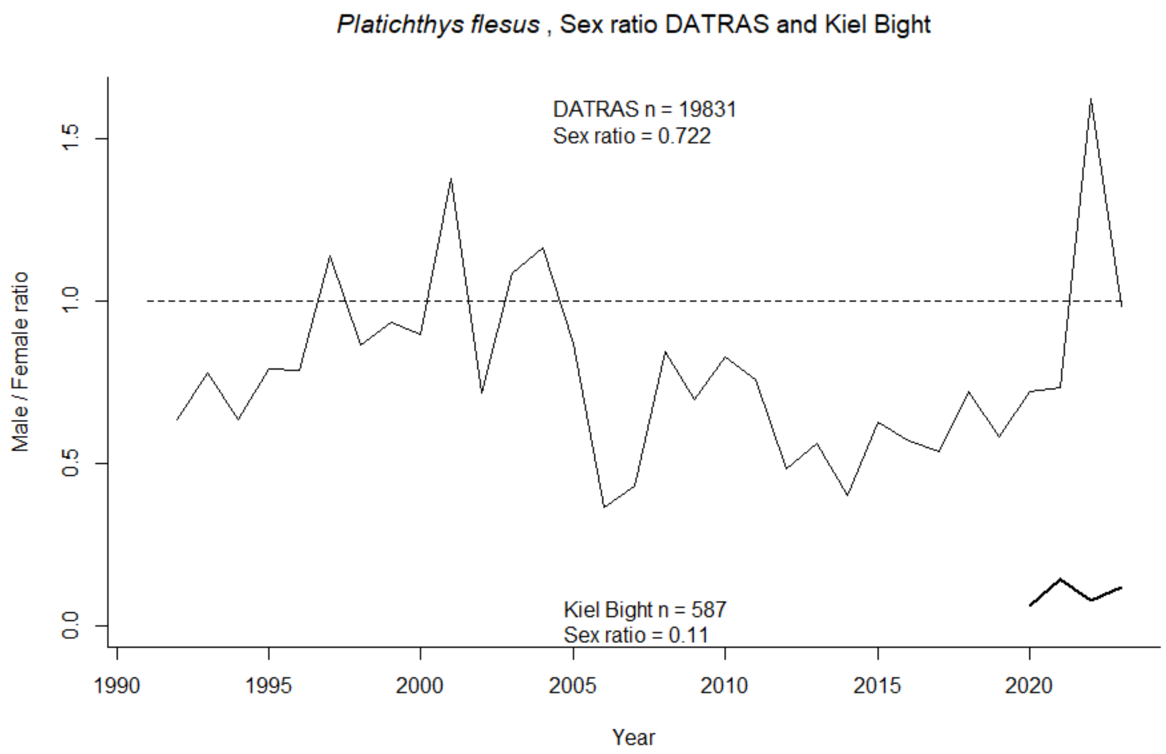


Figure 59. Time series of sex ratios. While the sex ratio in the wider Western Baltic Sea covered by DATRAS includes the dashed 1:1 line, the sex ratio in the shallower Kiel Bight (bold curve in the lower right) is strongly dominated by females, which presumably come there for feeding while the males remain in the spawning areas.

Spawning season: Relative size of ovaries was used to determine the spawning season of flounder in 2021-2023 as from before December (no data were available for October/November) to March, with a peak in January (Figure 60, Figure 61). This is about two months earlier than the traditional spawning season indicated as February to April in the Kattegatt, Sound and western Baltic Sea (Florin and Höglund 2008).

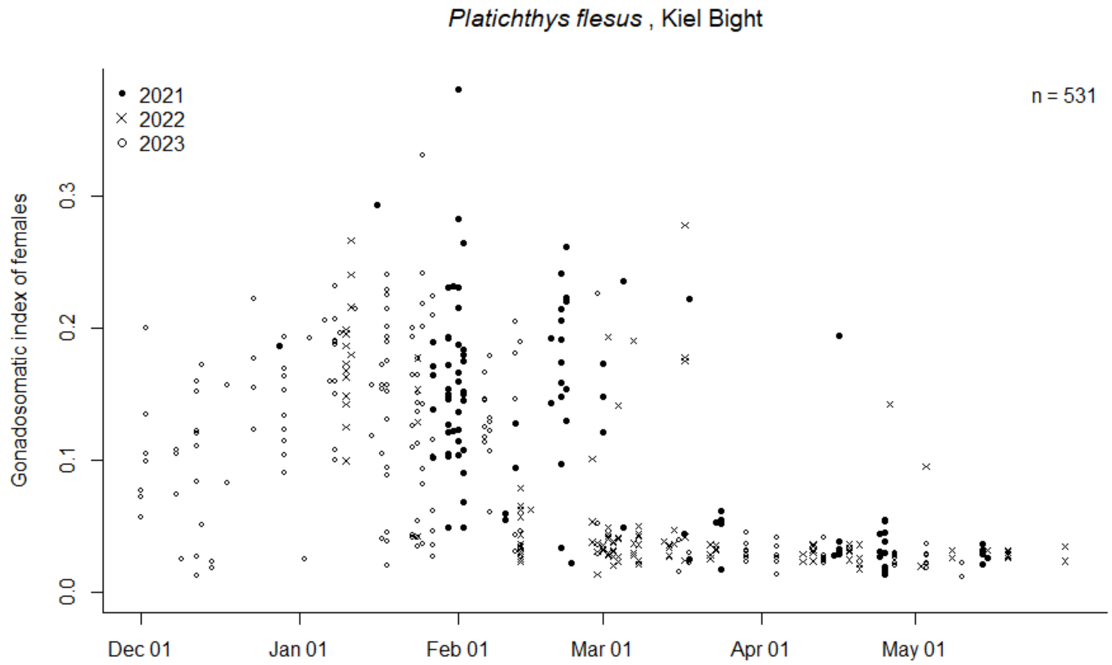


Figure 60. Timing of spawning as indicated by the gonadosomatic index of females in Kiel Bight, based on samples taken from December to May in 2021-2023 in commercial gill net fisheries. Note that no samples were taken in December-January 2022.

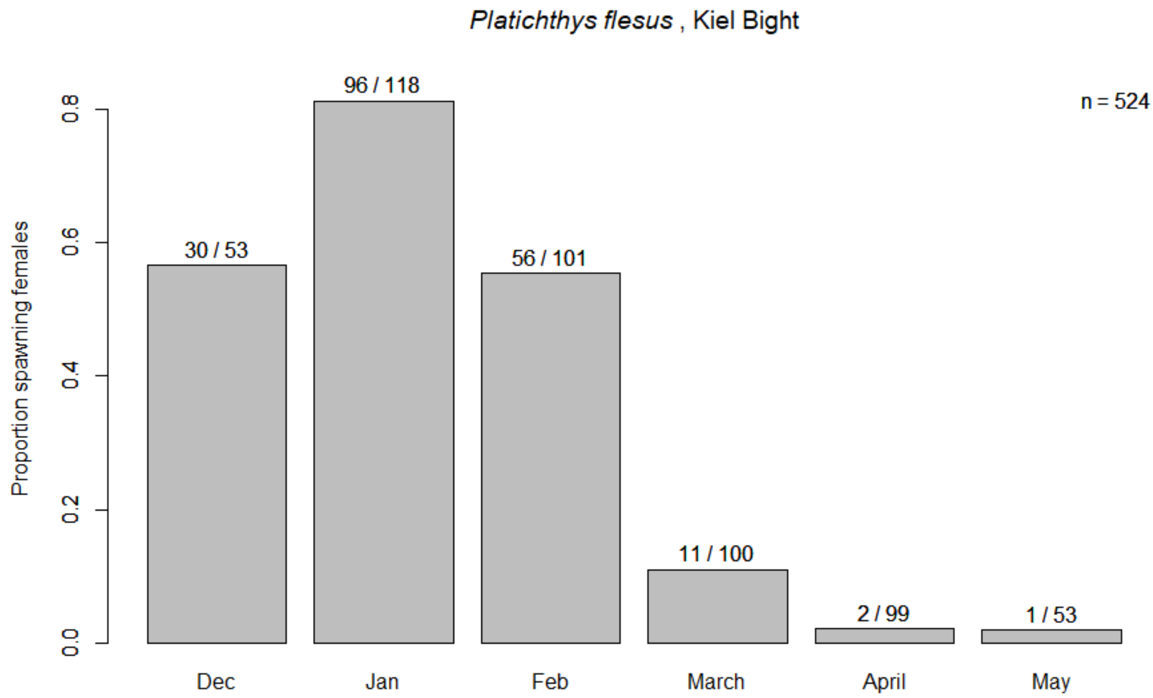


Figure 61. Proportion of actively spawning females by month, relative to the total number of females examined (numbers on top of bars), with a clear peak in January, based on samples taken from December to May in 2021-2023 in commercial gill net fisheries.

Diet composition: The fishers in Kiel Bight weighed stomachs and identified the most prominent food items for altogether 604 flounders (Table 7, Figure 62). Flounders clearly are benthic feeders, with the most common food item being small mussels (German: Muschelgrus, see Figure 63) reported from most non-empty stomachs.

Table 7. Frequency of occurrence of food items found in altogether 604 stomachs of which 256 (42%) contained food. Note that the sum of percentages in the last column exceeds 100 because stomachs can contain more than one food item. Food items are presented by functional groups. Main contributing groups are highlighted in orange and main contributing food items are highlighted in yellow.

Food I	**Food II**	**Names** (German, English)	**Scientific name**	**n**	**%**
zoobenthos					93.8
	worms				26.9
		Ringelwürmer, Seeringelwürmer, ragworms	*Hediste diversicolor*	26	10.1
		Wattwürmer, lugworms	*Arenicola marina*	14	5.5
		Würmer, worms		29	11.3
	mollusks				64.5
		Muscheln, mussels		165	64.5
	benthic crustaceans				2.4
		Garnelen, shrimp	*Palaemon sp.*	4	1.6
		Strandkrabben, green crab	*Carcinus maenas*	2	0.8
nekton					
	finfish				4.7
		Sandaal, sandeel		1	0.4
		Fische, Jungfische, unspecified fish		11	4.3

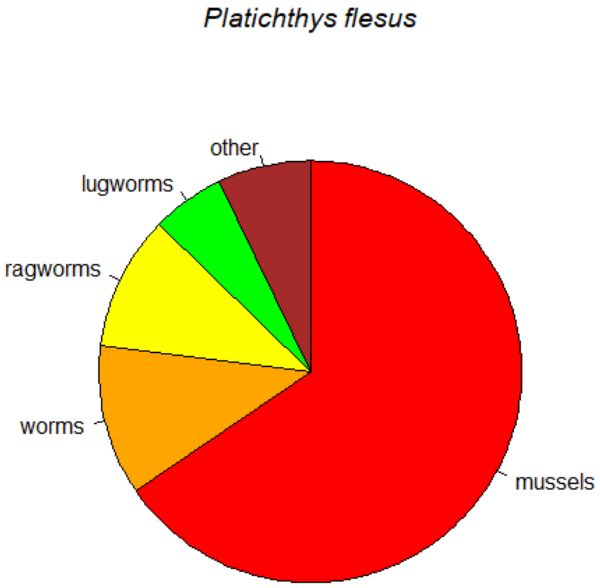


Figure 62. Six most frequently encountered food items in flounder stomachs, based on commercial catches from January to May 2021 to 2023 in Kiel Bight.

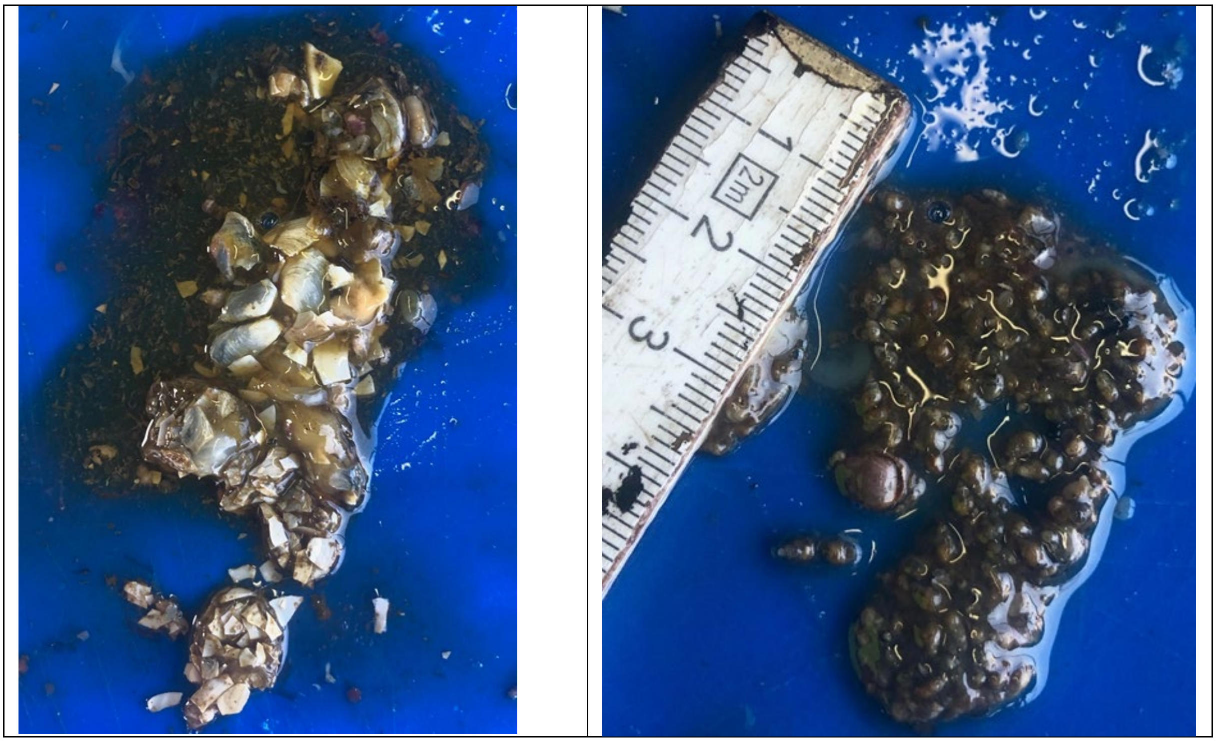


Figure 63. Mussels in flounder stomach, March 2021, Kiel Bight.

Note that most of the stomach analyses were done during the spawning season, confirming that at least female flounders feed during spawning intervals. This feeding is apparently not sufficient to increase condition, which shows a small decrease from January to May accounting for 2% of the observed variability, with condition here measured as body weight of females without ovaries and stomach weight relative to length cubed (Figure 64).

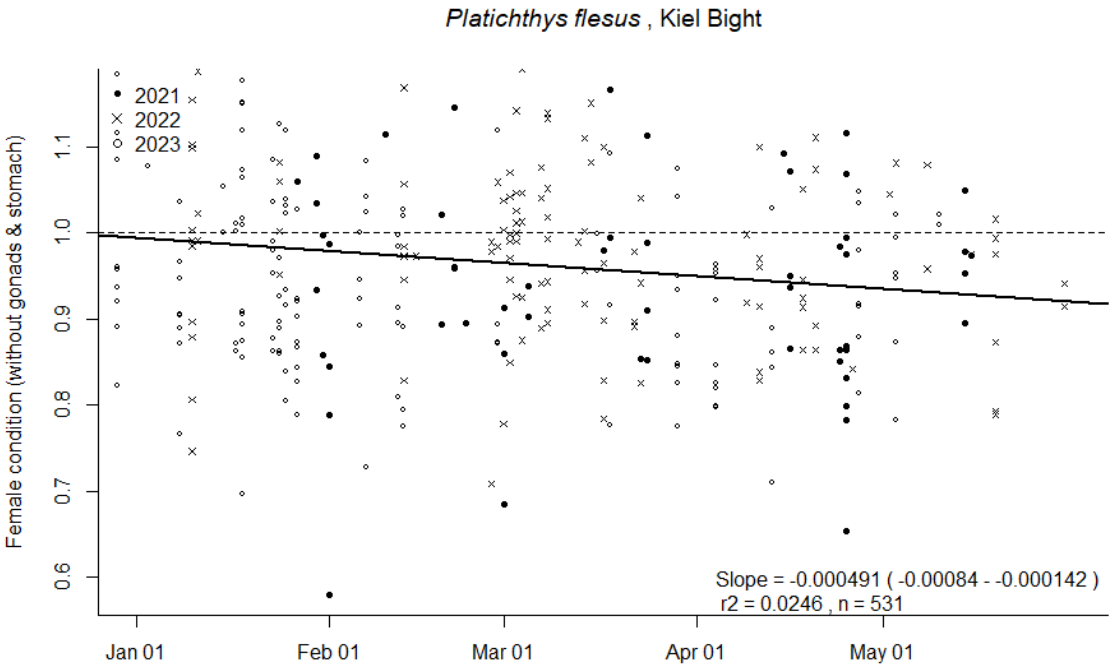


*Figure 64. Condition (C = 100 * W/L3) of females in Kiel Bight, based on samples taken from December to May in 2021-2023 in commercial gill net and trawl fisheries. Note that weight of stomach and gonads was excluded. The bold line suggests a weight decrease in muscles and bones during the spawning season, however it accounts for only 2% of the variability.*

Somatic growth: Thousands of flounders caught in standard scientific surveys have been aged for stock assessment purposes, however, the uncertainty of these age readings is very wide, suggesting e.g. that three year old flounders can be between 11 to 40 cm long (Figure 65). Fitting a growth curve to these length-at-age data strongly underestimates asymptotic length (L_{inf}) when compared with observed lengths. Instead, a more convincing growth curve was obtained by setting L_{inf} equal to the maximum observed length L_{max} = 53 cm (Table 8) and using the median length of one year old flounders according to DATRAS to anchor the growth curve (Figure 65).

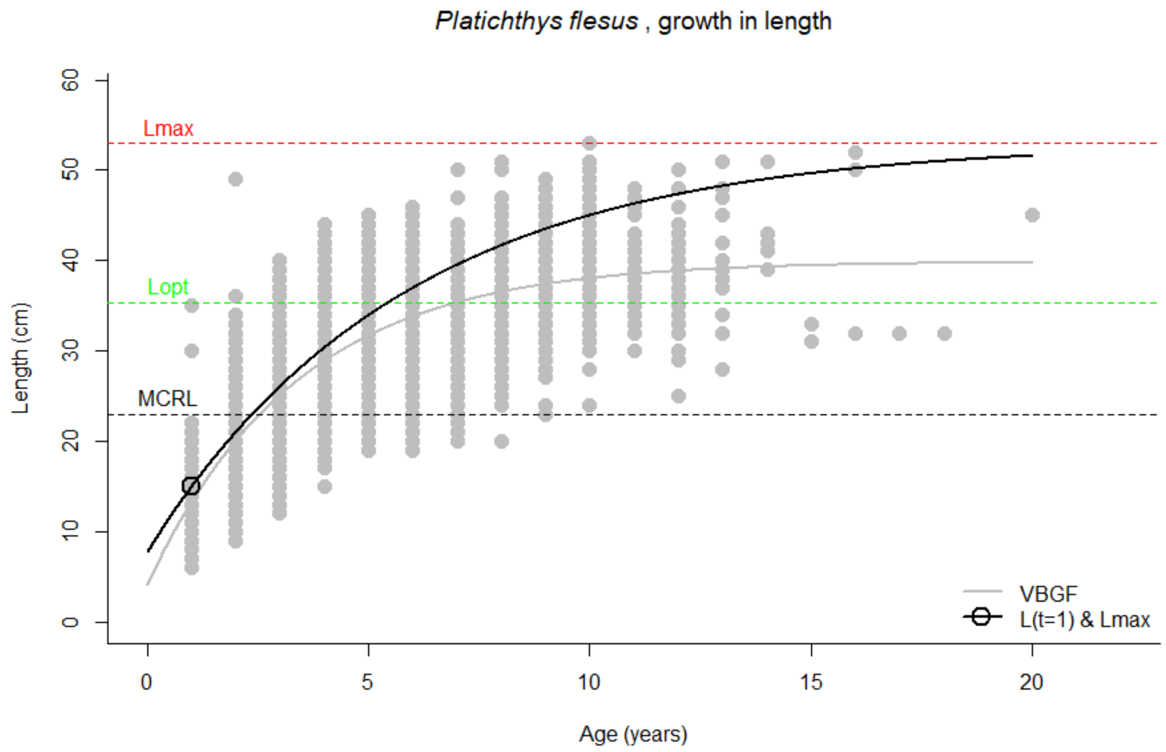


Figure 65. Growth in length based on DATRAS age readings from 2020-2022, first quarter, area 22 and 24. Note highly variable length-at-age readings in older fish and the underestimation of L_{max} by the fitted asymptotic length (L_{inf}), making the derived growth parameters doubtful. The black curve uses instead L_{max} as a proxy for L_{inf} and the most common length of one year old fish and a user-provided estimate of t_0, resulting in a more plausible growth curve (Froese 2022).

Fisheries management considerations: There is an optimal length (L_{opt}) for catching fish, where the increase in body weight has reached a maximum, and where most individuals have already reproduced 1-3 times. This is also the length where catches will be highest for a given effort or where for a given catch the least number of fish will be killed (Froese et al. 2016). A proxy for L_{opt} can be derived as 2/3 of maximum length (see Material and Methods), which for flounder in the western Baltic gives L_{opt} = 35.3 cm with an optimum length at first capture as L_{c_opt} = 29.7 cm (Table 8). The Minimum Conservation Reference Length (MCRL) for flounder in the Baltic Sea is 23 cm. These reference lengths can be used to determine the appropriateness of the selectivity of the most common fishing gears (gill nets and trawls) in the western Baltic and Kiel Bight.

Fishers in Kiel Bight use gill nets with mesh sizes from the legal minimum size of 55 mm up to voluntarily used 80 mm or more (all measured knot to knot). A comparison of the size selectivity of mesh sizes of 55, 70, 75 and 80 mm for flounder shows that the legal mesh size of 55 mm catches individuals below L_{c_opt}. Only the mesh sizes of 75 and 80 mm give a size distribution in the catch that includes L_{opt} within the length range that contains 50% of the caught fish (Figure 66).

The selectivity of commercial trawls with 110 to 120 mm stretched mesh size has a peak for catches of flounder well below L_{c_opt} and L_{opt} and also catches flounders below MCRL (Figure 67). Thus, the legal minimum mesh sizes for gill nets and trawls are too small and should be increased by about 50% to avoid capture of undersized and immature flounders and to approach the optimum length of capture.

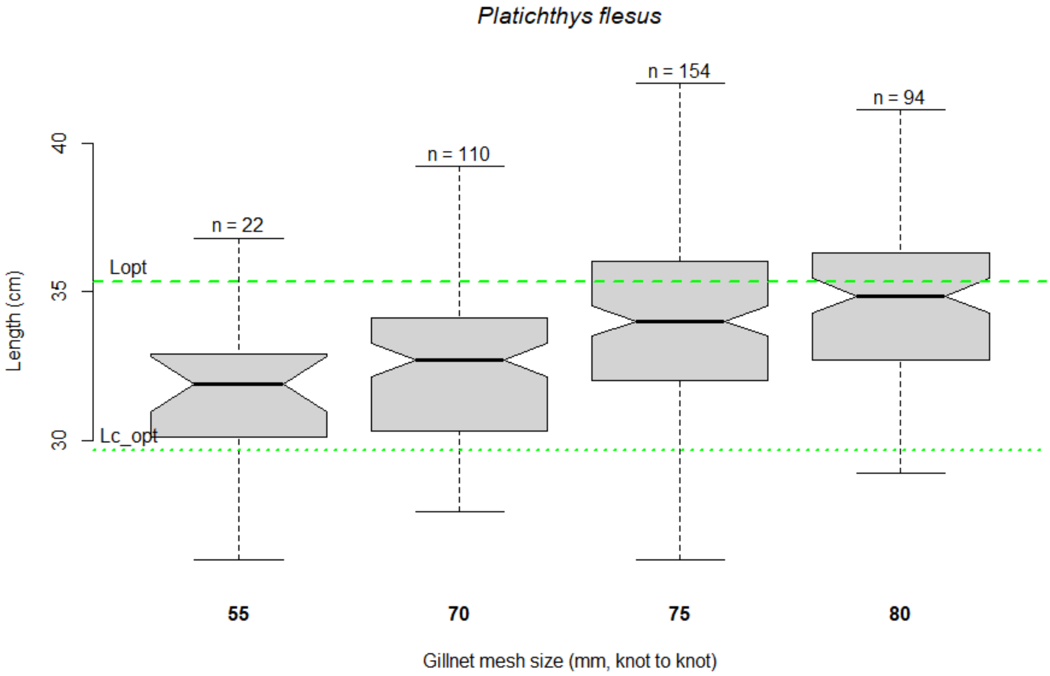


Figure 66. Length distribution in gill nets from 55 mm (knot to knot), which is the legal minimum mesh size, to 70 – 80 mm, which are preferred by fishers who do not want to catch juveniles. The dashed green horizontal line indicates the length L_{opt} at which the catch for a given fishing pressure is maximized and number of fish killed for the allowed catch in weight is minimized. The dotted green line indicates the optimal start length of selectivity. Data from commercial fishing in Kiel Bight, December to May 2020-2023.

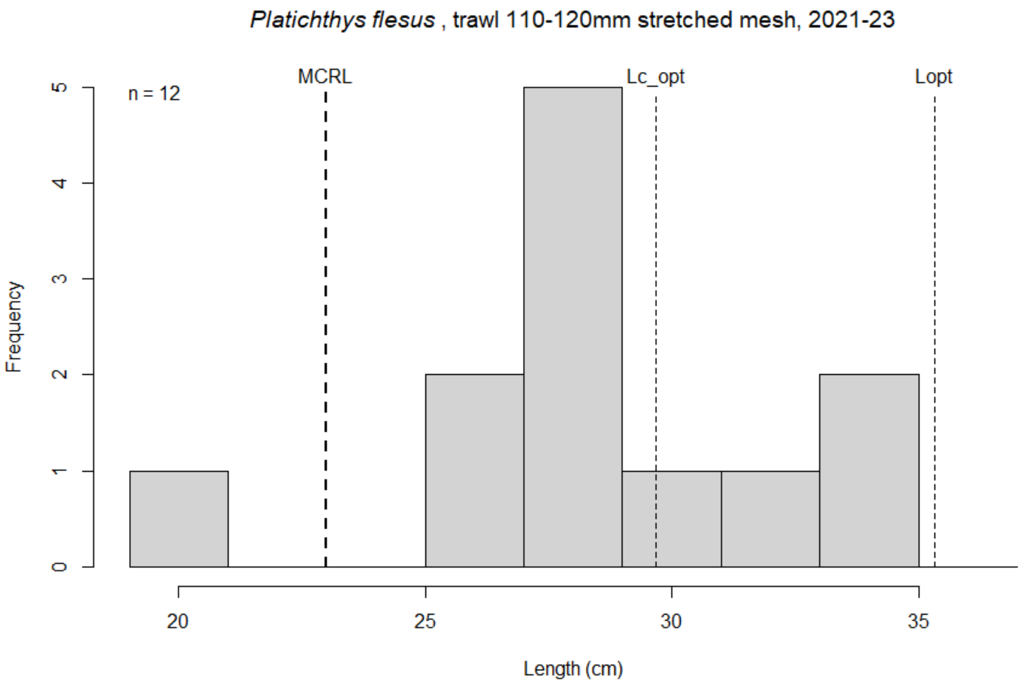


Figure 67. Selectivity of commercial trawl with 110 mm stretched mesh size, the legal minimum mesh size is 90 mm. Even this voluntarily enlarged mesh size is too narrow for flounder, with fish caught below the minimum conservation reference length (MCRL) and below the optimal start of selectivity (Lc_opt). If the suitable gill net mesh sizes of 75 and 80 mm (knot to knot) are taken as guidance, then about 150 – 160 mm stretched mesh size would have the correct selectivity for flounder, plaice and cod.

Another standard management measure is to protect fish from capture during the spawning season, in order to maximize reproductive output and the probability of successful recruitment. For flounder in the Baltic Sea, no such protection during the spawning season exists. Spawning flounders do also not benefit from the prohibition to catch cod with trawls below 20 m of water depth from February 1 to March 31 for vessels longer than 15 m. As can be seen from the data collected in Kiel Bight for this study (Figure 68), mature flounders regularly enter shallower waters during that period where they are subject to legally ongoing fishing. Thus, there is no protection of spawning flounders in the western Baltic Sea.

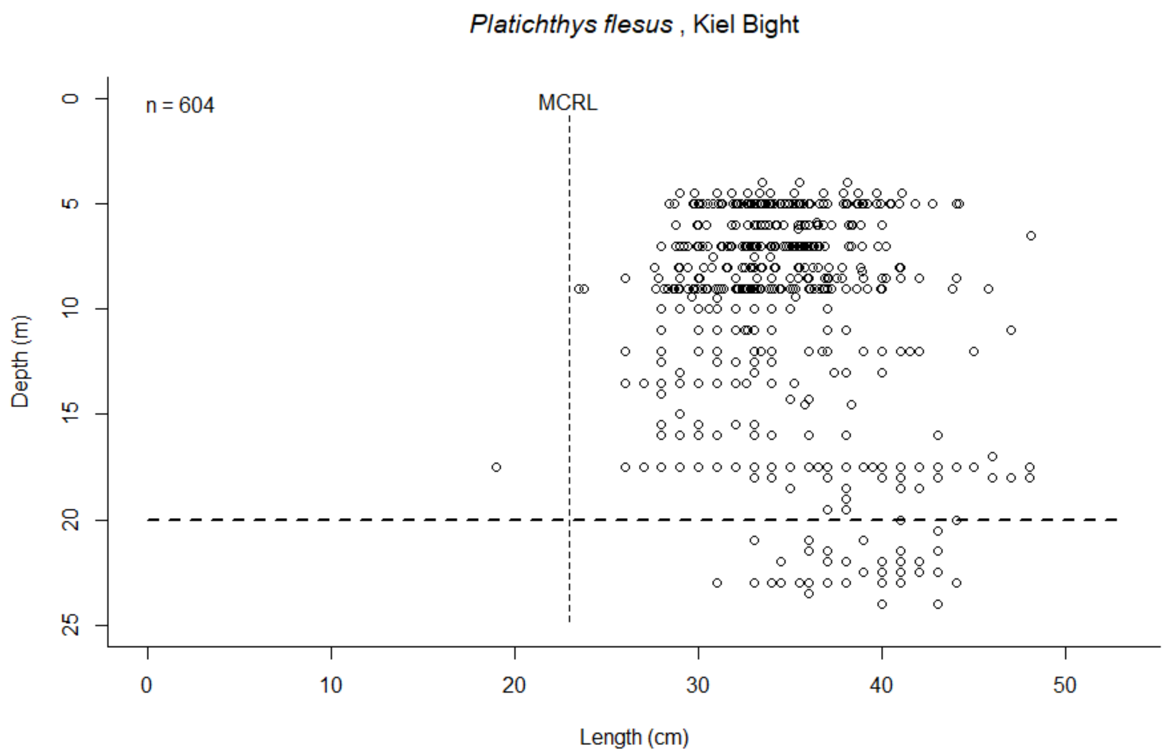


Figure 68. Length-distribution of flounder by depth of capture by commercial fishers from December to May 2021-2023 in Kiel Bight. Note that while fewer small individuals were caught below 20 m, large mature/spawning individuals occurred at all depths.

A summary of relevant reference points extracted from DATRAS for the western Baltic Sea or established in this study is presented in Table 8.

*Table 8. Key reference points for flounder (Platichthys flesus) derived from catches of commercial fishers in Kiel Bight, between December and May, and from scientific surveys as documented in DATRAS for areas 22 and 24, taken in the first quarter. Doubtful estimates are marked with **??***

Species	Flounder	*Platichthys flesus*				Pleuronectidae	
Parameter		estimate	LCL	UCL	n r^2	Unit	Method
Lmax KB	Maximum length	48.1				cm	largest on record
Lmax datras	Maximum length	53.0				cm	largest on record
Lmax	Maximum length	53				cm	chosen for study
a.f KB	W=**a**L^b, females	0.0445	0.0292	0.0679	n=515	g/cm^b	log-log regression
b.f KB	W=a$L^{\mathbf{b}}$, females	2.60	2.49	2.72	r^2=0.78		log-log regression
a.m KB	W=**a**L^b, males	0.101	0.0331	0.307	n=57	g/cm^b	log-log regression
b.m KB	W=a$L^{\mathbf{b}}$, males	2.35	2.03	2.67	r^2=0.797		log-log regression
a.c KB	W=**a**L^b, combined	0.0429	0.029	0.0635	n=601	g/cm^b	log-log regression
b.c KB	W=a$L^{\mathbf{b}}$, combined	2.61	2.5	2.72	r^2=0.791		log-log regression
Wmax KB	Maximum weight	1400				g	largest on record
Wmax DATRAS	Maximum weight	2114				g	largest on record
Wmax LWR	Maximum weight	1373				g	Wmax=a.c $Lmax^{b.c}$
Wmax	Maximum weight	1400				g	chosen for study
tmax DATRAS	Maximum age	20				years	largest on record
L_opt	Optimum length	35.3				cm	2/3 Lmax
Lc_opt	Optimum capture	29.7				cm	0.56 Lmax
Wopt	Optimum weight	476				g	a.c $Lopt^{b.c}$
Wc_opt	Optimum capture	302				g	a.c $Lopt^{b.c}$
MCRL	Minimum length	23				cm	EU law
Lm50 KB	50% mature fem.	30.3 **??**	29.7 **??**	30.8 **??**	n=529	cm	ogive
Lm90 KB	90% mature fem.	35.1 **??**	34.1 **??**	36.3 **??**		cm	ogive
Lm50 DATRAS	50% mature fem.	20.8	18.1	23.3	n=9977	cm	ogive, SMALK
Lm90 DATRAS	90% mature fem.	35.5 **??**	30.8 **??**	40.8 **??**		cm	ogive, SMALK
tm50 DATRAS	50% mature fem.	4				years	first age > 0.5 mature
tm90 DATRAS	90% mature fem.	7				years	first age > 0.9 mature
sex ratio KB	males / females	0.11 : 1			n=587		n (sex=m) / n (sex=f)
sex ratio DATRAS	males / females	0.72 : 1			n=19831		n (sex=m) / n (sex=f) Exchange 1991-2023
gsi.95 KB	Gonad/Body weight	0.241			n=407		95th percentile of GSI
gsi.slope KB	Gonad/Body slope	1.30	1.04	1.57	r^2=0.186		gonads ~ body weight
spawning season	peak, range	Jan	Dec	March	n=215	month	L>Lm90, mat > 10%
Linf DATRAS	Asymptotic length	39.9 **??**	39.4 **??**	40.3 **??**	n=1600	cm	VBGF fit
K DATRAS	Growth parameter	0.296 **??**	0.284 **??**	0.31 **??**		$year^{-1}$	VBGF fit
t0 DATRAS	Growth parameter	-0.35 **??**				years	VBGF fit
SE DATRAS	SE of residuals	3.97 **??**				cm	VBGF fit
Linf KB	Asymptotic length	53				cm	Linf=Lmax
K KB	Growth parameter	0.174				$year^{-1}$	from median L(t=1)
t0 KB	Growth parameter	-0.9				years	t0=t0.user

Dab (*Limanda limanda*)

Status: ICES recognizes one stock of dab (*Limanda limanda*) for the whole Baltic Sea (ICES-dab 2023), although there are probably numerous subpopulations adapted to the different salinity levels which are important for reproduction with pelagic eggs. The stock size indicator fluctuates around a high level since 2020, suggesting a healthy and stable stock size with regular recruitment in 2022, despite the impacts of climate change on the western Baltic Sea (Dutheil et al. 2022, Froese et al. 2022). This assessment is confirmed by catch-per-unit-of effort (CPUE) data from Kiel Bight (Figure 69).

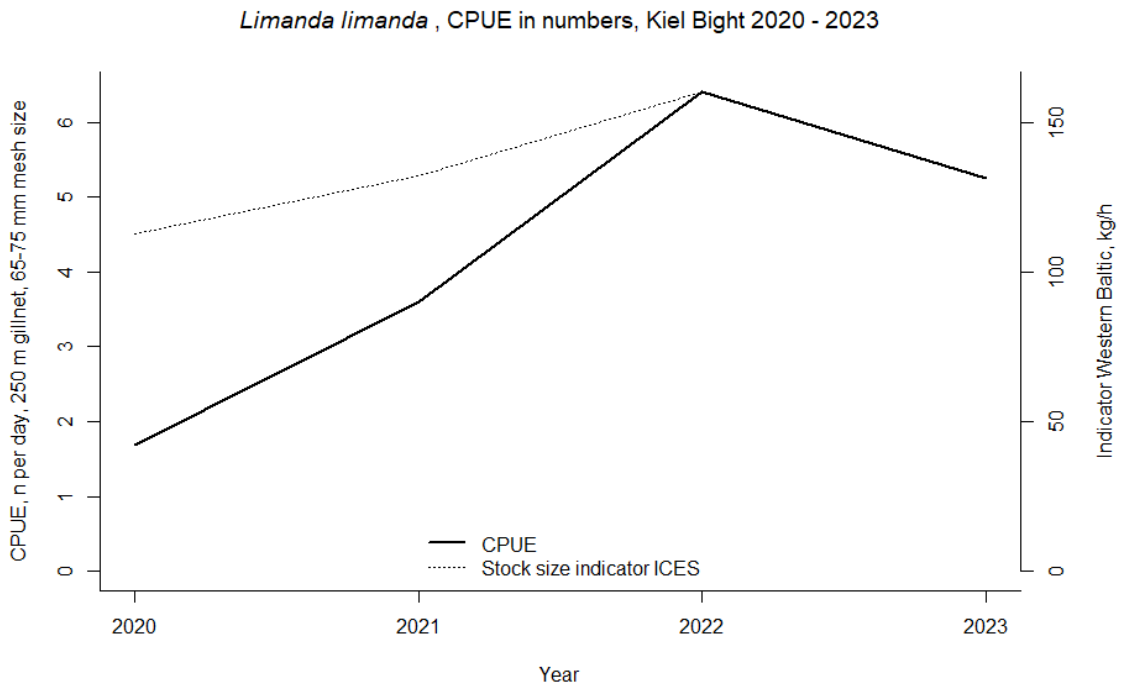


Figure 69. Average number of dab caught per day in Kiel Bight by commercial fishers with 250 m of gill nets with 70-75 mm mesh size (knot to knot), from December to May in 2019 – 2023 (bold curve). No stock size indicator data (kg/h) were available from ICES-dab (2023) for 2023.

Fishing pressure: A length-based indicator proposed by Froese and Sampang (2012) and adapted by ICES (ICES-dab 2023) suggests that dab are fished below the maximum sustainable level. This is confirmed by dab catches in 2022 being the lowest since 1970 (ICES-dab 2023, Fig. 1). Note that the dab stock is not managed by catch limits or any other measures.

Healthy age and size structure: A healthy age and size structure of commercial fish stocks is a requirement for good environmental status in the Marine Strategy Framework Directive (MSFD 2008) of the European Union. The maximum age of dab found in surveys in the western Baltic is 12 years (Table 9). Figure 70 shows the frequency distribution of a reasonably healthy stock, with all year classes present, albeit with a strong decline in numbers after being fully selected by fishing at 3 years of age. The decline is caused by past higher catches (before 2021, ICES-dab 2023) but is cushioned by a mean length of capture well above length at maturation (Figure 70, Figure 71, Figure 72 and see respective sections below).

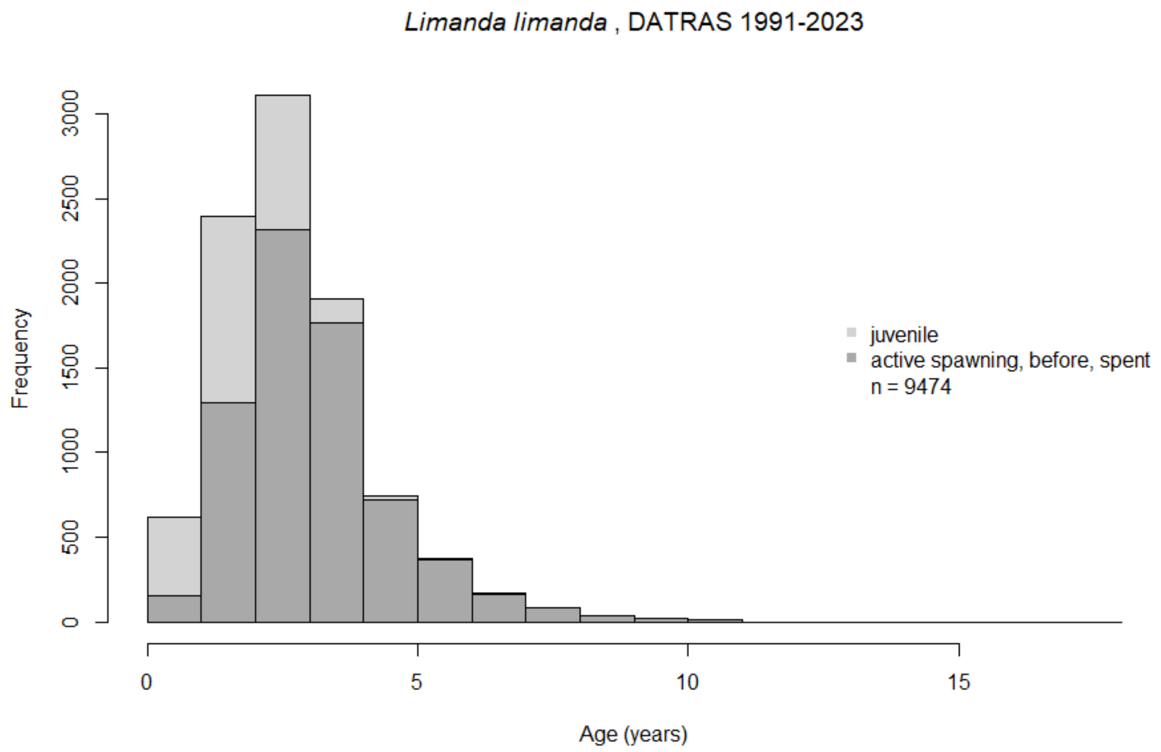


Figure 70. Age frequency of juveniles and adults based on the SMALK database (1st quarter, area 22 and 24). Note that only above age 3 more than 90% are mature. Also, maturity of one year old dab seems doubtful.

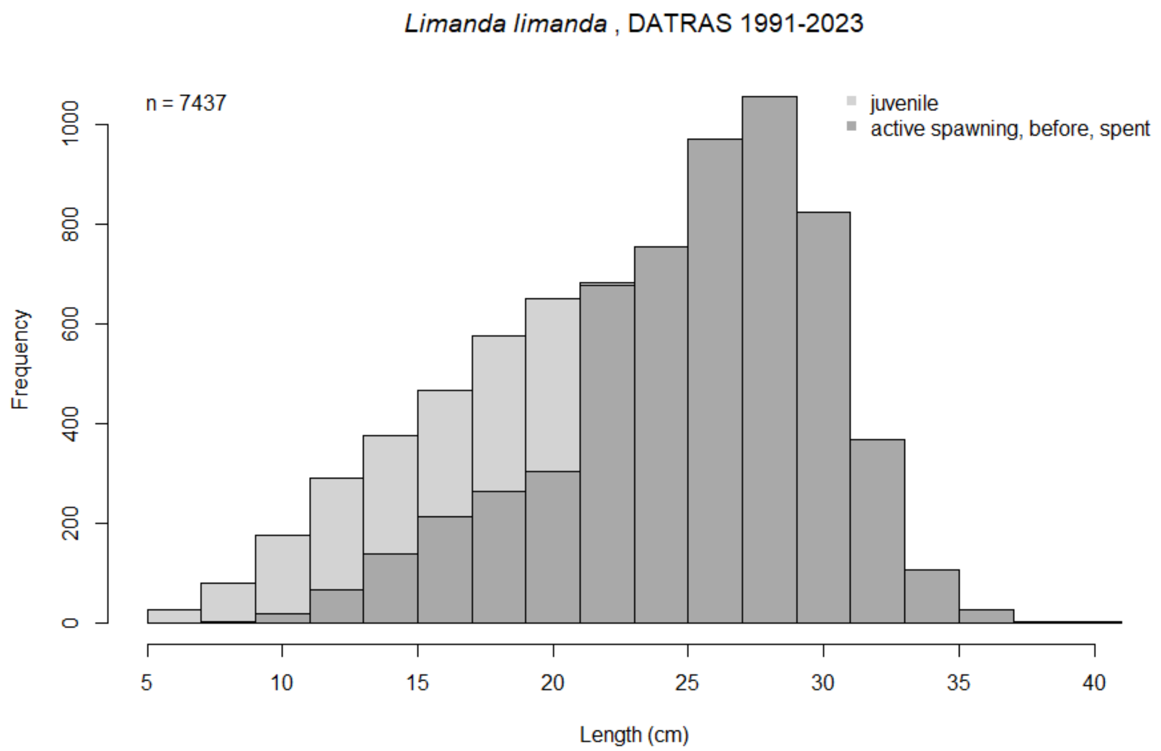


Figure 71. Length frequency of juveniles and adults based on the DATRAS database (1st quarter, area 22 and 24). Note that about 90% maturity of individuals is reached above 22 cm length. Full development of gonads and participation in spawning below 20 cm is doubtful (see Figure 75).

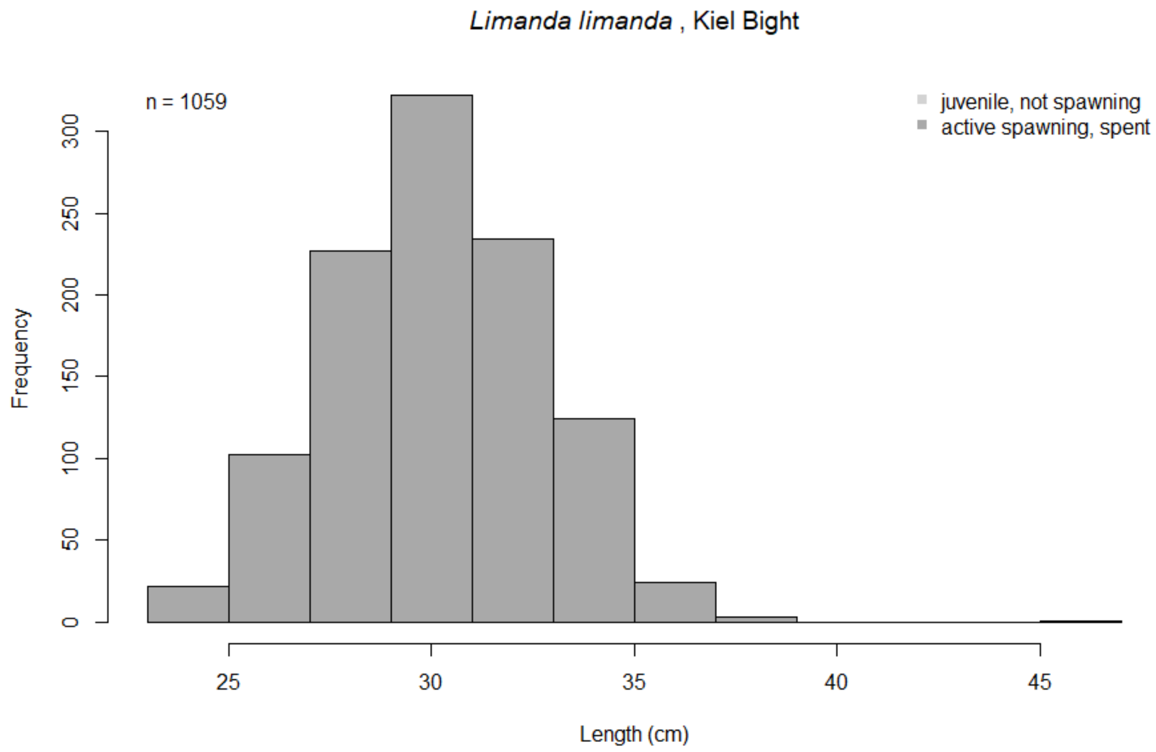


Figure 72. Length frequency of dab based on data from commercial fishers (2020-2023). Note that commercial fishers use larger mesh sizes to avoid capture of juvenile dab.

Length-weight relationship and condition: The parameters of the length-weight relationship (Table 9, Figure 73) describe flounder as an only slightly more roundish than fusiform species, indicated by *a* = 0.011 being close to the typical fusiform value of *a* = 0.01 (Froese 2006). Also, flounder do not change their body shape or proportions as they grow through late juvenile and adult life stages, indicated by *b* = 3.0 (Froese 2006). Much but not all of the variability in the data is accounted for by the coefficient of determination (r^2 = 0.77, Table 9) of the log-log linear relation between body weight and length, with the decrease in condition (see next paragraph) possibly playing an additional role. There is only one outlying specimen (erroneous measurements or starving) which was excluded from this and other analyses.

Median body weight for a given length (condition) dropped from 1.17 to 1.04 (13%) in catches from Kiel Bight from 2020 to 2023 (Figure 74), confirming reports from fishers that dab and commercial fish in general were getting thinner. A comparison with DATRAS survey data for the western Baltic confirmed this observation, showing a decline from 1.14 in 2010 to 1.04 in 2023 (Figure 75).

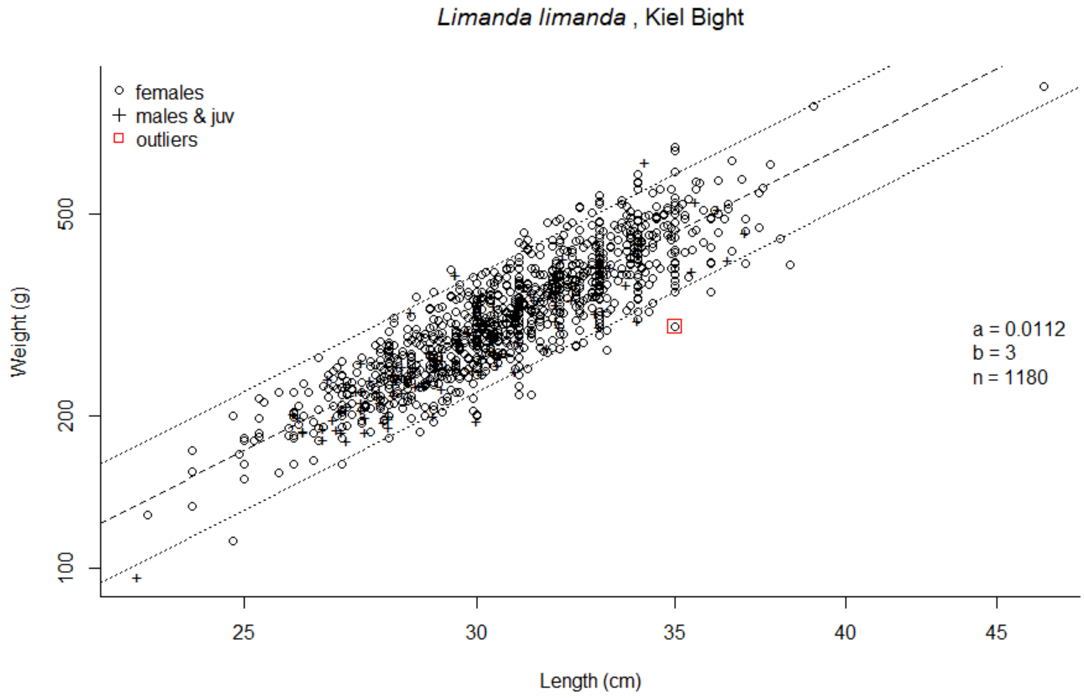


Figure 73. Length-weight relationship for dab (Limanda limanda) in Kiel Bight, based on samples taken from December to May in 2020-2023 in commercial gill net and trawl fisheries. The dashed line indicates the overall fit and the dotted lines indicated the 95% confidence limits.

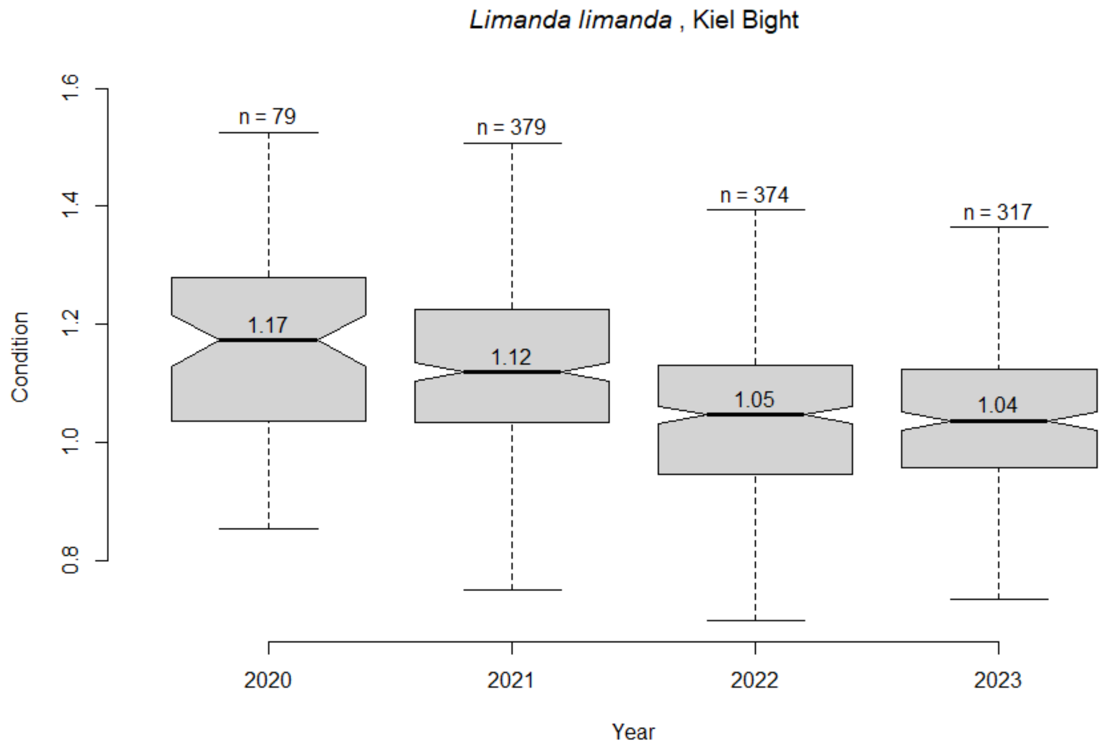


Figure 74. Comparison of Condition C = 100 Weight/Length^3 from 2020 to 2023, based on commercial catches from January to May in Kiel Bight. Note clear decline in condition, with lowest values in 2023.*

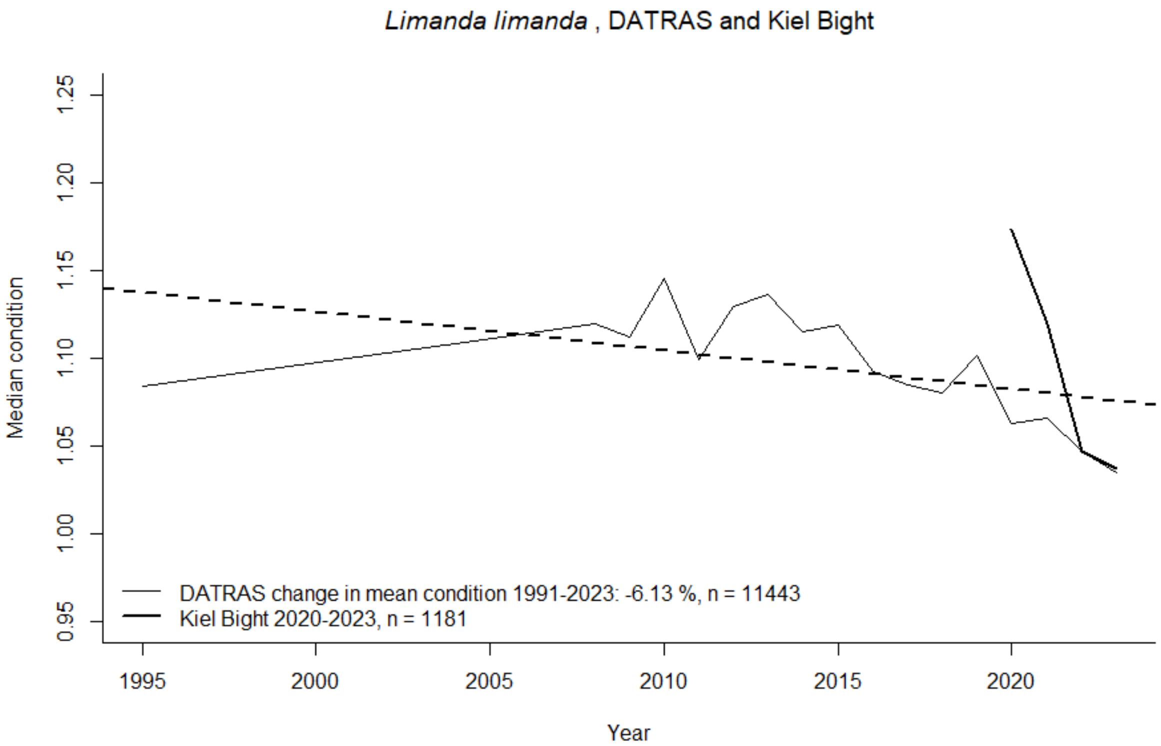


Figure 75. Change in median condition based on DATRAS (black curve, 1st quarter, area 22 and 24) and 2020-2023 data from commercial fishers in Kiel Bight (bold curve).

Length and age at maturation: The size and age where 50% or 90% of female dab have reached sexual maturity and participate in spawning is L_{m50} = 16.2 cm and L_{m90} = 23.2 cm (Figure 76, Table 9), at ages 2 and 4 (Figure 70, Table 9), based on survey data. An ogive curve fitted to data derived in this study suggests L_{m50} = 13.9 cm (Figure 77), which however is unreliable because fishers in Kiel Bight used larger mesh sizes to avoid capture of small dab, cod, plaice and flounders (Figure 35), which leads to a lack of dab around the size of maturation (Figure 72).

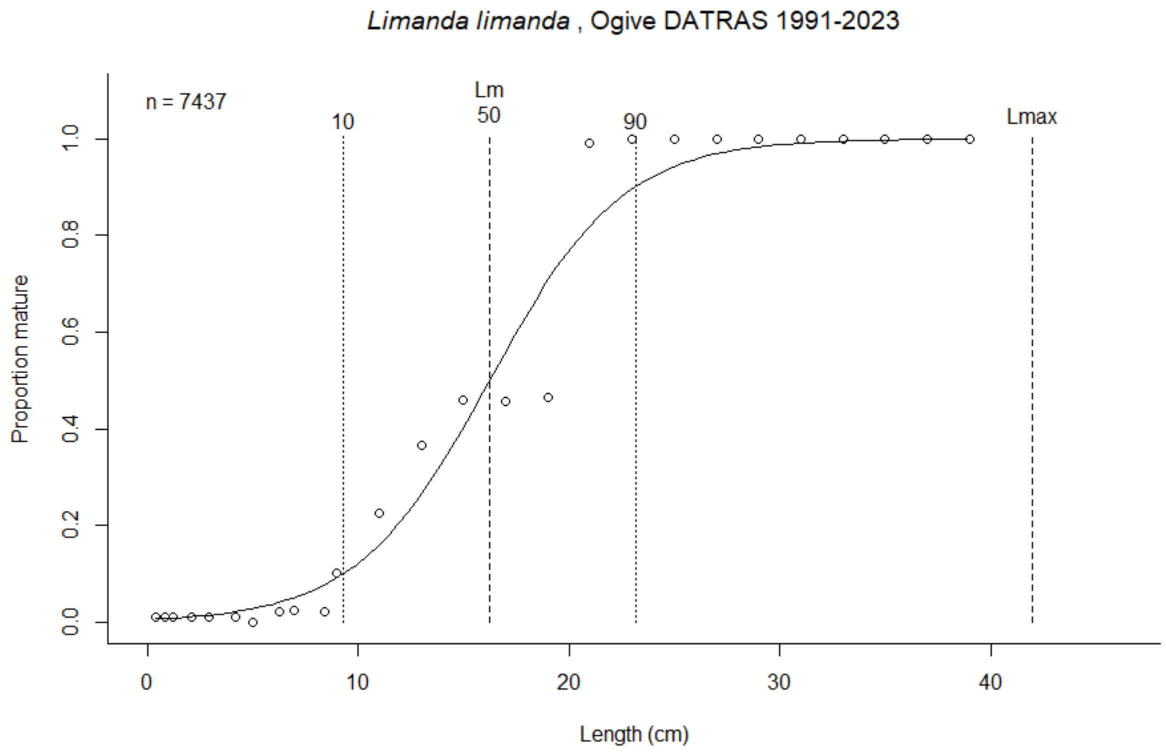


Figure 76. Proportion of mature females based on DATRAS (1st quarter, area 22 and 24). There is some doubt that females below 15 cm length would really fully develop their ovaries and participated in spawning (see Figure 75).

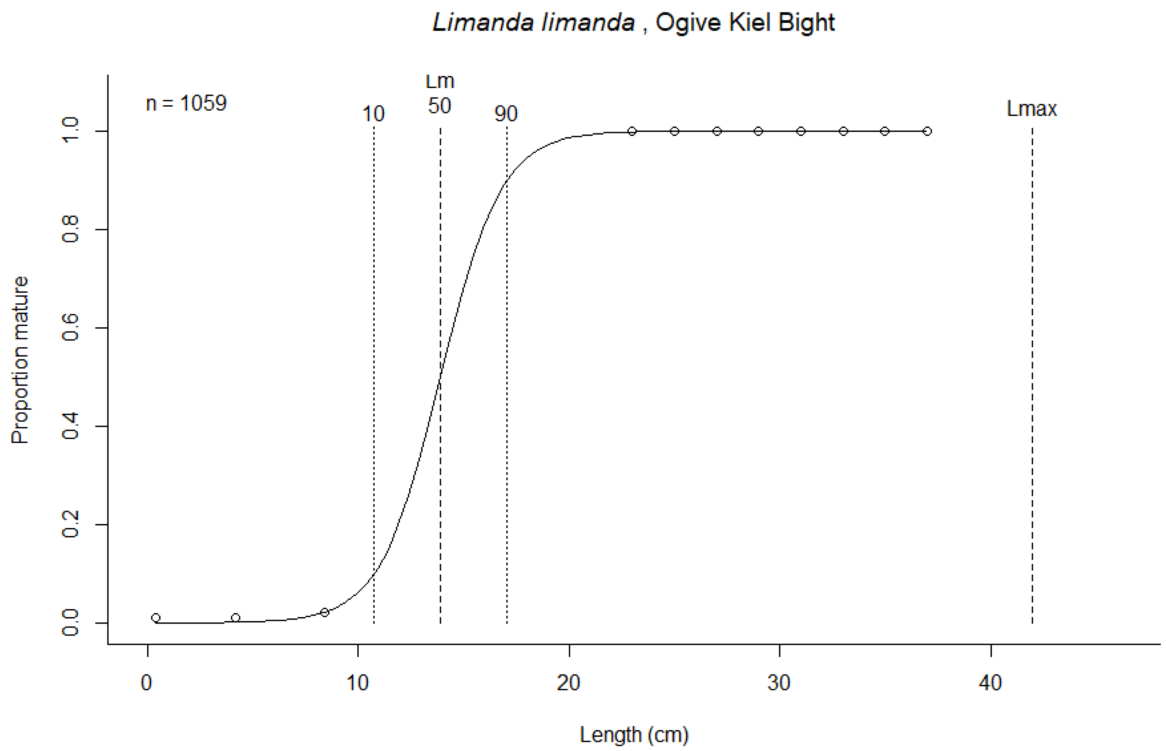


Figure 77. Proportion of mature females based on data from commercial fishers in Kiel Bight (2021-2023). Note that commercial fishers avoid capture of juvenile dab, i.e., L_m is not supported by data and should not be used.

Fecundity as a function of body weight: The base assumption of the relation between fecundity and body weight is that the number of eggs of a female or the maximum weight of the gonads grows about proportionally with body weight. Overall, the fully developed ovaries of dab females examined in Kiel Bight took up about 17% of total body weight (Table 9, Figure 78). The available data on relative weight of ovaries (gonado-somatic index) collected in this study suggest that the increase in dab fecundity was considerably higher (slope = 1.98) than predicted by a directly proportional increase in body weight (Table 9, Figure 79).

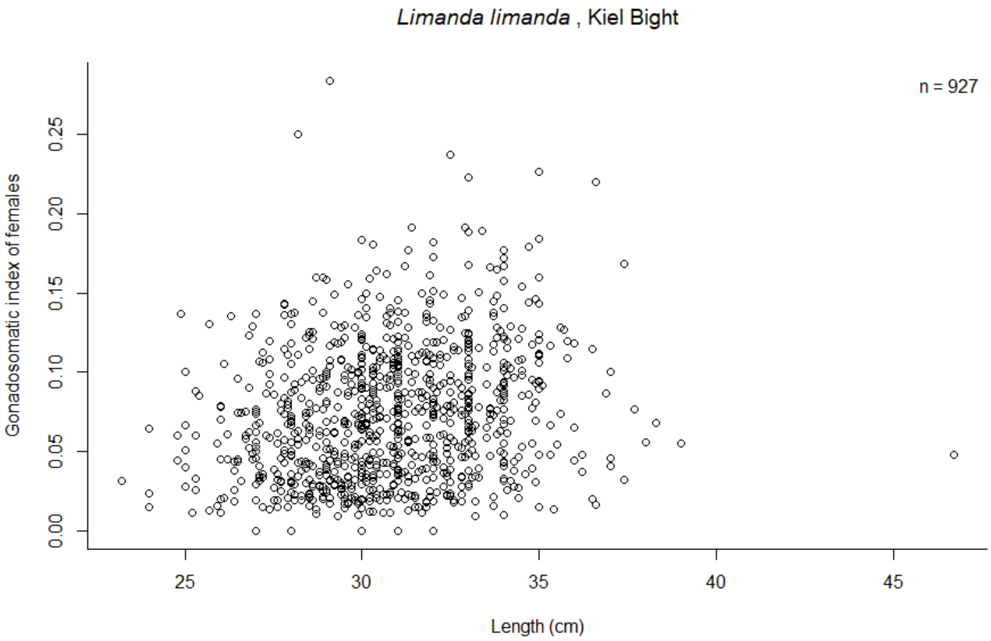


Figure 78. Relative weight of ovaries (GSI) plotted over body length of females in Kiel Bight, 2021-2023.Note that the participating fishers did not catch small dab, so the length of maturation cannot be derived from these data.

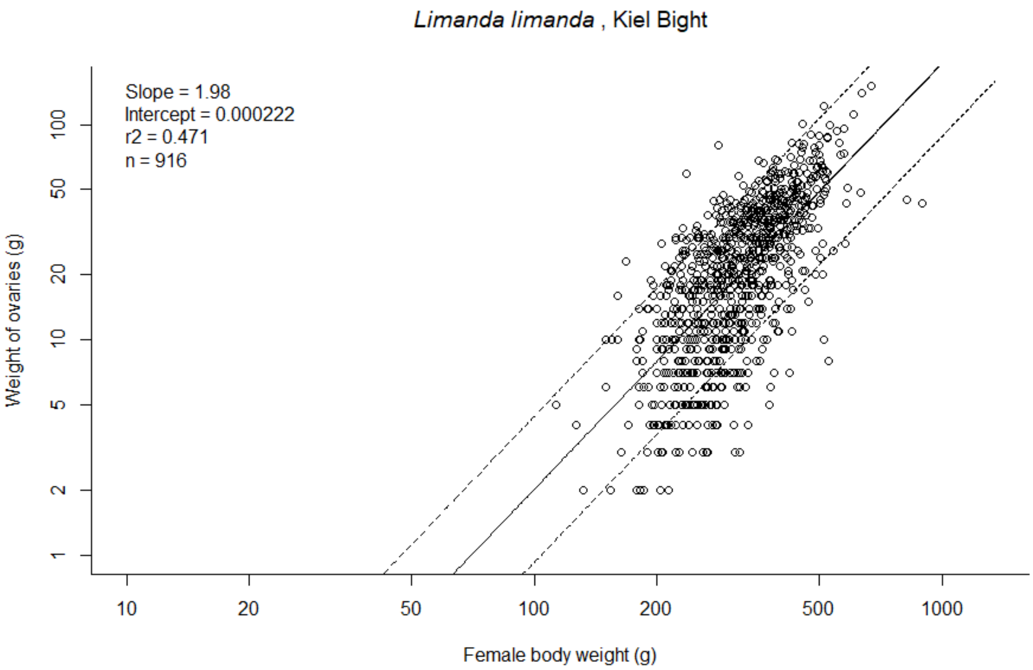


Figure 79. Weight of ovaries in different stages over body weight based on data from commercial fishers in Kiel Bight (2021-2023). Note that the slope > 1 suggests that the weight of ovaries and thus fecundity increase faster than body weight.

Sex ratio: Whereas the male/female sex ratio of dab fluctuated around 0.6:1 in survey data taken from throughout the western Baltic Sea, there were only very few male dab present in the shallow waters of Kiel Bight during the spawning seasons of 2020-2023 (Table 9, Figure 80). Female dab are determinate spawners where the number of eggs in the ovary is fixed before the onset of spawning (Murua & Saborido-Rey 2003). Similar as for cod, plaice, and flounder, a working hypothesis for the strongly distorted sex ratio of dab in shallow waters is that male dab stay in the spawning grounds in deeper water whereas female dab visit shallow water for feeding (and maybe relief from pursuing males) between batch spawning events.

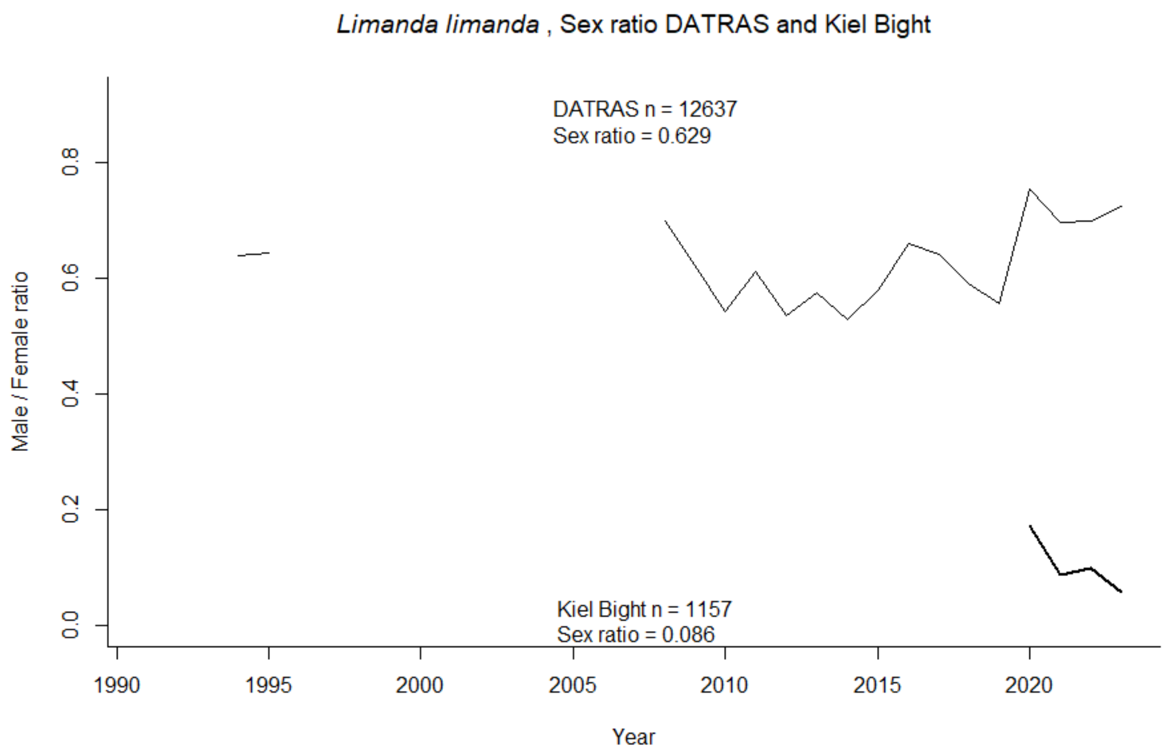


Figure 80. Time series of sex ratios observed in the western Baltic based on DATRAS Exchange (1st Quarter, areas 22 and 24, upper curve) and in Kiel Bight, January to May 2021-2023 (lower bold curve). Apparently male dab rarely enter the shallow waters of the southern Kiel Bight during the spring spawning season.

Spawning season: Relative size of ovaries was used to determine the spawning season of dab in 2021-2023 as from January to May and maybe even to June (no data were available for June), with a peak in March (Figure 81, Figure 82). This is about two months earlier than the traditional spawning season indicated as from April to June for the North Sea and from April to August for the Baltic Sea (Muus and Nielsen 1999).

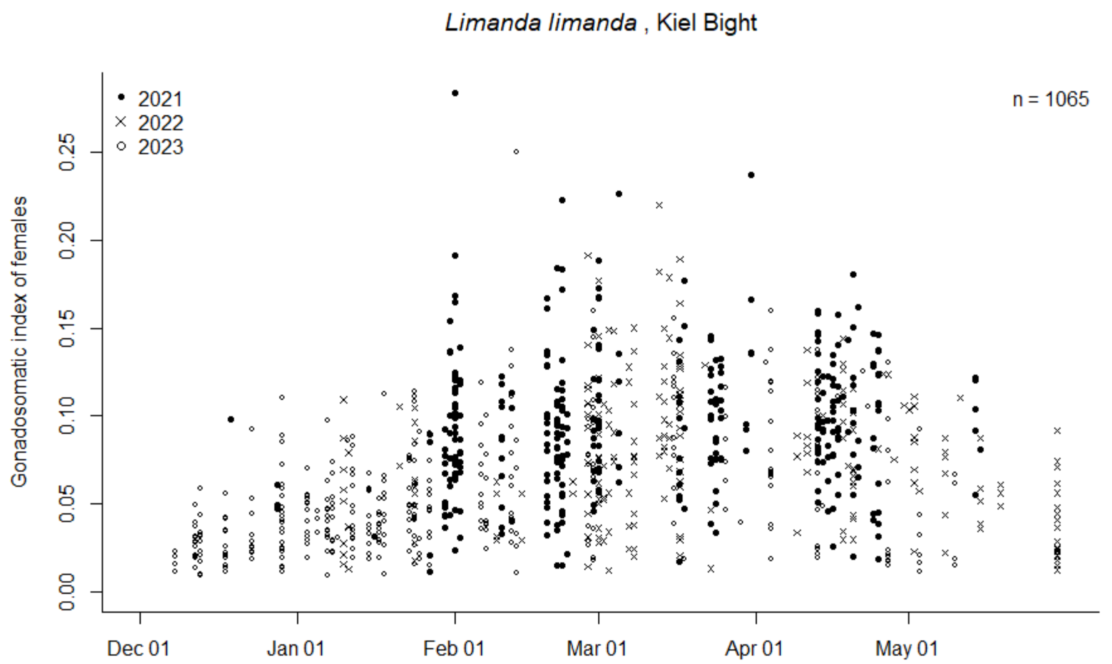


Figure 81. Timing of spawning as indicated by the gonadosomatic index of females in Kiel Bight, based on samples taken from December to May in 2021-2023 in commercial gill net fisheries. Note that no samples were taken in December 2022.

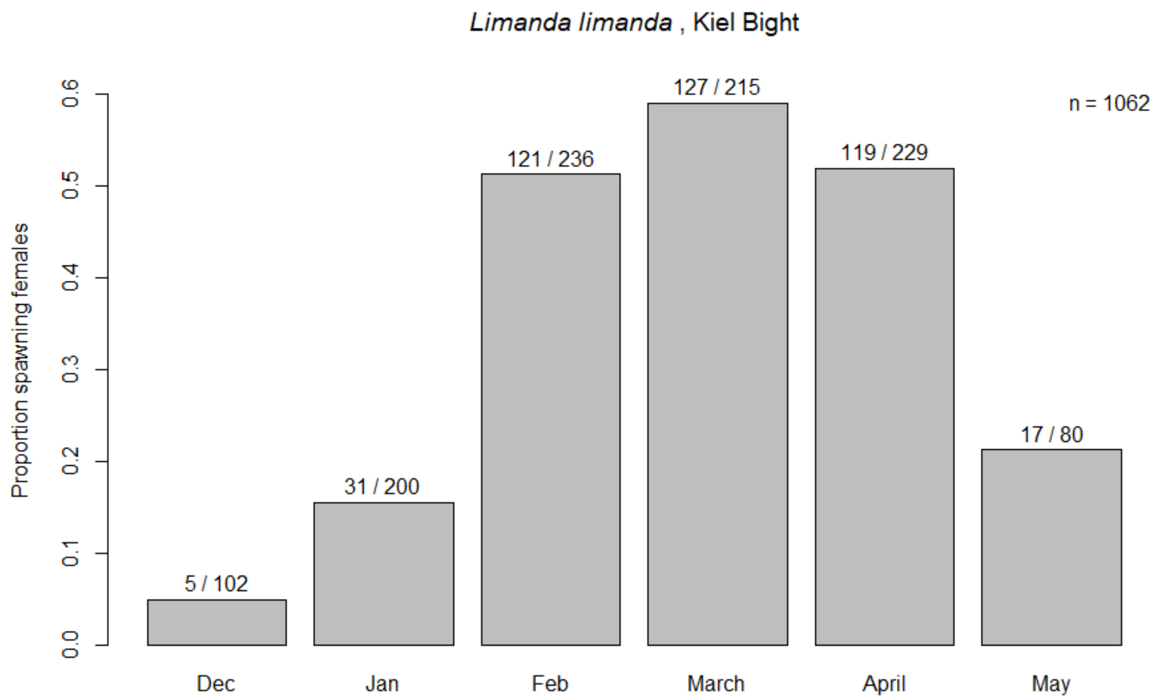


Figure 82. Proportion of spawning females by month, based on samples taken from December to May in 2021-2023 in commercial gill net fisheries. Spawning occurs from January to May with an extended peak in February to March.

Diet composition: The fishers in Kiel Bight weighed stomachs and identified the most prominent food items for altogether 1181 dab (Table 9, Figure 83). Dab are mostly benthic feeders, with the most common food item being small mussels and snails (Figure 84), followed by worms and, somewhat surprising for the small species, green crabs and a variety of small fish.

Table 9. Frequency of occurrence of food items found in altogether 1181 stomachs of which 717 (61%) contained food. Note that the sum of percentages in the last column exceeds 100 because stomachs can contain more than one food item. Food items are presented by functional groups. Main contributing groups are highlighted in orange and main contributing food items are highlighted in yellow.

Food I	**Food II**	**Names** (German, English)	**Scientific name**	**n**	**%**
zoobenthos					87.9
	worms				30.4
		Ringelwürmer, Seeringelwürmer, ragworms	*Hediste diversicolor*	122	17.0
		Wattwürmer, lugworms	*Arenicola marina*	53	7.4
		Würmer, worms		43	6.0
	mollusks				42.0
		Muscheln, mussels		299	41.7
		Schnecken, snails		2	0.3
	benthic crustaceans				15.3
		Flohkrebse, amphipods	*Gammarus sp.*		
		Garnelen, shrimp	*Palaemon sp.*	14	2.0
		Strandkrabben, green crab	*Carcinus maenas*	91	12.7
		Krebse, crustaceans		4	0.6
	echinoderms				0.2
		Schlangenstern, brittle star		1	0.1
		Seestern, starfish		1	0.1
zooplankton					1.3
	jellyfish				0.6
		Qualle, jellyfish	*Aurelia aurita*	4	0.6
	fish eggs/larvae				0.7
		Fischlaich, Fischrogen, Rogen, roe		5	0.7
nekton					12.5
	finfish				12.5
		Aalmutter, eelpout	*Zoarces viviparus*	1	0.1
		Butterfish, rock gunnel	*Pholis gunnelus*	1	0.1
		Grundel, gobies	*Gobius niger, Neogobius melanostomus, Aphia minuta*	1	0.1
		Hering, herring	*Clupea harengus*	3	0.5
		Neunauge, lamprey		2	0.3
		Sandaal, sandeel	*Ammodytes sp.*	3	0.5
		Sardelle, anchovy	*Engraulis encrasicolus*	5	0.7
		Sprotte, sprat	*Sprattus sprattus*	1	0.1
		Plattfisch, flatfish		2	0.3
		Fische, Jungfische, unspecified fish		70	9.8

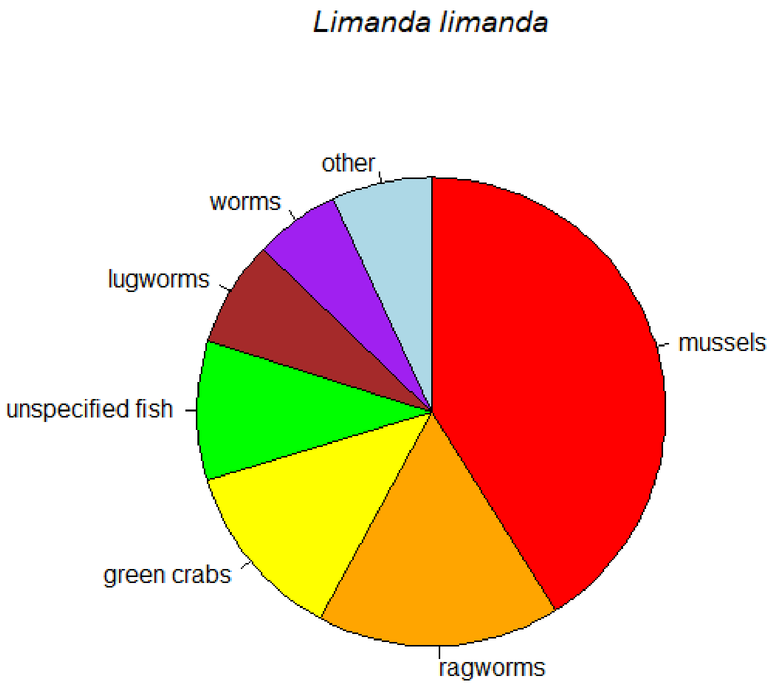


Figure 83. Seven most frequently encountered food items in stomachs, based on commercial catches from January to May 2021 to 2023 in Kiel Bight.

Figure 84. Snail shells in dab stomach, April 2021, Kiel Bight.

Note that most of the stomach analyses were done during the spawning season, confirming that at least female dab feed during spawning intervals. This feeding is apparently not sufficient to increase condition (slope of linear fit includes zero in its confidence limits), with condition here measured as body weight of females without ovaries and stomach weight relative to length cubed (Figure 85).

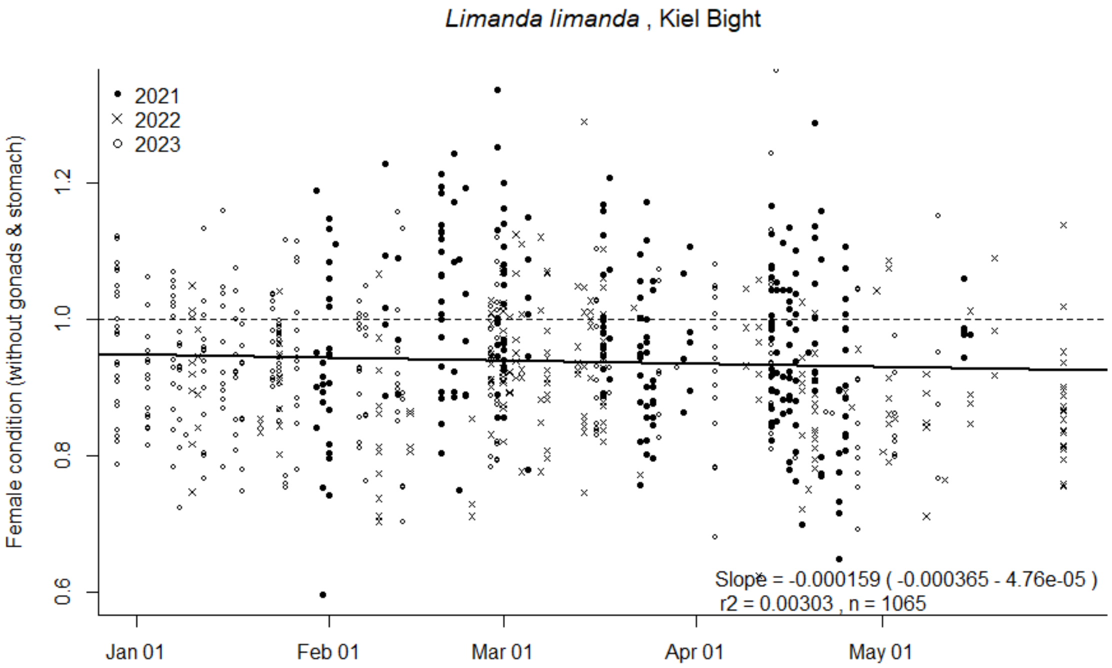


*Figure 85. Condition (C = 100 * W/L3) of females in Kiel Bight, based on samples taken from December to May in 2021-2023 in commercial gill net and trawl fisheries. Note that weight of stomach and gonads was excluded, i.e., the bold line shows the weight of muscles and bones. There is a high scatter in the data and the regression accounts for less than 1% of the variability.*

Somatic growth: Thousands of dab are caught annually in standard scientific surveys and have been aged for stock assessment purposes. However, the uncertainty of these age readings is very wide, suggesting e.g. that two year old dab can be between 6 to 33 cm long (Figure 86). Fitting a growth curve to these length-at-age data strongly underestimates asymptotic length (L_{inf}) when compared with observed lengths. Instead, a more convincing growth curve was obtained by setting L_{inf} equal to the maximum observed length L_{max} = 42 cm and using the median length of one year old flounders according to DATRAS to anchor the growth curve (Table 10, Figure 86) (Froese 2022).

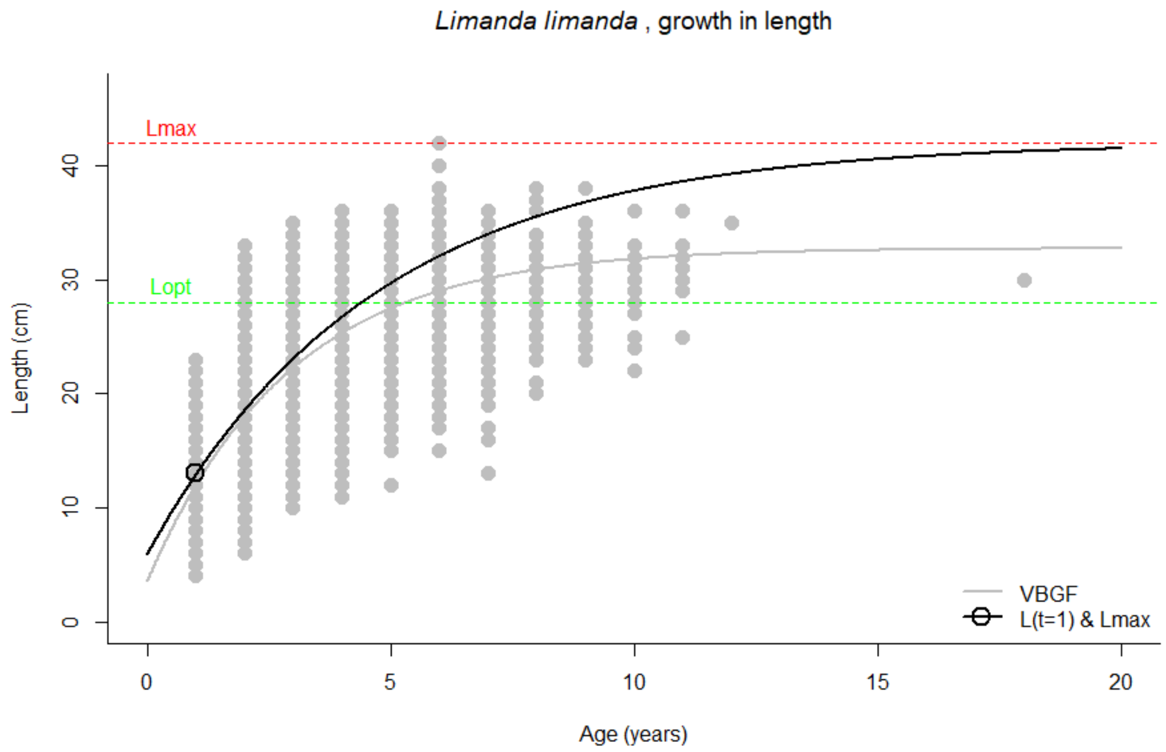


Figure 86. Growth in length based on DATRAS age readings from 2020-2022, first quarter, area 22 and 24. Note highly variable length-at-age readings in older fish and the underestimation of L_{max} by the fitted asymptotic length (L_{inf}), making the derived growth parameters doubtful. The black curve uses instead L_{max} as a proxy for L_{inf} and the most common length of one year old fish and a user-provided estimate of t_0, resulting in a more plausible growth curve (Froese 2022).

Fisheries management considerations: There is an optimal length (L_{opt}) for catching fish, where the increase in body weight has reached a maximum, and where most individuals have already reproduced 1-3 times. This is also the length where catches will be highest for a given effort or where for a given catch the least number of fish will be killed (Froese et al. 2016). A proxy for L_{opt} can be derived as 2/3 of maximum length (see Material and Methods), which for dab in the western Baltic gives L_{opt} = 28 cm with an optimum length at first capture as L_{c_opt} = 23.5 cm (Table 10). There is no Minimum Conservation Reference Length (MCRL) for flounder in the Baltic Sea. L_{opt} and L_{c_opt} were used to determine the appropriateness of the selectivity of common gill nets in the western Baltic and Kiel Bight.

Fishers in Kiel Bight use gill nets with mesh sizes from the legal minimum size of 55 mm up to voluntarily used 80 mm or more (all measured knot to knot). A comparison of the size selectivity of mesh sizes of 55, 70, 75 and 80 mm for dab shows that all mesh sizes catch individuals above L_{c_opt} with a median length above L_{opt}. In other words, even the small legal mesh size of 55 mm is sufficiently large for this small species, while mesh sizes of 75 and 80 mm catch only large dab which may be easier to market alongside flounder and plaice.

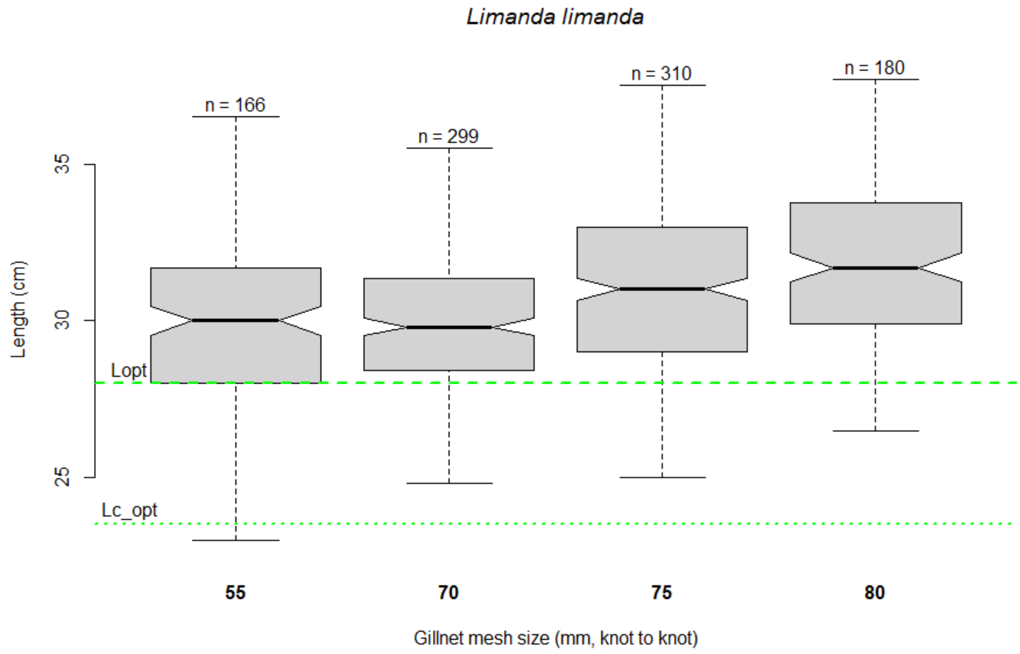


Figure 87. Boxplot of length distribution in gill nets from 55 mm (knot to knot), which is the legal minimum mesh size, to 70 – 80 mm, which are preferred by fishers who do not want to catch juveniles. The upper green horizontal line indicates the length L_{opt} at which the catch for a given fishing pressure is maximized and number of fish killed for the allowed catch in weight is minimized. The lower green line is the optimum length at first capture. Note that dab is smaller than the target species (cod, plaice, flounder) and benefits from these larger mesh sizes. Data from commercial fishing in Kiel Bight, December to May 2020-2023.

Another standard management measure is to protect fish from capture during the spawning season, in order to maximize reproductive output and the probability of successful recruitment. For dab in the Baltic Sea, no such protection during the spawning season exists. Spawning dab do also not benefit from the prohibition to catch cod with trawls below 20 m of water depth from February 1 to March 31 for vessels longer than 15 m. As can be seen from the data collected in Kiel Bight for this study (Figure 88), mature dab regularly occur in shallower water during that period where they are subject to legally ongoing fishing. Thus, there is no protection of spawning dab in the western Baltic Sea.

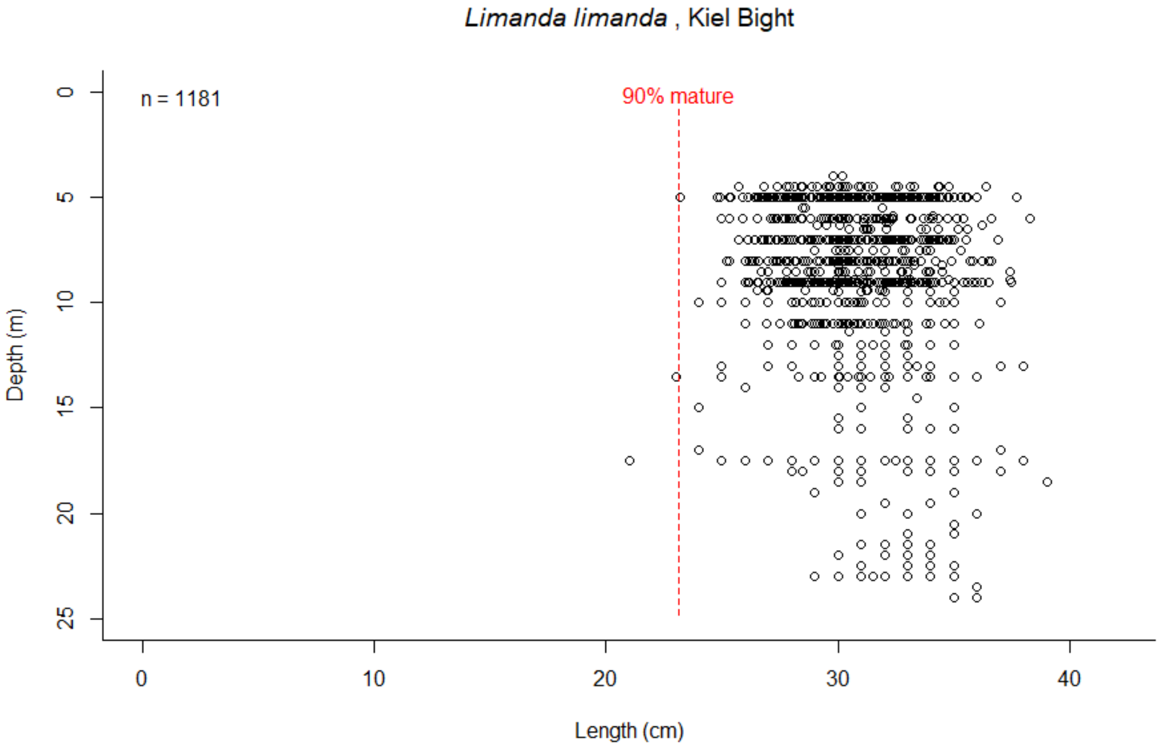


Figure 88. Length-distribution by depth of dab capture by commercial fishers from December to May 2021-2023 in Kiel Bight.

A summary of relevant reference points extracted from DATRAS for the western Baltic Sea or established in this study is presented in Table 10.

Table 10. Key reference points for dab (Limanda limanda) derived from catches of commercial fishers in Kiel Bight, between December and May, and from scientific surveys as documented in DATRAS for areas 22 and 24, taken in the first quarter. Doubtful estimates are marked with ***??***

Species	Dab	*Limanda limanda*				Pleuronectidae	
Parameter		estimate	LCL	UCL	n r^2	Unit	Method
Lmax KB	Maximum length	46.7				cm	largest on record
Lmax datras	Maximum length	36				cm	largest on record
Lmax	Maximum length	42				cm	chosen for study
a.f KB	$W=\mathbf{a}L^{b}$, females	0.0123	0.00875	0.0173	n=1046	g/cm^b	log-log regression
b.f KB	$W=aL^{\mathbf{b}}$, females	2.96	2.86	3.06	r^2=0.77		log-log regression
a.m KB	$W=\mathbf{a}L^{b}$, males	0.0187	0.00703	0.0499	n=101	g/cm^b	log-log regression
b.m KB	$W=aL^{\mathbf{b}}$, males	2.82	2.53	3.11	r^2=0.79		log-log regression
a.c KB	$W=\mathbf{a}L^{b}$, combined	0.0112	0.00812	0.0155	n=1180	g/cm^b	log-log regression
b.c KB	$W=aL^{\mathbf{b}}$, combined	2.99	2.89	3.08	r^2=0.77		log-log regression
Wmax KB	Maximum weight	895				g	largest on record
Wmax DATRAS	Maximum weight	742				g	largest on record
Wmax LWR	Maximum weight	791				g	Wmax=a.c Lmax$^{b.c}$
Wmax	Maximum weight	791				g	chosen for study
tmax DATRAS	Maximum age	12				years	largest on record
L_opt	Optimum length	28				cm	2/3 Lmax
Lc_opt	Optimum capture	23.5				cm	0.56 Lmax
Wopt	Optimum weight	236				g	a.c Lopt$^{b.c}$
Wc_opt	Optimum capture	140				g	a.c Lopt$^{b.c}$
MCRL	Minimum length	NA				cm	EU law
Lm50 KB	50% mature fem.	13.9 **??**	10.7 **??**	15.3 **??**	n=1059	cm	ogive
Lm90 KB	90% mature fem.	17.1 **??**	10.6 **??**	18.9 **??**		cm	ogive
Lm50 DATRAS	50% mature fem.	16.2	15.3	17.2	n=7436	cm	ogive, SMALK
Lm90 DATRAS	90% mature fem.	23.2	21.5	25		cm	ogive, SMALK
tm50 DATRAS	50% mature fem.	2				years	first age > 0.5 mature
tm90 DATRAS	90% mature fem.	4				years	first age > 0.9 mature
sex ratio KB	males / females	0.086			n=1157		n (sex=m) / n (sex=f)
sex ratio DATRAS	males / females	0.629			n=12637		n (sex=m) / n (sex=f) Exchange 1991-2023
gsi.95 KB	Gonad/Body weight	0.167			n=916		95th percentile of GSI
gsi.slope KB	Gonad/Body slope	1.98			r^2=0.47		gonads ~ body weight
spawning season	peak, range	March	Jan	May	n=1065	month	L>Lm90, mat > 10%
Linf DATRAS	Asymptotic length	32.8 **??**	32.2 **??**	33.4 **??**	n=10024	cm	VBGF fit
K DATRAS	Growth parameter	0.342 **??**	0.323 **??**	0.362**??**		year^{-1}	VBGF fit
t0 DATRAS	Growth parameter	-0.36 **??**				years	VBGF fit
SE DATRAS	SE of residuals	4.16 **??**				cm	VBGF fit
Linf KB	Asymptotic length	42				cm	Linf=Lmax
K KB	Growth parameter	0.215				year^{-1}	from median L(t=1)
t0 KB	Growth parameter	-0.7				years	t0=t0.user

Turbot (*Scophthalmus maximus*)

Status: ICES recognizes one stock of turbot (*Scophthalmus maximus*) for the whole Baltic Sea (ICES-tur 2021), although there are probably numerous subpopulations adapted to the different salinity levels which are important for reproduction with pelagic eggs. The stock size indicator fluctuates around the same level since 2001, suggesting a stable stock size with regular recruitment despite the impacts of climate change on the western Baltic Sea (Dutheil et al. 2022, Froese et al. 2022). This assessment is confirmed by catch-per-unit-of effort (CPUE) data from Kiel Bight, which also fluctuate around a mean value (Figure 89).

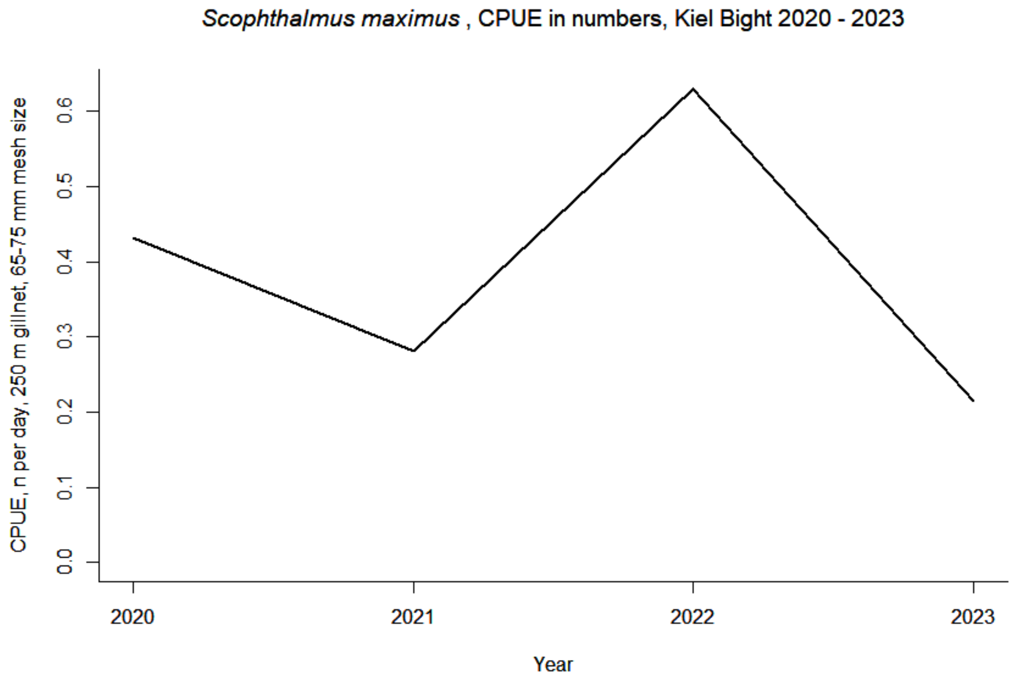


Figure 89. Average number of turbot caught per day in Kiel Bight by commercial fishers with 250 m of gill nets with 70-75 mm mesh size (knot to knot), from December to May in 2020 – 2023 (bold curve). No ICES stock size indicator data were available for the period.

Fishing pressure: ICES provides no information on fishing pressure, but advised to 'Reduce catch' from 2012 to 2018 (ICES-tur 2023, Table 3). The slow decline in numbers at increasing lengths, both in DATRAS (Figure 90) and in Kiel Bight data (Figure 91), suggests fishing pressure to be below the sustainable maximum in recent years. This is helped by turbot landings in 2020 (the last available estimate) being the lowest since 1984 (ICES-tur 2021, Fig. 1). Note that the turbot stock is not managed by catch limits or any other measures except a minimum legal landing length (MCRL) of 30 cm.

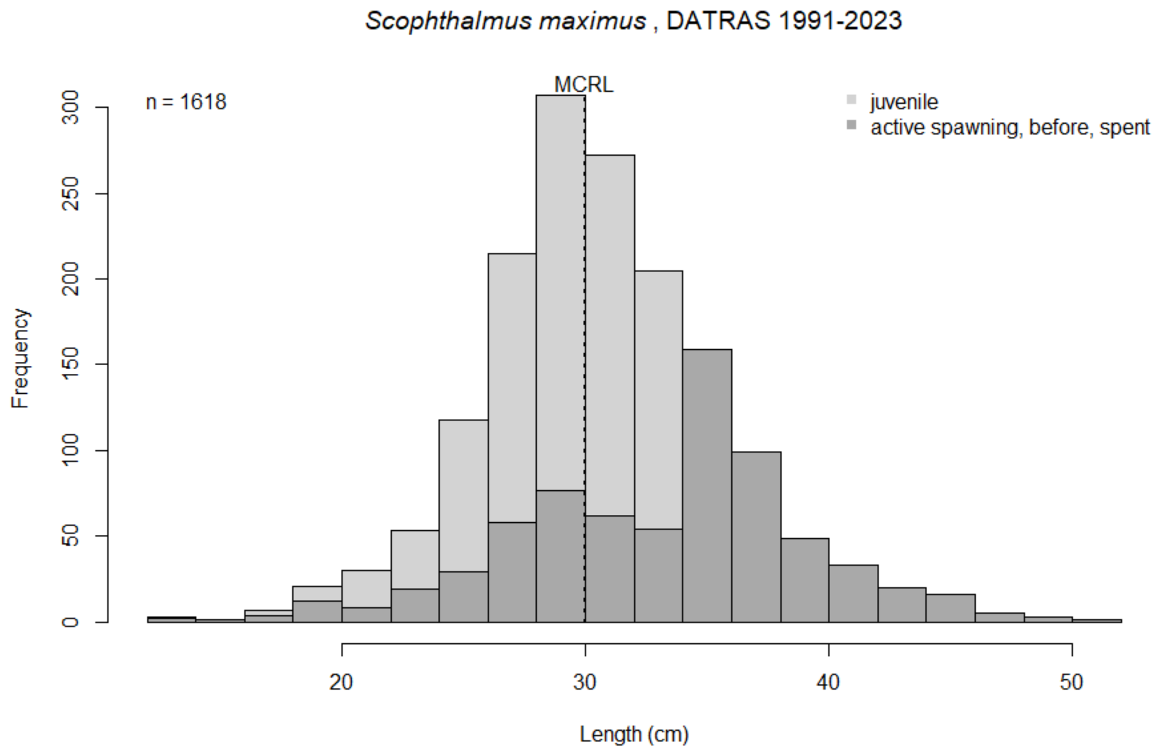


Figure 90. Length frequency of juveniles and adults based on the SMALK database (1st quarter, area 22 and 24). MCRL indicates the legal minimum conservation reference length. Note that length at maturity may be overestimated because the spawning season was only partly covered by this investigation.

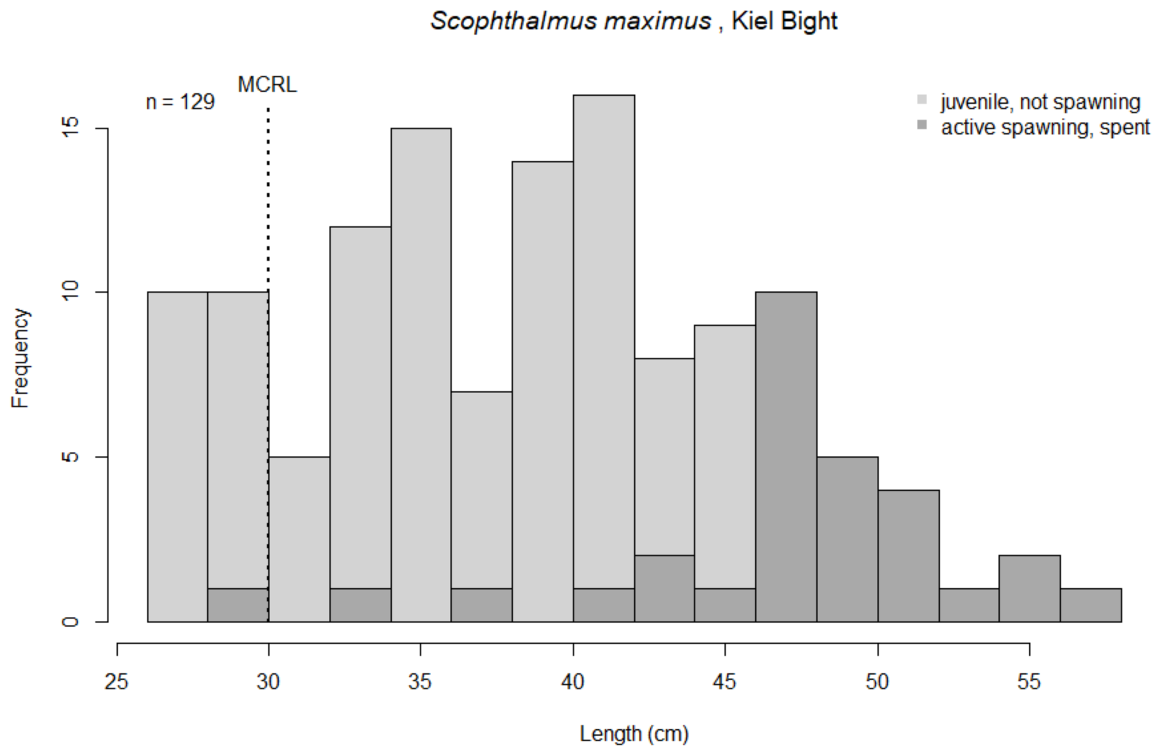


Figure 91. Length frequency of juveniles and adults based on data from commercial fishers (2020-2023). MCRL indicates the legal minimum conservation reference length. Note that length at maturity may be overestimated because the spawning season was only partly covered by this investigation.

Healthy age and size structure: A healthy age and size structure of commercial fish stocks is a requirement for good environmental status in the Marine Strategy Framework Directive (MSFD 2008) of the European Union. The maximum age of turbot found surveys in the western Baltic is 26 years (Table 11). Figure 92 shows the frequency distribution of a reasonably healthy stock, with all year classes present, albeit with a strong decline in numbers after being fully selected by fishing at 4 years of age. Note that more than 50% of caught turbot reach maturity only after 6-7 years, indicating that the onset of fishing is too early for this large and long-lived species.

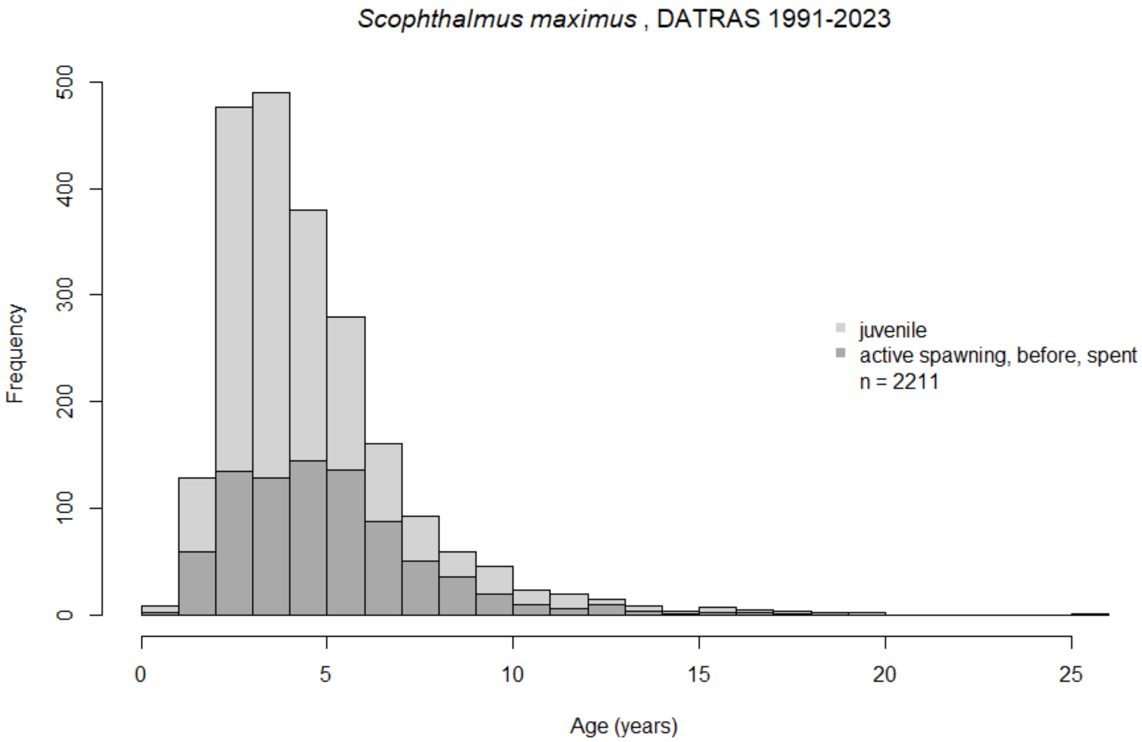


Figure 92. Age frequency of juveniles and adults based on the SMALK database (1st quarter, area 22 or 24). Note that age at maturity may be overestimated because the spawning season was only partly covered by this investigation.

Length-weight relationship and condition: The parameters of the length-weight relationship (Table 11, Figure 93) describe turbot as a more roundish than fusiform species, indicated by *a* = 0.019 being well above the typical fusiform value of *a* = 0.01 (Froese 2006). Also, turbot do not change their body shape or proportions as they grow through late juvenile and adult life stages, indicated by *b* = 3.0 (Froese 2006). Most of the variability in the data is accounted for by the coefficient of determination (r^2 = 0.94, Table 11) of the log-log linear relation between body weight and length. There are only five outlying specimen (erroneous measurements or starving or obese fish) which were excluded from this and other analyses.

Median body weight for a given length (condition) dropped from 2.15 to 2.05 (-5%) in catches from Kiel Bight from 2020 to 2023 (Figure 94), confirming reports from fishers that commercial fish in general were getting thinner. A comparison with DATRAS survey data for the western Baltic confirmed this observation, albeit with a lower decline of 2.5% from 1995 to 2023 (Figure 95).

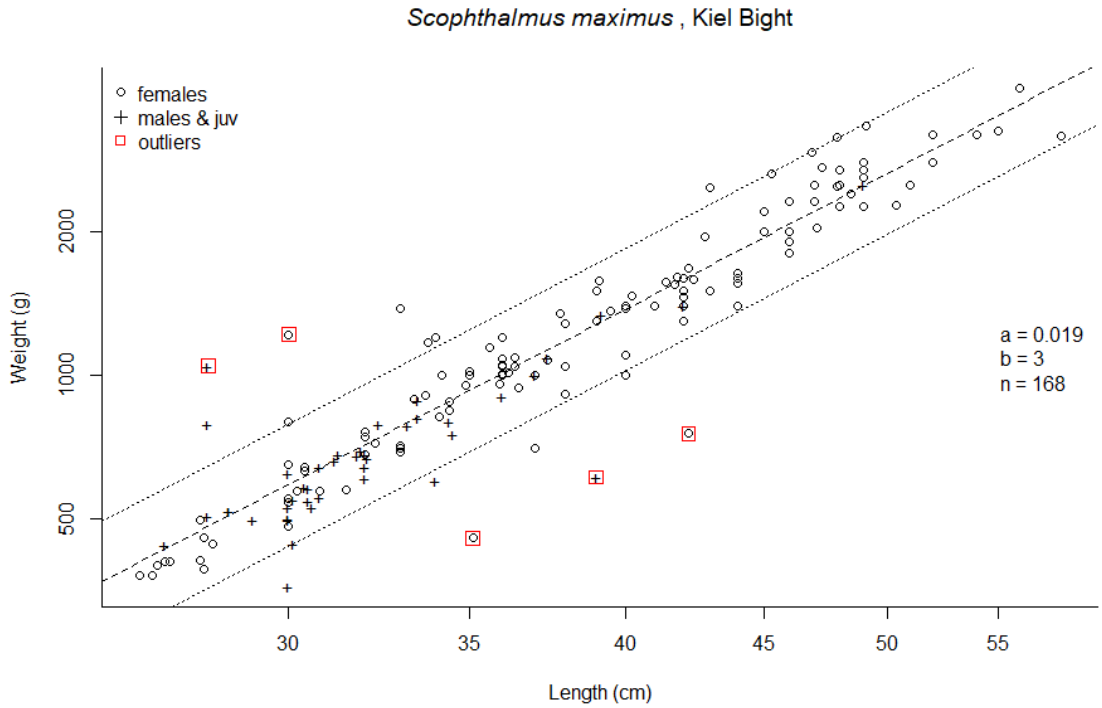


Figure 93. Length-weight relationship for turbot (Scophthalmus rhombus) in Kiel Bight, based on samples taken from December to May in 2020-2023 in commercial gill net and trawl fisheries. The dashed line indicates the overall fit and the dotted lines indicated the 95% confidence limits.

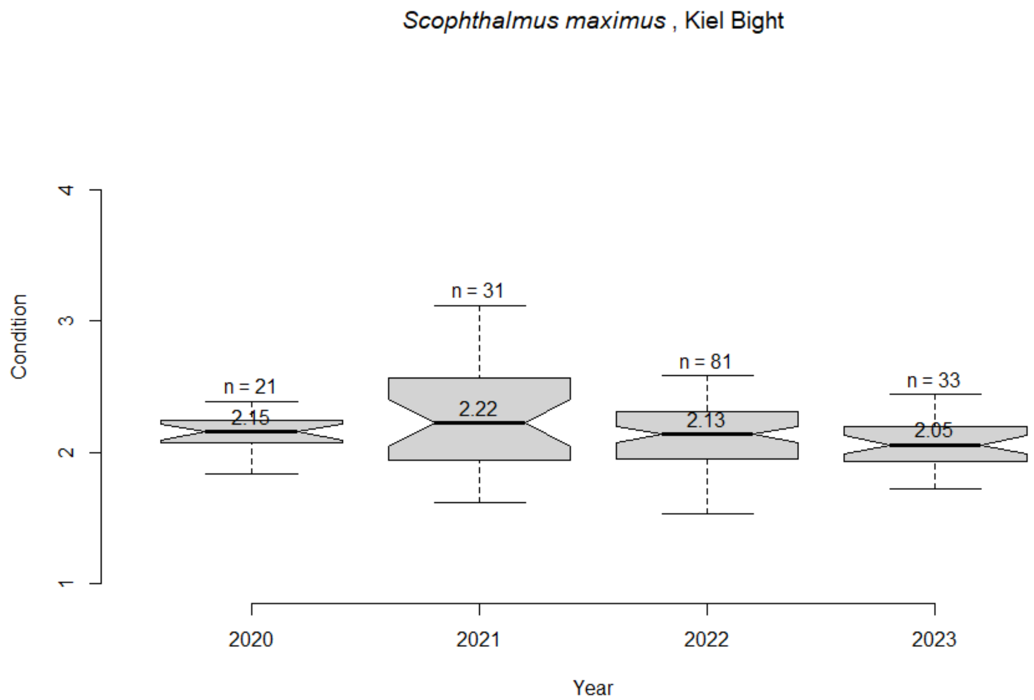


Figure 94. Comparison of Condition C = 100 Weight/Length^3 from 2020 to 2023, based on commercial catches from January to May in Kiel Bight. Note decline in condition in 2023.*

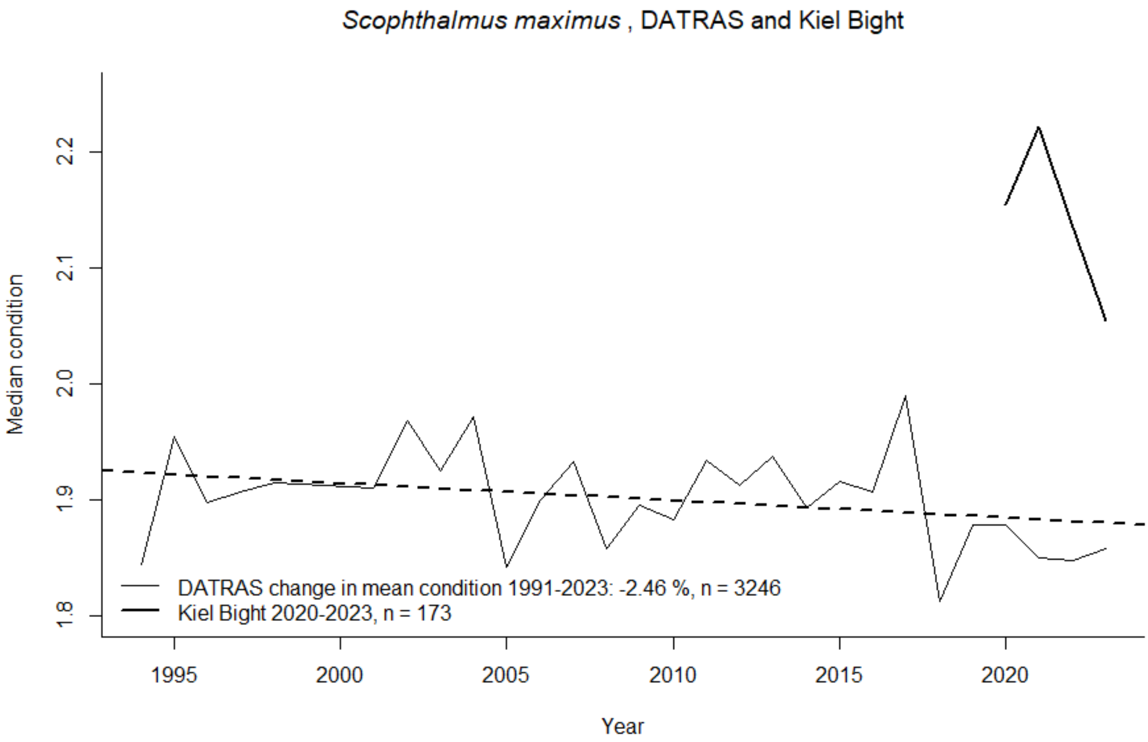


Figure 95. Change in median condition based on DATRAS (black curve and dashed line, 1st quarter, area 22 and 24) and 2020-2023 data from commercial fishers in Kiel Bight (bold curve).

Length and age at maturation: The size and age where 50% or 90% of female turbot have reached sexual maturity and participate in spawning is L_{m50} = 25.4 cm (Figure 96, Table 11) at ages 7 (Figure 92, Table 11), based on survey data, but there is some doubt that females below 20 cm length would really fully develop their ovaries and participated in spawning, i.e., the L_{m50} = 25.4 cm based on highly variable and partly doubtful survey data may be too low. An ogive curve fitted to data derived in this study suggests L_{m50} = 44.5 cm (Figure 97), which however is unreliable because fishers in Kiel Bight used larger mesh sizes to avoid capture of small dab, cod, plaice and flounders (Figure 35), which leads to a lack of turbot around the size of maturation (Figure 97). Additional variability is injected by the spawning season of turbot starting in May being only marginally covered by the Kiel Bight data.

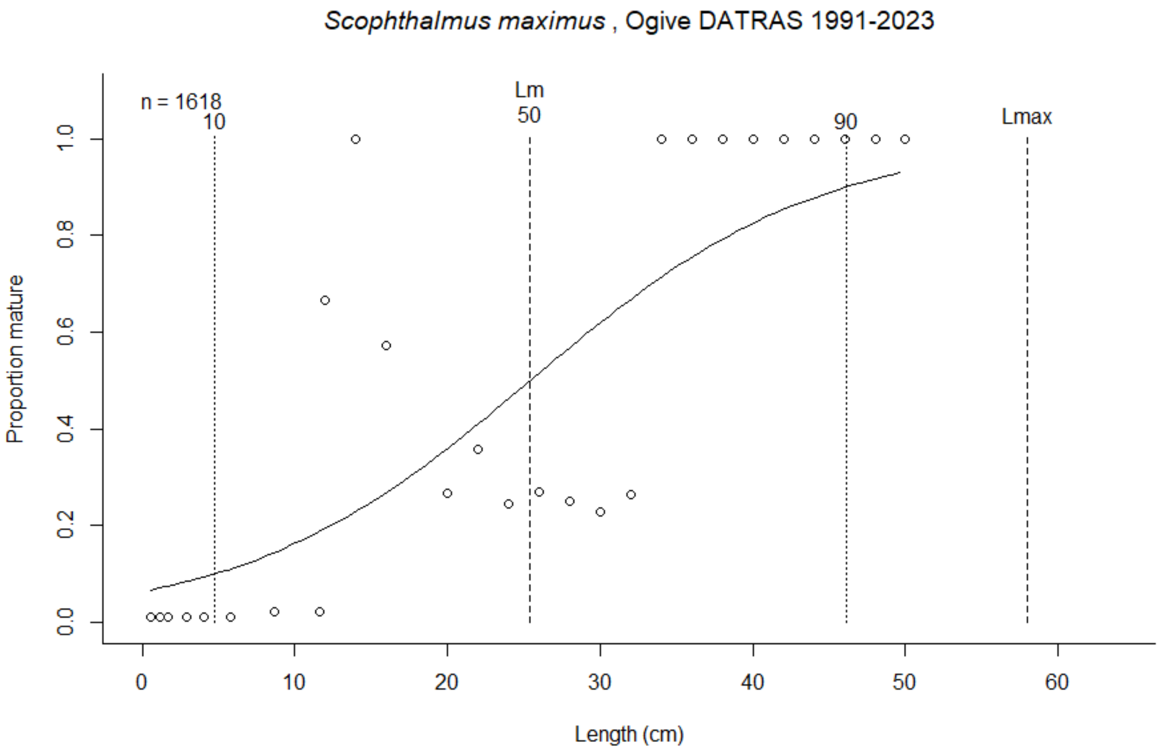


Figure 96. Proportion of mature females based on the SMALK database (1st quarter, area 22 and 24). There is some doubt that females below 20 cm length would really fully develop their ovaries and participated in spawning.

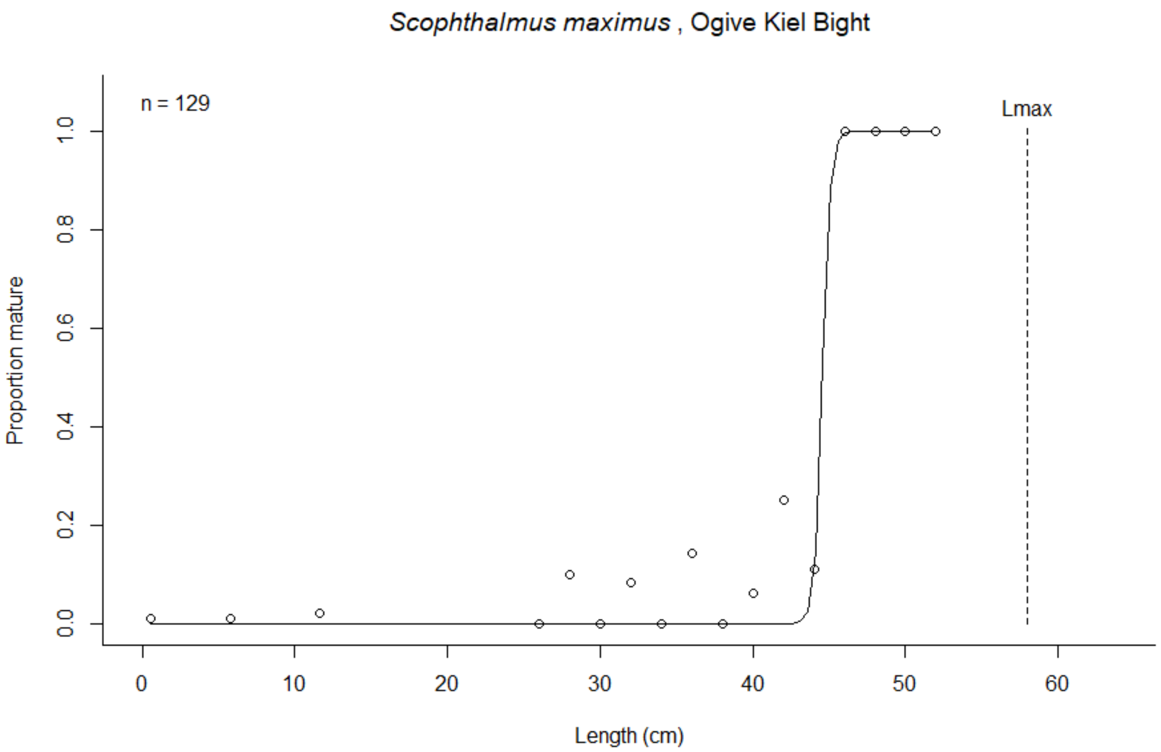


Figure 97. Proportion of mature females based on data from commercial fishers in Kiel Bight (2020-2023). Note that length at maturity may be overestimated because the turbot spawning season was only partly covered by this investigation.

Fecundity as a function of body weight: The base assumption of the relation between fecundity and body weight is that the number of eggs of a female or the maximum weight of the gonads grows about proportionally with body weight. Overall, the fully developed ovaries of turbot females examined in Kiel Bight took up about 36% of total body weight (Table 11, Figure 98). The available data on relative weight of ovaries (gonado-somatic index) collected in this study suggest that the increase in turbot fecundity was higher (slope = 1.32) than predicted by a directly proportional increase in body weight (Table 11, Figure 99).

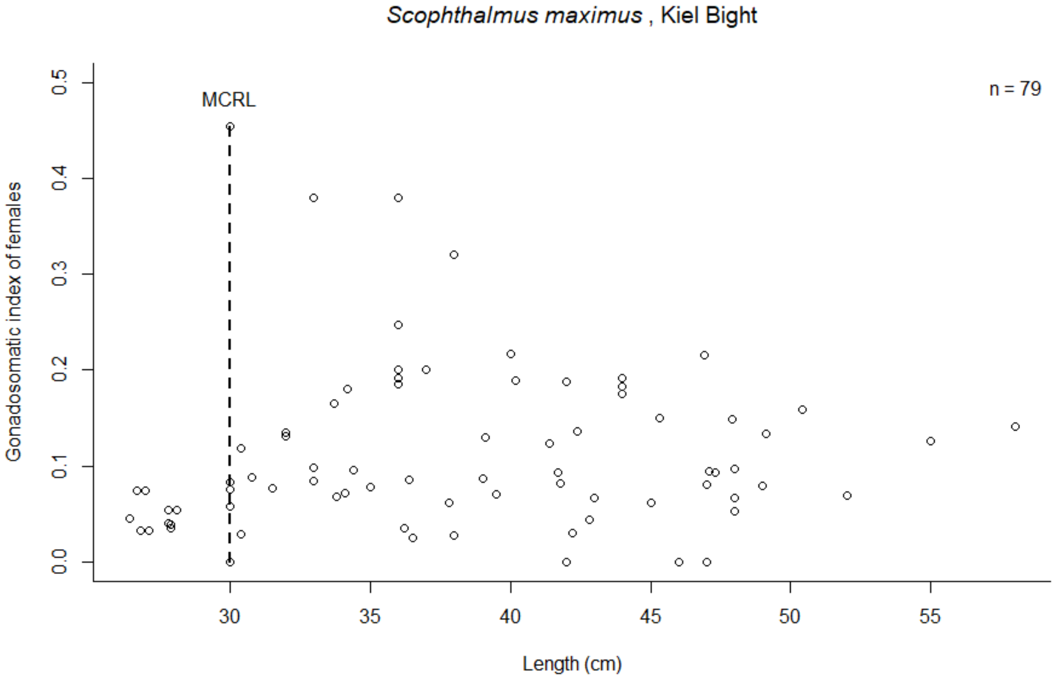


Figure 98. Relative weight of ovaries (GSI) plotted over body length of females in Kiel Bight, 2020-2023. Note that the turbot spawning season was only partly covered by this investigation.

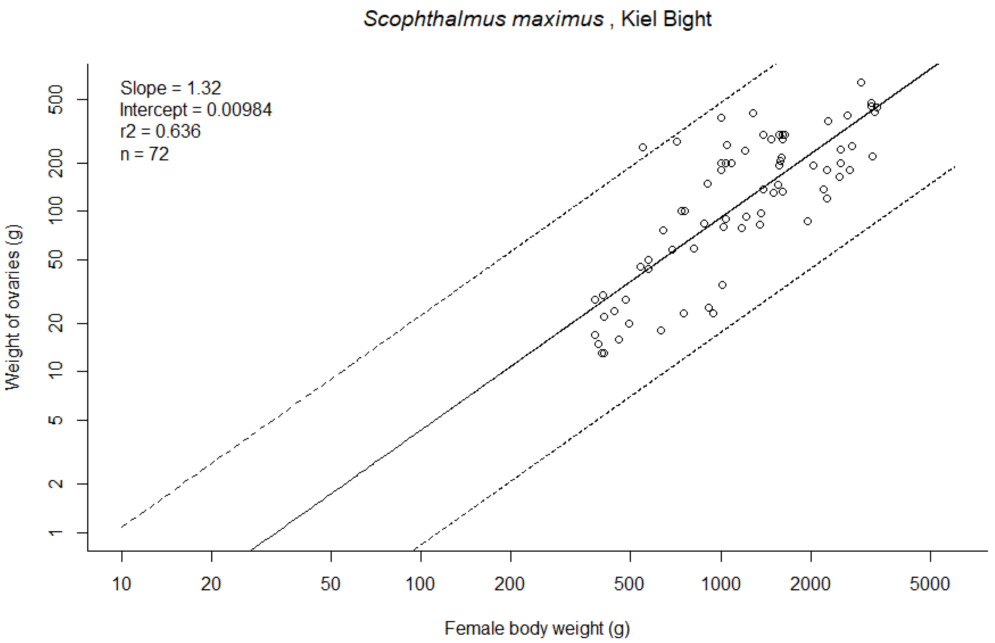


Figure 99. Weight of ovaries in different stages over body weight based on data from commercial fishers in Kiel Bight (2020-2023). Note that a slope > 1 suggests that the weight of ovaries and thus fecundity increases faster than body weight.

Sex ratio: Whereas the male/female sex ratio of turbot fluctuated around 1:1 in survey data taken from throughout the western Baltic Sea, there were only few male turbot present in the shallow waters of Kiel Bight during Winter and at the start of the spawning seasons in May of 2020-2023 (Table 11, Figure 100).

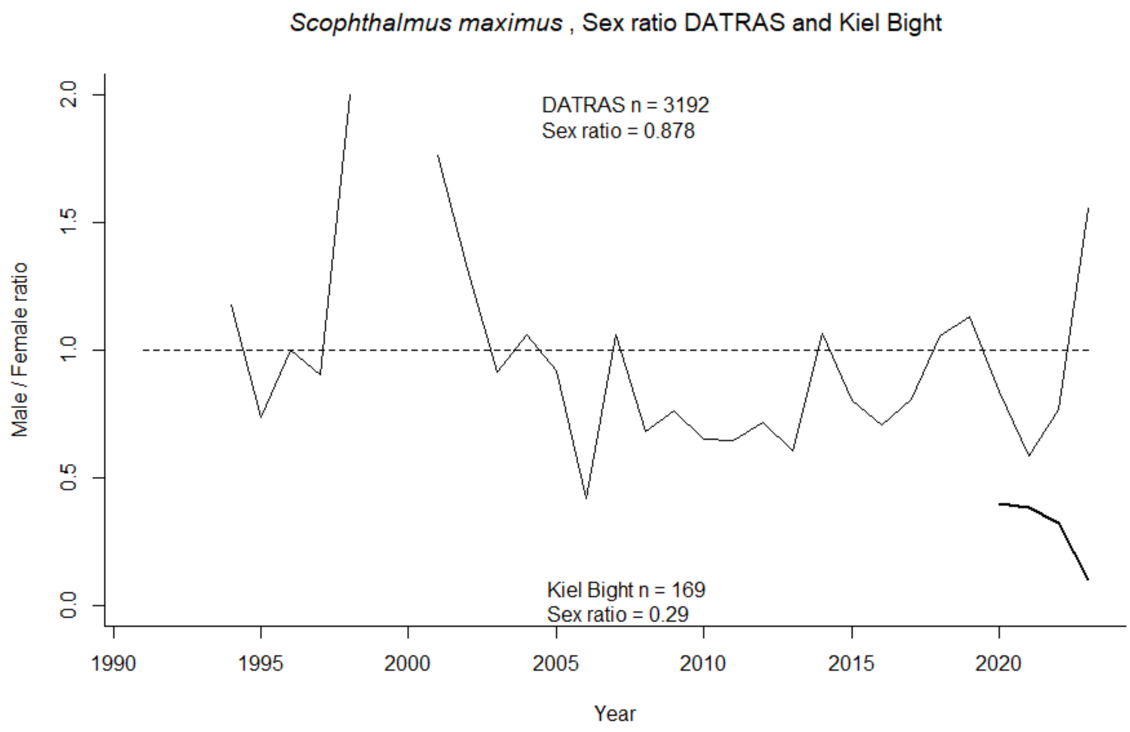


Figure 100. Time series of annual sex ratios, based on DATRAS (upper curve) and Kiel Bight (lower bold curve). While the sex ratio in the wider Western Baltic Sea covered by DATRAS includes the dashed 1:1 line, the sex ratio in the shallower Kiel Bight is strongly dominated by females.

Spawning season: In the Baltic, the warm-adapted turbot spends the cold months in deeper and then warmer waters and juveniles and adults move into shallower waters in spring (Florin and Franzen 2010). This pattern is confirmed by the increase in numbers of turbot caught in Kiel Bight in March and April. The traditional spawning season of turbot in the Baltic is during summer from May to August (Florin and Franzen 2010). Relative size of ovaries was used to determine the spawning season of turbot in 2021-2023 in Kiel Bight as from April to May and beyond (no data were available for June to August) (Figure 101, Figure 102). These data suggest that turbot spawning starts about one month earlier than in the last century.

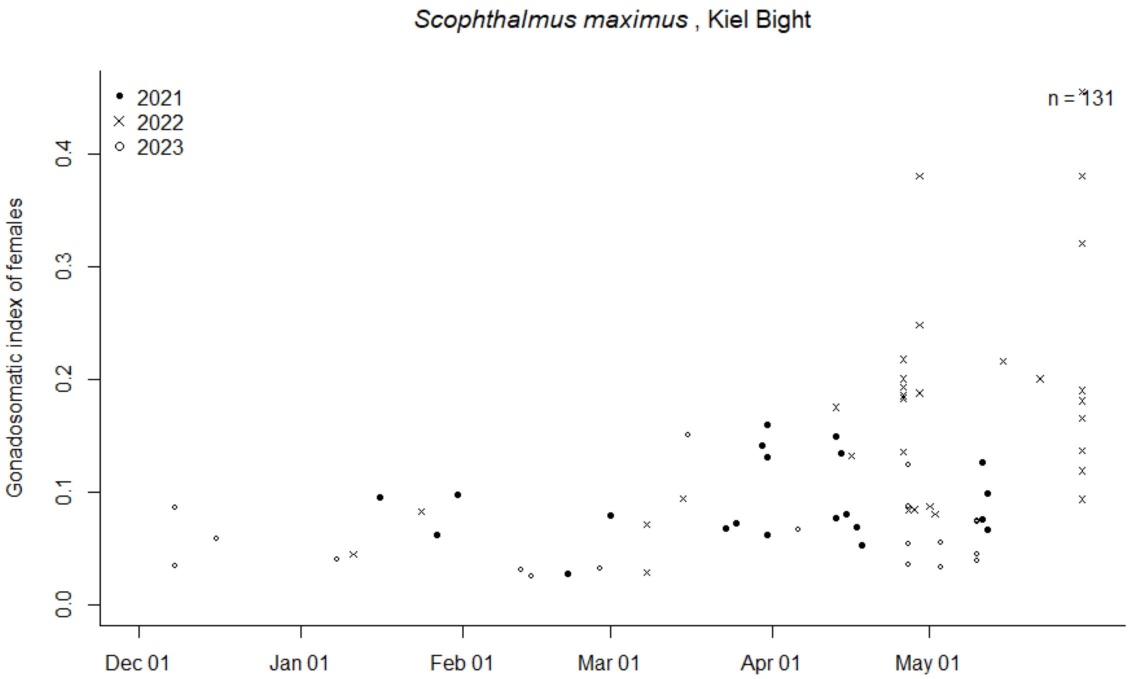


Figure 101. Timing of spawning as indicated by the gonadosomatic index of females in Kiel Bight, based on samples taken from December to May in 2021-2023 in commercial gill net fisheries. The data suggest that spawning is only commencing in May.

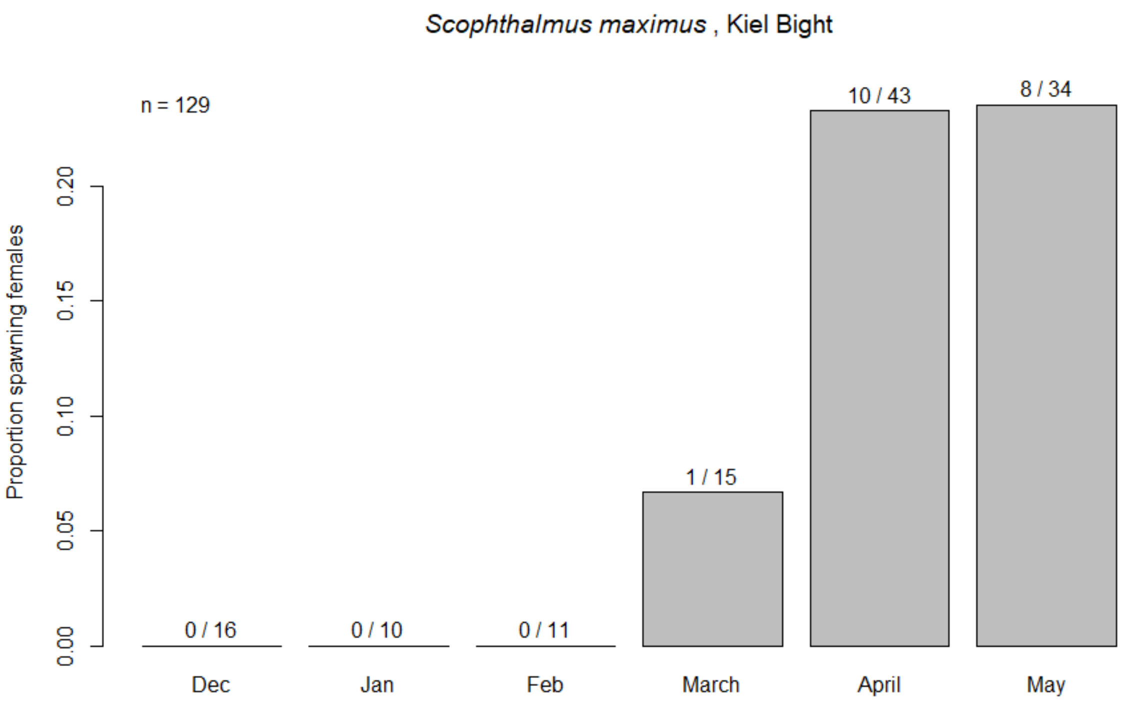


Figure 102. Monthly number of actively spawning females (L > Lm90 and gsi > 0.05) relative to the total number of females examined (numbers on top of bars), for years 2020 to 2023 in Kiel Bight. The data suggest that spawning is only commencing in May.

Diet composition: The fishers in Kiel Bight weighed stomachs and identified the most prominent food items for altogether 173 turbot (Table 11, Figure 103). Turbot are top predators feeding mostly on other fish, with sprat (*Sprattus sprattus*), flatfish, anchovies (*Engraulis encrasicolus*), herring (*Clupea harengus*) plus a variety of young fish and other small fish being the most common food items.

Table 11. Frequency of occurrence of food items found in altogether 173 stomachs of which 73 (42%) contained food. Note that the sum of percentages in the last column exceeds 100 because stomachs can contain more than one food item. Food items are presented by functional groups. Main contributing groups are highlighted in orange and main contributing food items are highlighted in yellow.

Food I	**Food II**	**Names** (German, English)	**Scientific name**	**n**	**%**
zoobenthos					17.8
	worms				10.9
		Ringelwürmer, Seeringelwürmer, ragworms	*Hediste diversicolor*	2	2.7
		Würmer, worms		6	8.2
	mollusks				1.4
		Muscheln, mussels		1	1.4
	benthic crustaceans				5.5
		Garnelen, shrimp	*Palaemon sp.*	4	5.5
nekton					85.1
	finfish				85.1
		Dorsch, cod	*Gadus morhua*	1	1.4
		Hering, herring	*Clupea harengus*	5	6.9
		Sandaal, sandeel	*Ammodytes sp.*	1	1.4
		Sardelle, anchovy	*Engraulis encrasicolus*	6	8.2
		Seenadel, pipefish	*Syngnathus sp.*	1	1.4
		Sprotte, sprat	*Sprattus sprattus*	14	19.2
		Steinpicker, hooknose	*Agonus cataphractus*	1	1.4
		Wittling, whiting	*Merlangius merlangus*	2	2.7
		Plattfisch, flatfish		10	13.7
		Fische, Jungfische, unspecified fish		21	28.8

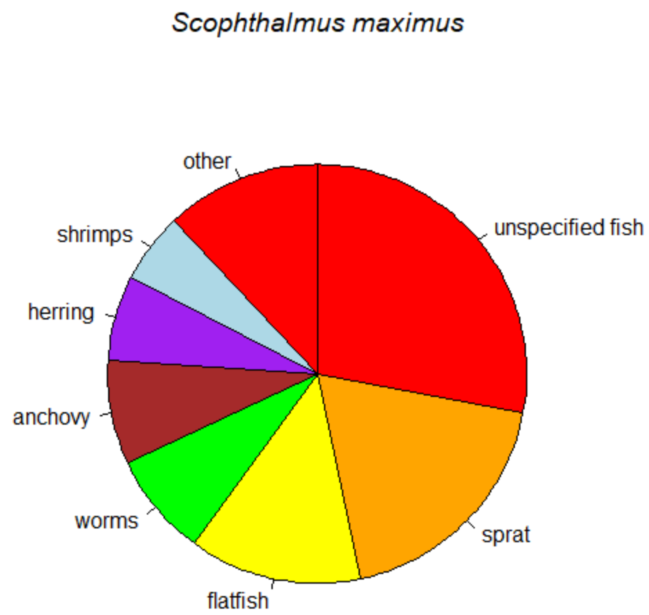


Figure 103. Four most frequently encountered food items in plaice stomachs, based on commercial catches from January to May 2021 to 2023 in Kiel Bight. Note high proportion (75%) of fish in the diet.

Somatic growth: Thousands of turbot have been caught in standard scientific surveys and have been aged for stock assessment purposes. However, the uncertainty of these age readings is very wide, suggesting e.g. that two year old turbot can be between 11 to 36 cm long (Figure 104). Fitting a growth curve to these length-at-age data strongly underestimates asymptotic length (L_{inf}) when compared with observed lengths. Instead, a more convincing growth curve was obtained by setting L_{inf} equal to the observed maximum length L_{max} = 58 cm and using the median length of two year old turbot according to DATRAS to anchor the growth curve (Table 12, Figure 104) (Froese 2022).

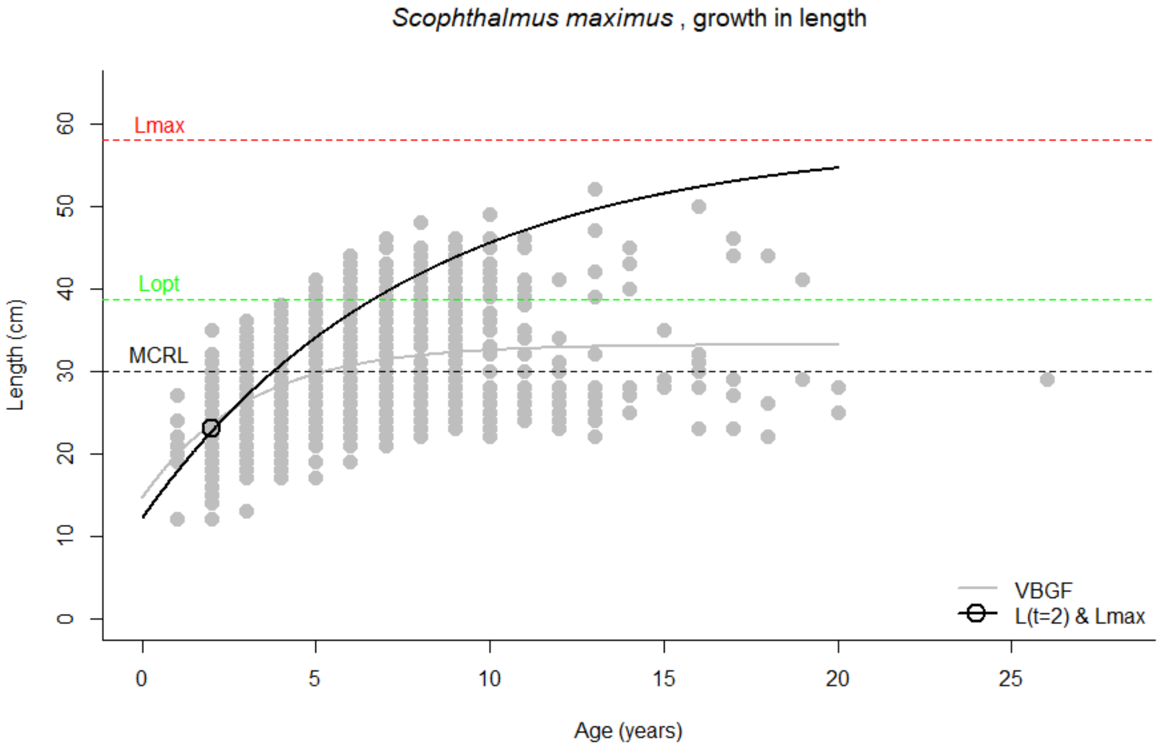


Figure 104. Growth in length based on DATRAS age readings from 2020-2022, first quarter, area 22 and 24. Note highly variable length-at-age readings in older fish and the underestimation of L_{max} by the fitted asymptotic length (L_{inf}), making the derived growth parameters doubtful. The black curve uses instead observed L_{max} as a proxy for L_{inf} and the median length of two-year old fish and a user-provided estimate of t_0, resulting in a more plausible growth curve (Froese 2022).

Fisheries management considerations: There is an optimal length (L_{opt}) for catching fish, where the increase in body weight has reached a maximum, and where most individuals have already reproduced 1-3 times. This is also the length where catches will be highest for a given effort or where for a given catch the least number of fish will be killed (Froese et al. 2016). A proxy for L_{opt} can be derived as 2/3 of maximum length (see Material and Methods), which for turbot in the western Baltic gives L_{opt} = 38.7 cm with an optimum length at first capture as L_{c_opt} = 32.5 cm (Table 12). The Minimum Conservation Reference Length for turbot in the Baltic Sea is MCRL = 30 cm. MCRL, L_{opt} and L_{c_opt} were used to determine the appropriateness of the selectivity of common gill nets in the western Baltic and Kiel Bight for turbot.

Fishers in Kiel Bight use gill nets with mesh sizes from the legal minimum size of 55 mm up to voluntarily used 80 mm or more (all measured knot to knot). A comparison of the size selectivity of mesh sizes of 55, 70, 75 and 80 mm for turbot is inconclusive because of the overall low number of turbot caught (Figure 105). However, the data show that even the larger mesh sizes of 70, 75 and 80 mm caught turbot below the legal landing size (MCRL). This confirms the assessment of ICES (ICES-tur 2021, Table 4) that about 2/3 of the landing of turbot in 2020 were caught by 'passive gears' (presumably gillnets) whereas about 1/3 was caught by 'active gears' (presumably bottom trawls), with the statement that discarding (of presumably turbot below MCRL) 'is known to take place and is considered substantial but could not be quantified'.

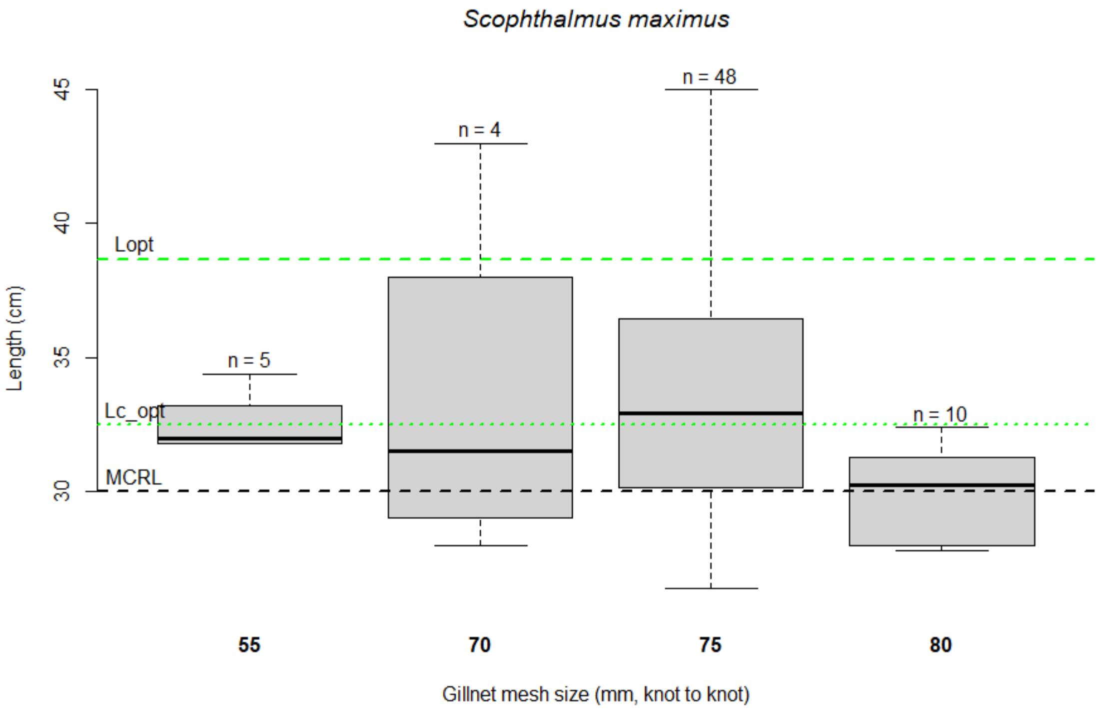


Figure 105. Boxplot of length distribution in gill nets from 55 mm (knot to knot), which is the legal minimum mesh size, to 70 – 80 mm, which are preferred by fishers who do not want to catch juveniles. The upper green horizontal line indicates the length L_{opt} at which the catch for a given fishing pressure is maximized and number of fish killed for the allowed catch in weight is minimized. Only the 75 mm mesh has enough numbers caught for an assessment, suggesting that larger mesh sizes would be better. Data from commercial fishing in Kiel Bight, December to May 2020-2023.

Turbot do also not benefit from the prohibition to catch cod with trawls below 20 m of water depth from February 1 to March 31 for vessels longer than 15 m. As can be seen from the data collected in Kiel Bight for this study (Figure 101, Figure 102), turbot regularly occur in shallow water from March onward where they are subject to legally ongoing fishing (Figure 106). Except for the MCRL (which results in substantial discarding), there is no protection of pre-spawning and spawning turbot in the western Baltic Sea.

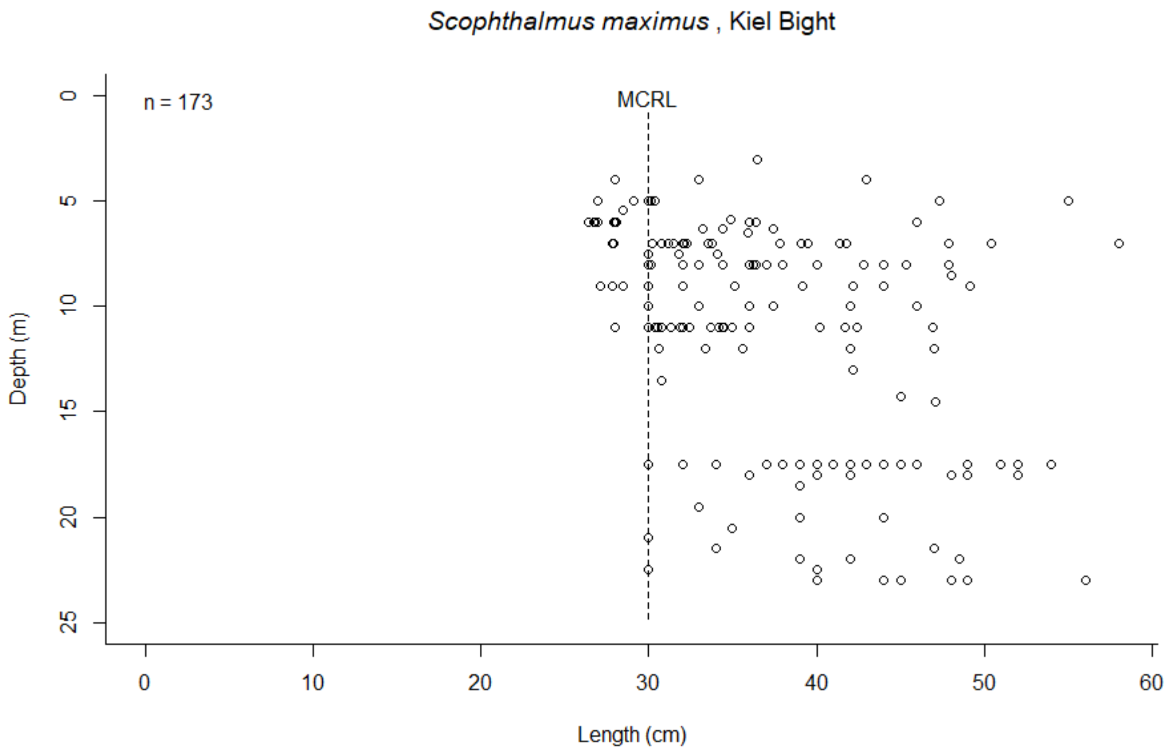


Figure 106. Length-distribution by depth of capture by commercial fishers from December to May 2021-2023 in Kiel Bight. Large individuals occur at all depths.

A summary of relevant reference points for turbot as extracted from DATRAS for the western Baltic Sea or established in this study for Kiel Bight is presented in Table 12.

Table 12. Key life history reference points for turbot (Scophthalmus maximus), with plausible 95% confidence limits (LCL, UCL) or coefficient of determination (r^2), where applicable, derived from catches of commercial fishers in Kiel Bight (KB) in 2020-2023, December/January and May, and from scientific surveys in the Western Baltic Sea as documented in DATRAS for the first quarter of the years 2000-2022 in areas 22 and 24. Doubtful estimates are marked with ***??***

Species	Turbot	*Scophthalmus maximus*				Scophthalmidae	
Parameter		estimate	LCL	UCL	n r^2	Unit	Method
Lmax KB	Maximum length	58				cm	largest on record
Lmax datras	Maximum length	49				cm	largest on record
Lmax	Maximum length	58				cm	chosen for study
a.f KB	W=**a**L^b, females	0.0279	0.0152	0.0512	n=123	g/cm^b	log-log regression
b.f KB	W=aL$^{\mathbf{b}}$, females	2.93	2.76	3.1	r^2=0.91		log-log regression
a.m KB	W=**a**L^b, males	0.0773	0.0146	0.411	n=41	g/cm^b	log-log regression
b.m KB	W=aL$^{\mathbf{b}}$, males	2.61	2.13	3.09	r^2=0.756		log-log regression
a.c KB	W=**a**L^b, combined	0.019	0.0122	0.0295	n=168	g/cm^b	log-log regression
b.c KB	W=aL$^{\mathbf{b}}$, combined	3.03	2.91	3.15	r^2=0.938		log-log regression
Wmax KB	Maximum weight	4000				g	largest on record
Wmax DATRAS	Maximum weight	3252				g	largest on record
Wmax LWR	Maximum weight	4222				g	Wmax=a.c Lmax$^{b.c}$
Wmax	Maximum weight	4000				g	chosen for study
tmax DATRAS	Maximum age	26				years	largest on record
L_opt	Optimum length	38.7				cm	2/3 Lmax
Lc_opt	Optimum capture	32.5				cm	0.56 Lmax
Wopt	Optimum weight	1235				g	a.c Lopt$^{b.c}$
Wc_opt	Optimum capture	728				g	a.c Lopt$^{b.c}$
MCRL	Minimum length	30				cm	EU law
Lm50 KB	50% mature fem.	44.5 **??**			n=129	cm	ogive
Lm90 KB	90% mature fem.	45.1 **??**				cm	ogive
Lm50 DATRAS	50% mature fem.	25.4	18.9	31.5	n=1617	cm	ogive, SMALK
Lm90 DATRAS	90% mature fem.	46.1 **??**	36.7 **??**	61.4 **??**		cm	ogive, SMALK
tm50 DATRAS	50% mature fem.	7				years	first age > 0.5 mature
tm90 DATRAS	90% mature fem.	19 **??**				years	first age > 0.9 mature
sex ratio KB	males / females	0.29 : 1			n=169		n (sex=m) / n (sex=f)
sex ratio DATRAS	males / females	0.88 : 1			n=3192		n (sex=m) / n (sex=f) Exchange 1991-2023
gsi.95 KB	Gonad/Body weight	0.36			n=72		95th percentile of GSI
gsi.slope KB	Gonad/Body slope	1.32	1.09	1.56	r^2=0.64		gonads ~ body weight
spawning season	peak, range	May	April	May	n=25	month	L>Lm90, mat > 10%
Linf DATRAS	Asymptotic length	33.2 **??**	32.5 **??**	34.0 **??**	n=2392	cm	VBGF fit
K DATRAS	Growth parameter	0.33 **??**	0.28 **??**	0.39 **??**		year^{-1}	VBGF fit
t0 DATRAS	Growth parameter	-1.74 **??**				years	VBGF fit
SE DATRAS	SE of residuals	4.52 **??**				cm	VBGF fit
Linf KB	Asymptotic length	58				cm	Linf=Lmax
K KB	Growth parameter	0.13				year^{-1}	from median L(t=2)
t0 KB	Growth parameter	-1.8				years	t0 = t0.user

Herring (*Clupea harengus*)

Status: The herring stock in the western Baltic spends the summer in the eastern North Sea off the Norwegian coast for feeding, spends the winter in the Kattegat and Belt Sea, and comes to the shallow waters of the western Baltic Sea for spawning in spring. Spawning stock biomass has declined from about 300 thousand tonnes in 1992 to below Blim (the biomass where there is a 50% probability of impaired recruitment) in 2007 and to the lowest value of about 50 thousand tonnes in 2019. The decline in spawning stock biomass was accompanied by the corresponding decline in recruitment from over 5 billion recruits in 1991 to less than 0.5 billion in 2021. ICES advised zero catch since 2019, noted that "ICES is not aware of any conservation measures for this stock" (ICES-her 2023, Table 5), and stressed that "measures to protect and restore known spawning habitats and nursery areas are needed" (ICES-her 2023, page 1). Data collected for herring in the Kiel Bight project were insufficient to produce a catch-per unit-of-effort graph.

Fishing pressure: Catch of herring has declined from close to 200 thousand tonnes in 1992 to about 6000 tonnes in 2022. The reason for the decline of biomass, recruitment and catch is the excessive fishing pressure far above maximum sustainable limits (F_{msy} and $F_{MAP} = F_{msy} * SSB_t / MSY_{Btrigger}$) until 2020. In addition to zero catch ICES advises that "it is of the highest importance to monitor and minimize additional environmental stressors" and "to protect the marine environment and ecosystems (e.g. nutrient load, freshwater run-off)" (ICES-her 2023, page 6).

Healthy age and size structure: A healthy age and size structure of commercial fish stocks is a requirement for good environmental status in the Marine Strategy Framework Directive (MSFD 2008) of the European Union. The maximum age of herring found in surveys in the western Baltic is 14 years (Table 13). Figure 107 shows the frequency distribution of a reasonably healthy stock, with all year classes present, albeit with a strong decline in numbers after being fully selected by fishing at 4 years of age. At the onset of fishing at age 4 about 90% of the herring have reached maturity. This avoidance of undersized herring in the catch is confirmed by the length frequencies obtained in the survey (Figure 108) and in Kiel Bight (Figure 109).

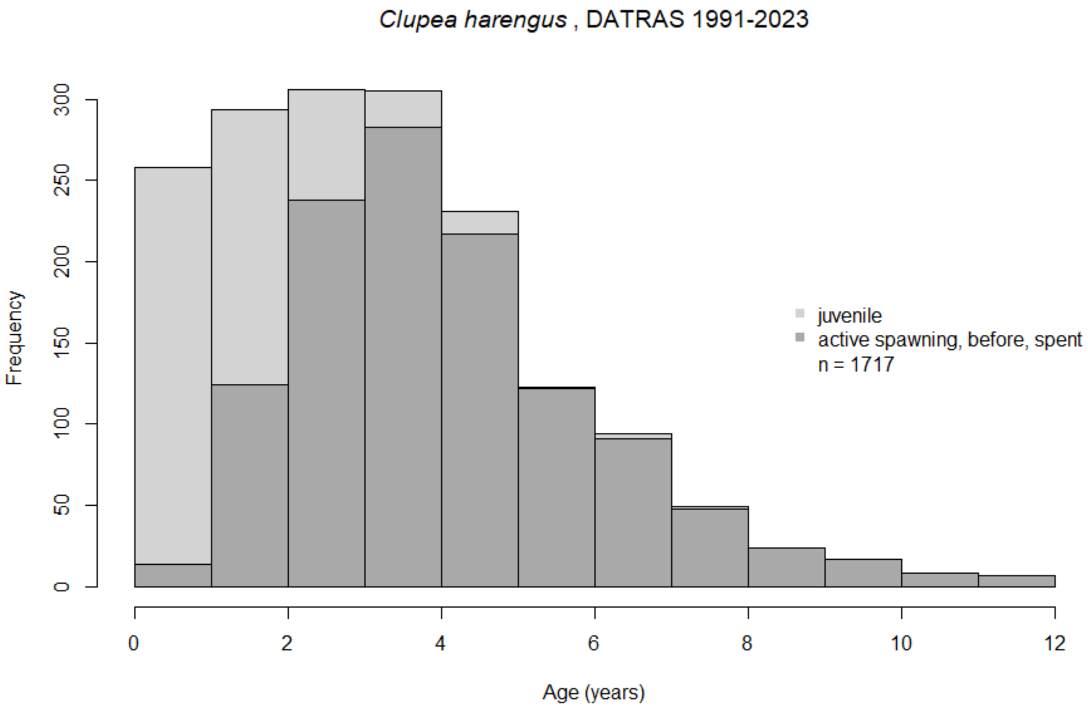


Figure 107. Age frequency of juveniles and adults based on the SMALK database (1st quarter, area 22 or 24).

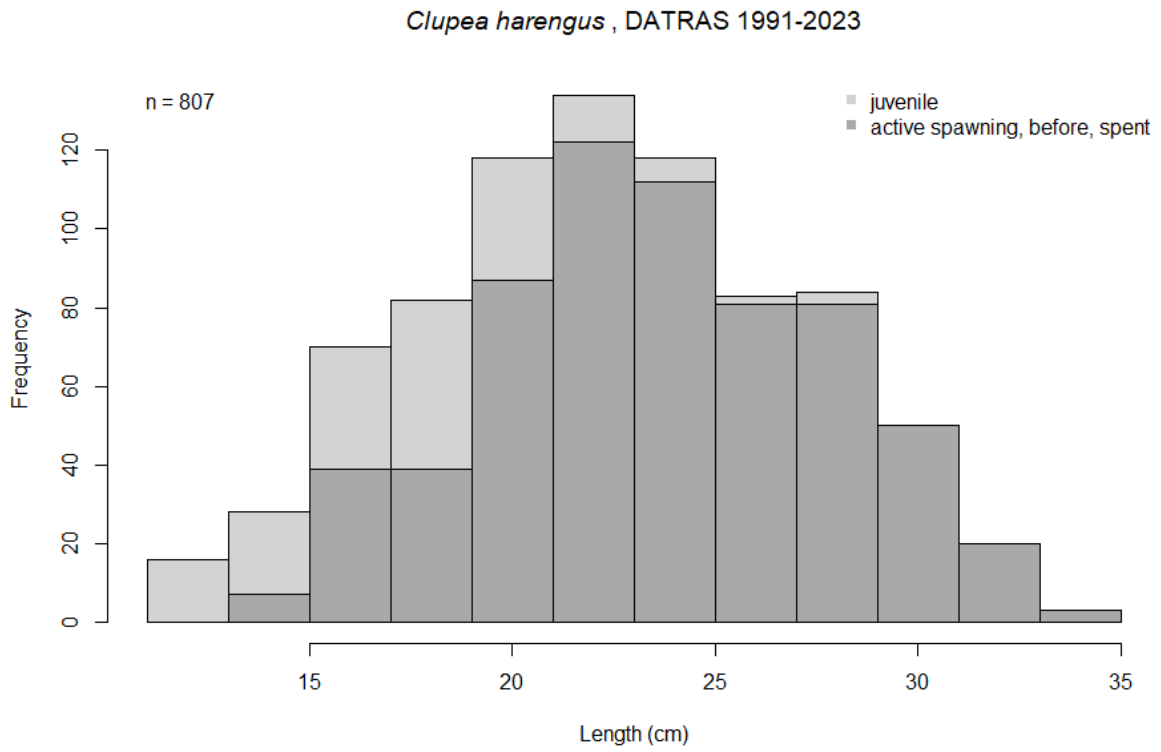


Figure 108. Length frequency of juveniles and adults based on the SMALK database (1st quarter, area 22 and 24).

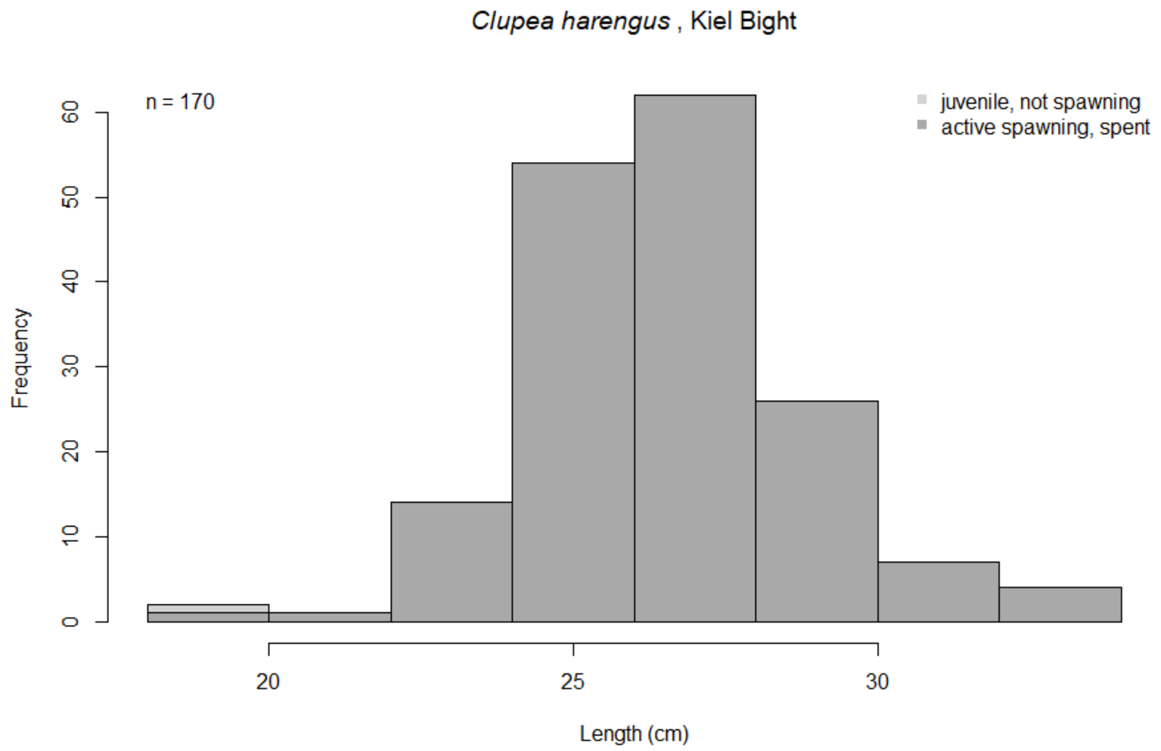


Figure 109. Length frequency of juveniles and adults based on data from commercial fishers (2021-2023).

Length-weight relationship and condition: The parameters of the length-weight relationship (Table 13, Figure 110) describe herring as a more elongated than fusiform species, indicated by *a* = 0.006 being well below the typical fusiform value of *a* = 0.01 (Froese 2006). Also, herring do not change their body shape or proportions much as they grow through late juvenile and adult life stages, indicated by *b* = 3.1 (Froese 2006). Most of the variability in the data is accounted for by the coefficient of determination (r^2 = 0.88, Table 13) of the log-log linear relation between body weight and length. There was only one outlying specimen (erroneous measurements or starving) which was excluded from this and other analyses.

Fishers from Kiel Bight reported that all commercial fish were getting thinner. This observation is confirmed by DATRAS survey data for the western Baltic from 1991 to 2020, showing a decline in herring condition of 12.5% (Figure 111).

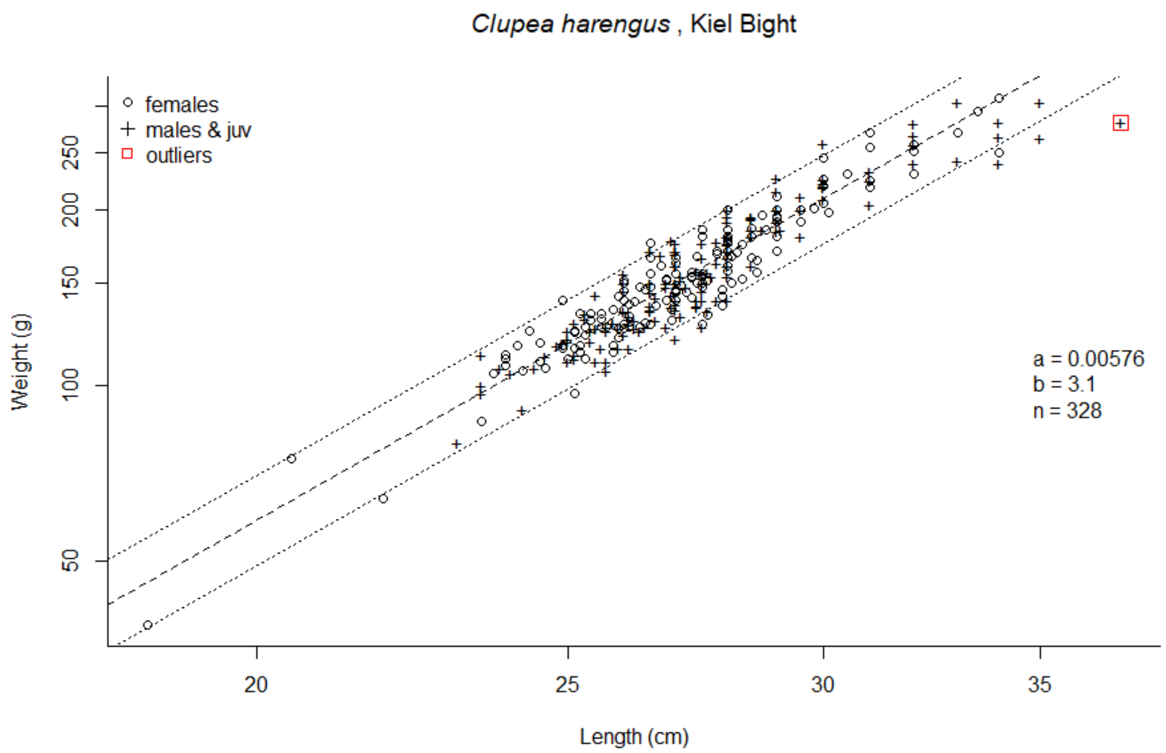


Figure 110. Length-weight relationship for plaice (Pleuronectes platessa) in Kiel Bight, based on samples taken from December to May in 2021-2023 in commercial gill net and trawl fisheries. The dashed line indicates the overall fit and the dotted lines indicated the 95% confidence limits.

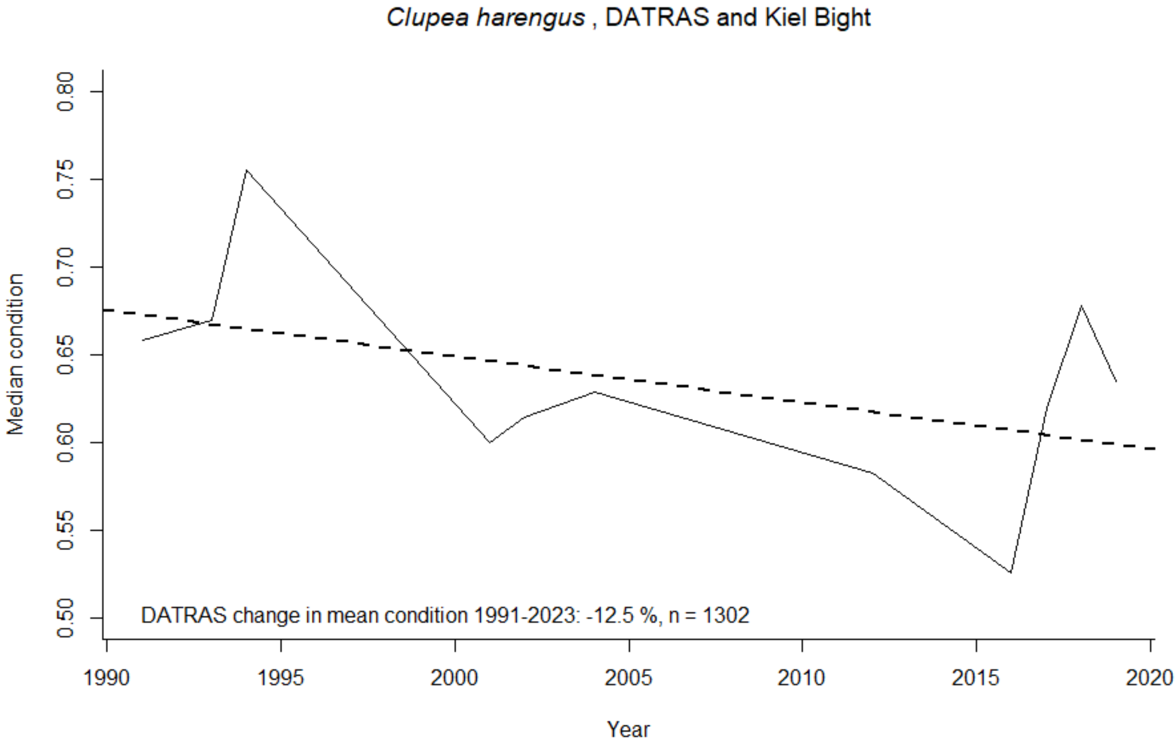


Figure 111. Change in median condition based on DATRAS (black curve and dashed line, 1st quarter, area 22 and 24).

Length and age at maturation: The size and age where 50% or 90% of female herring have reached sexual maturity and participate in spawning is L_{m50} = 16 cm and L_{m90} = 21.7 cm (Figure 108, Figure 112, Table 13) at ages 3 and 5 (Figure 107, Table 13), based on survey data. An ogive curve fitted to data derived in this study suggests L_{m50} = 18 cm (Figure 113), which is however is however less supported because of only few data being available for herring in Kiel Bight.

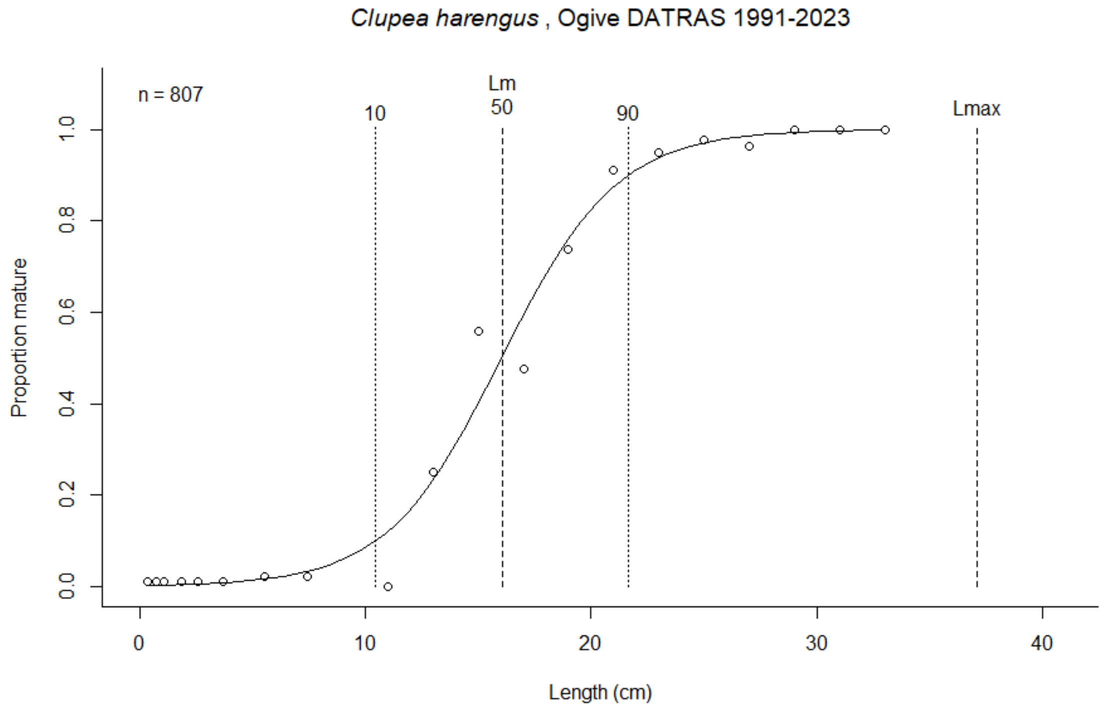


Figure 112. Proportion of mature females based on the SMALK database (1st quarter, area 22 and 24).

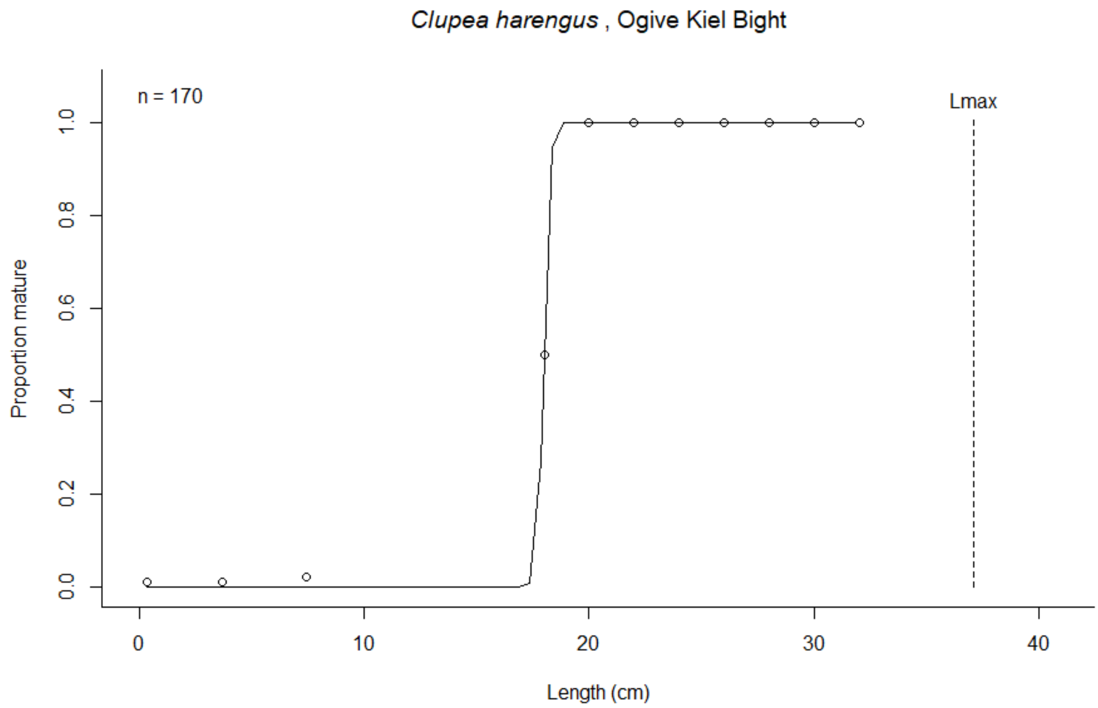


Figure 113. Proportion of mature females based on data from commercial fishers in Kiel Bight (2021-2023). Note that the available size range is insufficient for proper estimation of Lm50 and Lm90.

Fecundity as a function of body weight: The base assumption of the relation between fecundity and body weight is that the number of eggs of a female or the maximum weight of the gonads grows about proportionally with body weight. Overall, the fully developed ovaries of herring females examined in Kiel Bight took up about 28% (95th percentile) of total body weight (Table 13, Figure 114). The available data on relative weight of ovaries (gonado-somatic index) collected in Kiel Bight also suggest that the increase in herring fecundity was higher (slope = 1.78) than predicted by a directly proportional increase in body weight (Table 13, Figure 115).

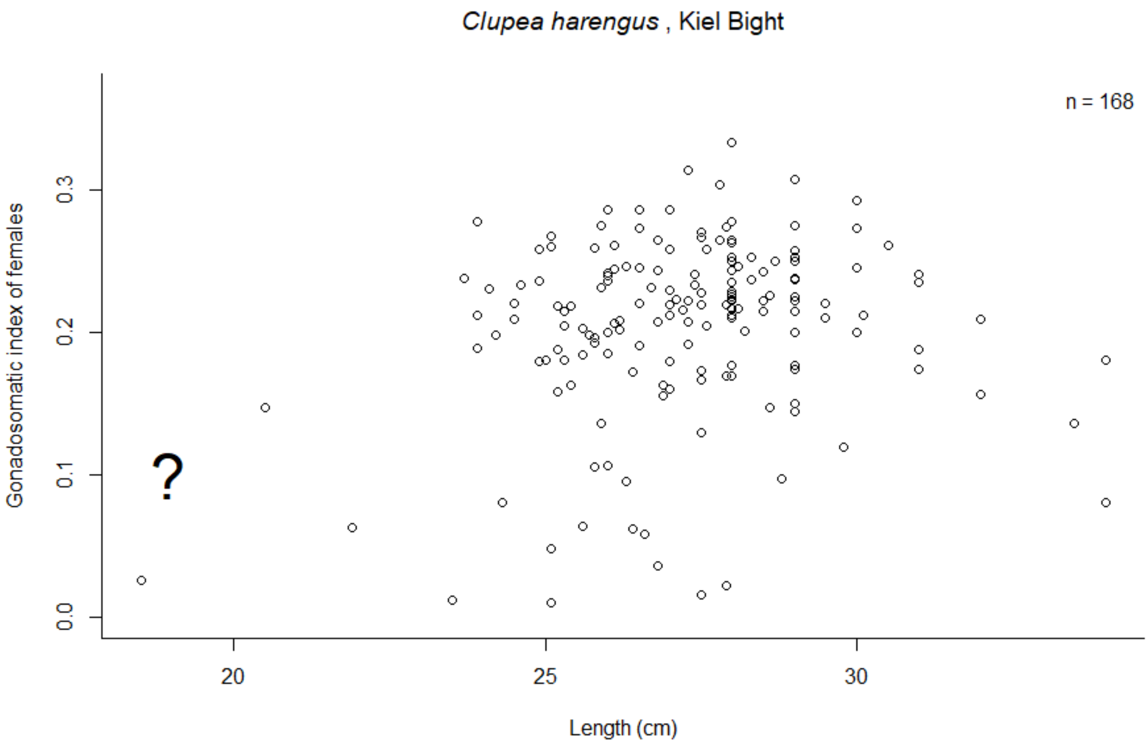


Figure 114. Relative weight of ovaries (GSI) plotted over body length of females in Kiel Bight, 2021-2023. The available data for small herring are too few to establish length at first maturity. No data were available for smaller herring (indicated by the question mark), making the determination of the lowest length with fully developed gonads difficult.

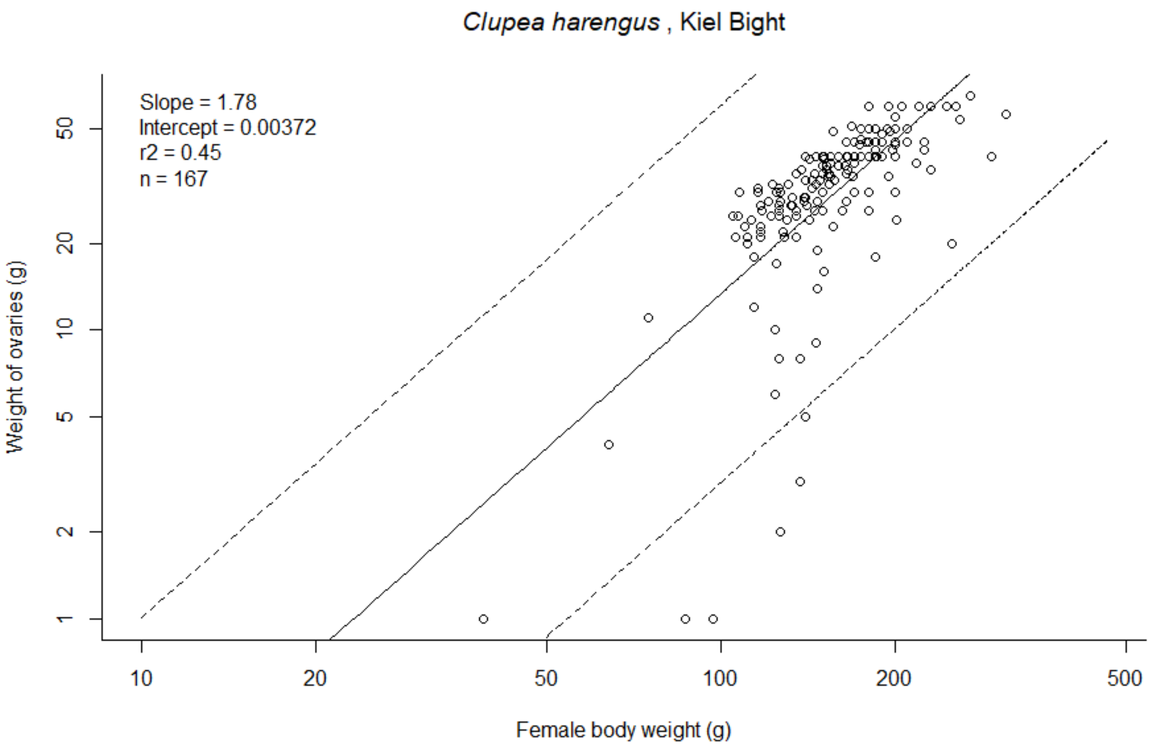


Figure 115. Weight of ovaries in different stages over body weight based on data from commercial fishers in Kiel Bight (2021-2023). Note that a slope > 1 suggests that the weight of ovaries and thus fecundity increases faster than body weight.

Sex ratio: The male/female sex ratio of herring fluctuated (strongly) around 1:1 in survey data taken from throughout the western Baltic Sea and in the (few) data taken by commercial fishers in Kiel Bight (Table 13, Figure 118). A close to 1:1 sex ratio was to be expected in Kiel Bight because herring spawn in several shallow water locations throughout that area.

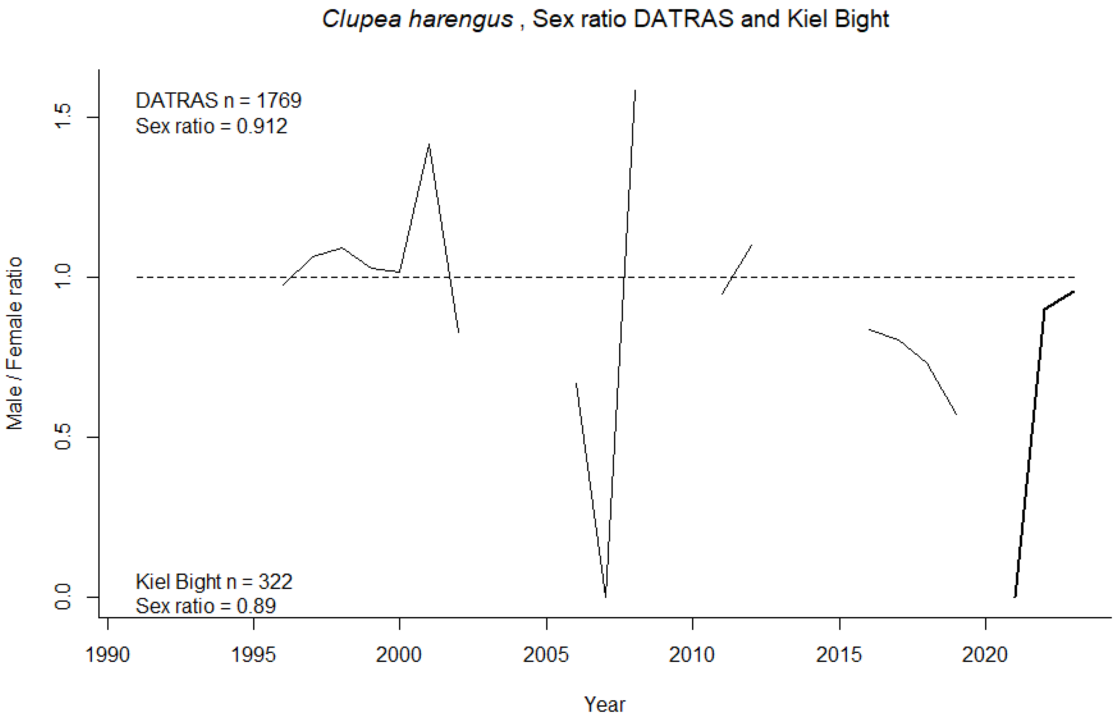


Figure 116. Time series of annual sex ratios, based on DATRAS (upper curve) and Kiel Bight (right bold curve). The two low values (2007 and 2021) are artifacts of too few data and should be ignored.

Spawning season: Herring arrive for spawning on vegetation and gravel in shallow waters of the western Baltic Sea and Kiel Bight once the water temperature has reached about 5°C. The available data for 2021-2023 (Figure 117, Figure 118) show the presence of ripe females in March and April, but the data were too few to properly determine range and peak of the herring spawning season.

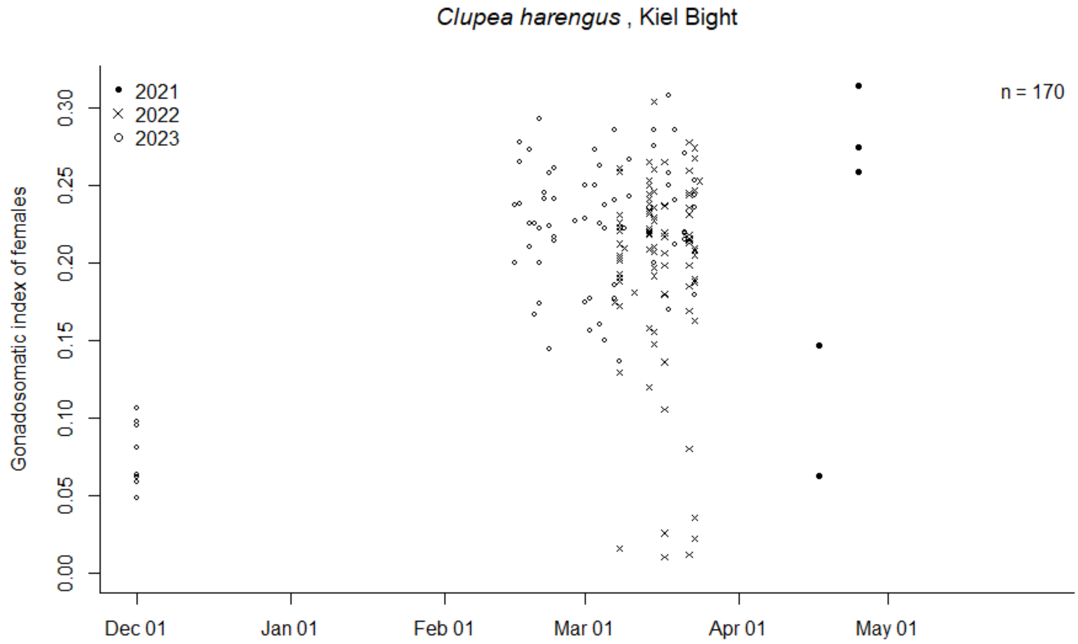


Figure 117. Timing of spawning as indicated by the gonadosomatic index of females in Kiel Bight, based on samples taken in 2021-2023 in commercial gill net fisheries. Note that data are lacking for Dec-Feb and April-May.

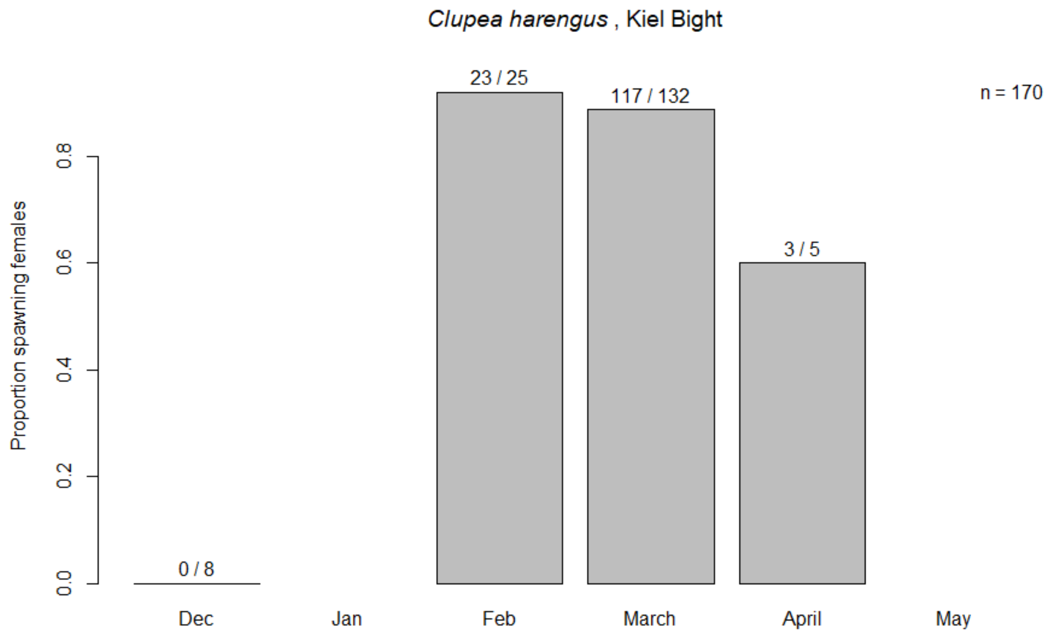


Figure 118. Monthly number of actively spawning females (L > Lm90 and gsi > 0.05) relative to the total number of females examined (numbers on top of bars), for years 2021 to 2023 in Kiel Bight. Note that data are lacking for Dec-Feb and April-May.

Somatic growth: Thousands of herring have been caught in standard scientific surveys and have been aged for stock assessment purposes. However, the uncertainty of these age readings is very wide, suggesting e.g. that one year old herring can be between 8 to 21 cm long (Figure 119). Fitting a growth curve to these length-at-age data strongly underestimates asymptotic length (L_{inf}) when compared with observed lengths. Instead, a more convincing growth curve was obtained by setting

L_{inf} equal to the maximum observed length L_{max} = 37.1 cm and using the median length of one year old herring according to DATRAS to anchor the growth curve (Table 13, Figure 119) (Froese 2022).

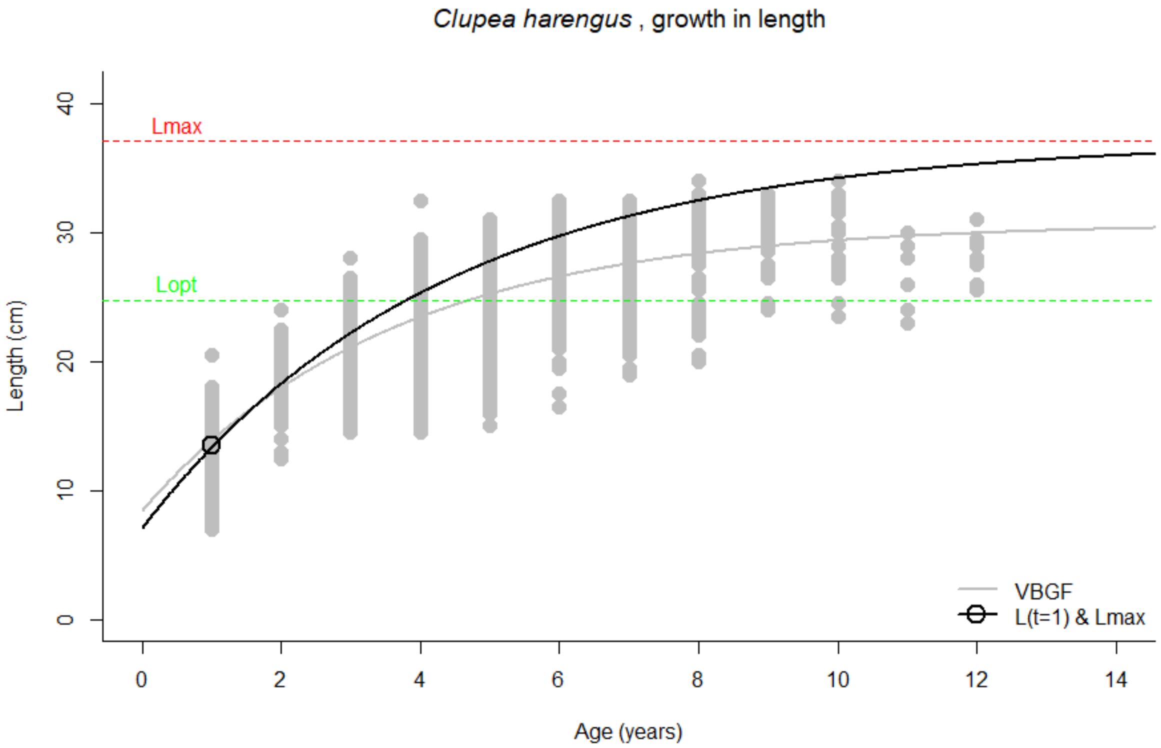


Figure 119. Growth in length based on DATRAS age readings from 2020-2022, first quarter, area 22 and 24. Note highly variable length-at-age readings in older fish and the underestimation of L_{max} by the fitted asymptotic length (L_{inf}), making the derived growth parameters doubtful. The black curve uses instead observed L_{max} as a proxy for L_{inf} and the median length of one year old fish and a user-provided estimate of t_0, resulting in a more plausible growth curve (Froese 2022).

Fisheries management considerations: There is an optimal length (L_{opt}) for catching fish, where the increase in body weight has reached a maximum, and where most individuals have already reproduced 1-3 times. This is also the length where catches will be highest for a given effort or where for a given catch the least number of fish will be killed (Froese et al. 2016). A proxy for L_{opt} can be derived as 2/3 of maximum length (see Material and Methods), which for herring in the western Baltic gives L_{opt} = 24.7 cm with an optimum length at first capture as L_{c_opt} = 20.8 cm (Table 13). The peak length in survey catches from 1991 to 2023 was 22 cm, which is above L_{c_opt} and close to the optimum length (Figure 108). The peak length in catches by commercial fishers in Kiel Bight was 27 cm, which is above L_{opt} and thus correct (Figure 109). Herring are not caught by the larger mesh sizes used for capturing cod and flatfish, and thus there would be no bycatch issues if the fishery for herring was closed completely until the stock size has recovered, as advised by ICES (ICES-her 2023).

A summary of relevant reference points for herring as extracted from DATRAS for the western Baltic Sea or established in this study for Kiel Bight is presented in Table 13.

Table 13. Key life history reference points for herring, with plausible 95% confidence limits (LCL, UCL) or coefficient of determination (r^2), where applicable, derived from catches of commercial fishers in Kiel Bight (KB) in 2020-2023, December/January and May, and from scientific surveys in the Western Baltic Sea as documented in DATRAS for the first quarter of the years 2000-2022 in areas 22 and 24. Doubtful estimates are marked with ***??***

Species	Herring	*Clupea harengus*				Clupeidae	
Parameter		estimate	LCL	UCL	n r^2	Unit	Method
Lmax KB	Maximum length	37.1				cm	largest on record
Lmax datras	Maximum length	30.5				cm	largest on record
Lmax	Maximum length	37.1				cm	chosen for study
a.f KB	W=**a**L^b, females	0.00506	0.00301	0.00851	n=170	g/cm^b	log-log regression
b.f KB	W=aL$^{\mathbf{b}}$, females	3.12	2.97	3.28	r^2=0.90		log-log regression
a.m KB	W=**a**L^b, males	0.00907	0.0048	0.0171	n=157	g/cm^b	log-log regression
b.m KB	W=aL$^{\mathbf{b}}$, males	2.95	2.75	3.14	r^2=0.86		log-log regression
a.c KB	W=**a**L^b, combined	0.00576	0.00384	0.00866	n=328	g/cm^b	log-log regression
b.c KB	W=aL$^{\mathbf{b}}$, combined	3.08	2.96	3.21	r^2=0.88		log-log regression
Wmax KB	Maximum weight	310				g	largest on record
Wmax DATRAS	Maximum weight	300				g	largest on record
Wmax LWR	Maximum weight	399				g	Wmax=a.c Lmax$^{b.c}$
Wmax	Maximum weight	310				g	chosen for study
tmax DATRAS	Maximum age	14				years	largest on record
L_opt	Optimum length	24.7				cm	2/3 Lmax
Lc_opt	Optimum capture	20.8				cm	0.56 Lmax
Wopt	Optimum weight	114				g	a.c Lopt$^{b.c}$
Wc_opt	Optimum capture	66.7				g	a.c Lopt$^{b.c}$
MCRL	Minimum length	NA				cm	EU law
Lm50 KB	50% mature fem.	18			n=170	cm	ogive
Lm90 KB	90% mature fem.	18.3				cm	ogive
Lm50 DATRAS	50% mature fem.	16	15.4	16.7	n=806	cm	ogive, SMALK
Lm90 DATRAS	90% mature fem.	21.7	20.3	23.1		cm	ogive, SMALK
tm50 DATRAS	50% mature fem.	3				years	first age > 0.5 mature
tm90 DATRAS	90% mature fem.	4				years	first age > 0.9 mature
sex ratio KB	males / females	0.89 : 1			n=322		n (sex=m) / n (sex=f)
sex ratio DATRAS	males / females	0.91 : 1			n=1769		n (sex=m) / n (sex=f) Exchange 1991-2023
gsi.95 KB	Gonad/Body weight	0.279			n=167		95th percentile of GSI
gsi.slope KB	Gonad/Body slope	1.78	1.48	2.08	r^2=0.45		gonads ~ body weight
spawning season	peak, range	Feb	Feb	April	n=168	month	L>Lm90, mat > 10%
Linf DATRAS	Asymptotic length	30.7 **??**	30.1**??**	31.5 **??**	n=2355	cm	VBGF fit
K DATRAS	Growth parameter	0.28 **??**	0.256 **??**	0.305**??**		year^{-1}	VBGF fit
t0 DATRAS	Growth parameter	-1.14 **??**				years	VBGF fit
SE DATRAS	SE of residuals	2.64 **??**				cm	VBGF fit
Linf KB	Asymptotic length	37.1			n=354	cm	Linf=Lmax
K KB	Growth parameter	0.234				year^{-1}	from median L(t=2)
t0 KB	Growth parameter	-0.9				years	t0 = t0.user

Results across species

Stations

Table 14. Summary of analysis of commercial species in Kiel Bight, 2020 – 2023.

Stations	all=452, gill=334, fyke=12, trawl=106		
Time frame	19.02.2020 – 31.05.2023, December to May		
	mean	**min**	**max**
Duration of gear deployment[h]	21.9	0.2 (trawl)	168 (fyke)
Depth [m]	11.3	3	24
Bottom temperature [°C]	5.25	2.52	11.3
Species analyzed:	**n**	**min cm**	**max cm**
Cod (*Gadus morhua*)	1382	9	106
Plaice (*Pleuronectes platessa*)	2465	19	55.7
Flounder (*Platichthys flesus*)	604	19	48.1
Dab (*Limanda limanda*)	1181	21	46.7
Turbot (*Scophthalmus maximus*)	173	26.4	58
Brill (*Scophthalmus rhombus*)	69	30	64
Lemon sole (*Microstomus kitt*)	85	29	38
Herring (*Clupea harengus*)	329	18.5	37.1

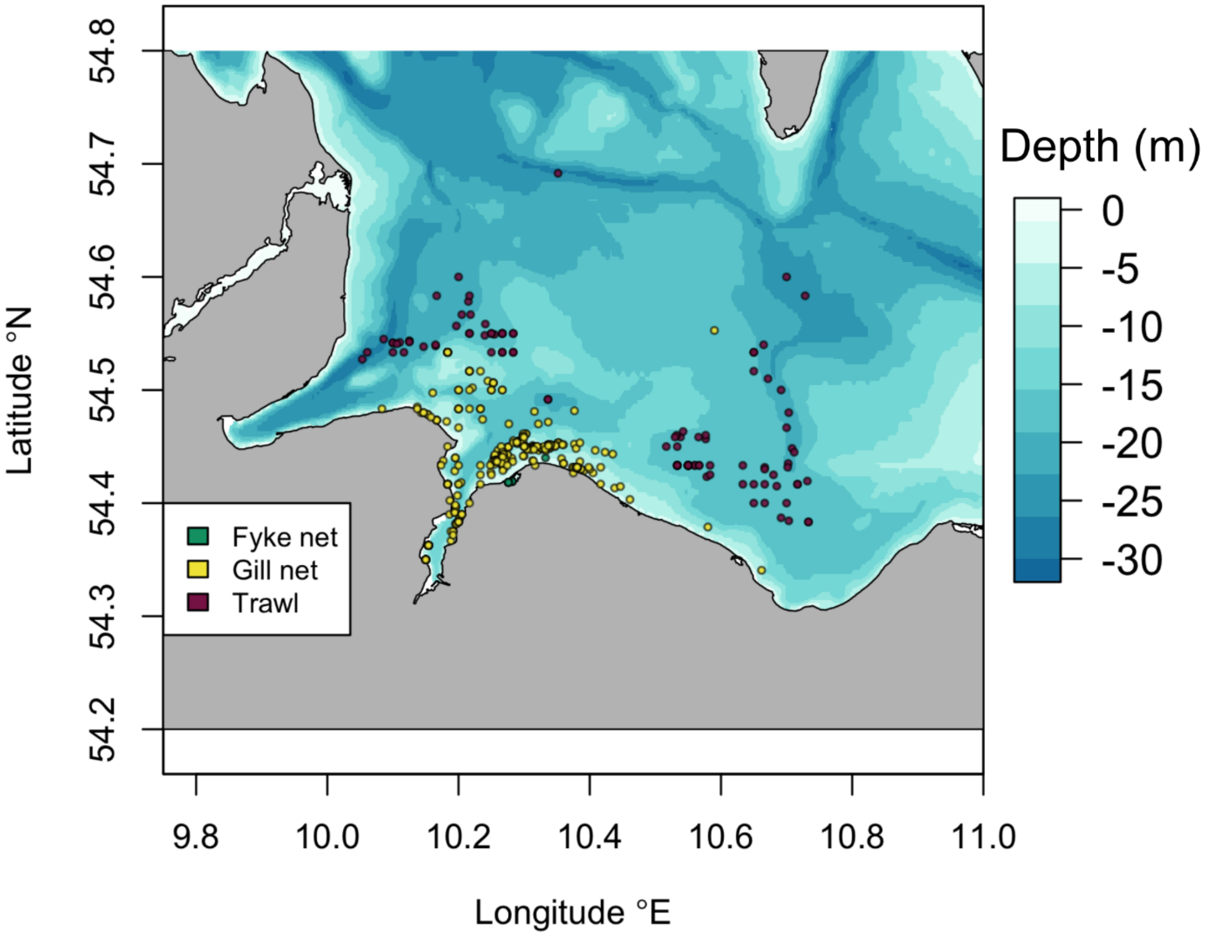


Figure 120. Stations with catch analyzed by commercial fishers in Kiel Bight, 2020-2023.

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