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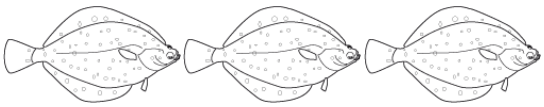
Evidence for a single plaice stock in the Baltic Sea

Working Document

Review of current stock boundaries and recent research publication on the stock structure



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What is the proposal for stock merging?

We propose to merge the two currently used stock units “ple.27.21-23” (Kattegat, Belt Seas, and the Sounds) and “ple.27.24-32” (Baltic Sea, excluding the Sound and Belt Sea) into one stock “ple.27.21-32” (Baltic Sea and Kattegat).
Recent genetic studies, historical and contemporary mark-recapture experiments, biological information and stock assessment trends are supporting the assumption that plaice in the Baltic Sea is in fact only stock that is extending into the Kattegat and has only very limited exchange with plaice in Skagerrak and North Sea.

Summary

Plaice in the Baltic Sea (subdivisions 22 to 32) has been split into two stocks based on a recommendation made by the Workshop on the Evaluation of Plaice Stocks (WKPESTO) in 2012, which was kept by the WKPLE benchmark in 2014. However, the WKPESTO decision was based on very little data, as the focus

of the group was to investigate the connection of plaice stocks in the Skagerrak towards the North Sea. The genetic study used at this time included very few samples from the Eastern Baltic Sea as reference material and did not sample the major part of the stock in the Belt Sea. Additional assumptions on possible spawning grounds also proved to be inaccurate, as shown by later distribution analyses.
A recent genetic study from 2022 (Weist et al. 2022) reported on the generation of an annotated draft plaice genome assembly in combination with population sequencing data—following the salinity gradient from the Baltic Sea into the North Sea. Genome-wide selection analyses (*xp-EHH*) did not display any differentiation between the two plaice stocks in the Baltic Sea, suggesting that there is in fact one Baltic plaice stock.
Additionally, the developments of the two stocks (in terms of survey indices, stock assessment trends, Stock-Recruitment-relationships) are almost identical. Historic and recent tagging studies display regular recaptures of plaice across their assumed stock boundaries, further supporting a merging of the two stock units into one stock, covering the Baltic Sea and Kattegat.

Background and recent publications on Baltic Sea plaice stock identity

History of stock ID in Baltic plaice

Presently, sole (*Solea Solea*) and plaice (*Pleuronectes platessa*) are the only flatfish species in the Baltic Sea regulated by catch limits. Plaice in the Baltic Sea was treated as a single stock (plaice in subdivisions 22-32) until WKPESTO (ICES 2012). ICES decided that plaice from Subdivisions 22 (the Belts) and 23 (the Sound), which were previously assumed to be part of the Baltic Sea stock, should be considered a separate stock unit together with Subdivision 21 (Kattegat) (ICES, 2012). Plaice in Subdivisions 24 to 32 was considered to be a different stock. The assessment units were amended to fit these new stock definitions, i.e. ple.27.21-23 and ple.27.24-32. For management purposes, however, the old areas were retained and a TAC is fixed for SD22-32 and Plaice in the Kattegat (SD21) separately.

WKPESTO (2012) was tasked to look at the stock ID of plaice in the Skagerrak (SD 20) and adjacent areas. The group focused almost exclusively on the Kattegat and Skagerrak populations and this was also reflected in the participation and data provided to the workshop (e.g., almost no data was available from the Baltic proper). Apparently, the group thought it should also propose new stocks further to the East even with the serious limitations of data available from that area.
There is very little information available in the WKPESTO (2012) report on the rationale of splitting SD24-32 from the westerly areas (SDs 22-32), among these is: "*5.3.3 BITS Survey: A combined BITS survey index for the area 22-25 was computed by ICESe, including the German Solea survey. This survey was not investigated during the WK, and this time series should be revised in order to include areas 24-25 only*". WKPESTO also stated that there are "indications that the spawning areas are likely to be located in the southern part of SD 25 and 26, but the exact spawning locations are not known" (ICES 2012), but did not provide further evidence or data on that matter. Historic and recent tagging studies and distribution maps from surveys and fisheries (presented in this working document) are indicating that the spawning grounds are rather located in the Arkona basin in SD24, neighboring the spawning grounds of the Bel Sea in SD22.
Scientific evidence from both areas in question such as genetics, maturity patterns, population dynamic, behavior, tagging or survey data were not analyzed. Nevertheless, WKPESTO (2012) recommended defining a separate stock in SD 24-32 and to adjust the management area to the new stock distribution area.

Overall, the null hypothesis "there is one plaice stock in (21)22-32" has never been rejected based on genetic evidence. ACOM decided to give advice for plaice in SD21-23 (and not split this in even smaller units), and a second stock in SD24-32 separately, but at the same time withdrew the recommendation to amend the management areas until the stock ID issues with Baltic plaice were satisfactorily resolved. WGBFAS repeatedly raised serious concerns about the validity of a separation between the eastern and the western populations.

Latest genetic evidence

Now, Weist et al. 2022 reported "the generation of an annotated draft plaice genome assembly in combination with population sequencing data—following the salinity gradient from the Baltic Sea into the North Sea together with samples from Icelandic waters—to illuminate genome-wide patterns of divergence." The sampling covered all relevant subdivisions (SDs 21, 22, 24, 25, 26) and at three locations in the North Sea, with plaice from Iceland as an outgroup. Weist et al. 2022 "detected subtle levels of genetic substructure among North Sea samples and between samples from the North Sea and the Baltic Sea (Table 2). Within the Baltic Sea, we observed low levels of genetic differentiation among all four sampling locations (SD 22, 23, 24, 25). And no significant population structure was identified among plaice specimens caught throughout the steep salinity gradient from the Baltic Sea following the shallow straits of the archipelago into the North Sea area based on neutral SNP markers…". More details can be found in Weist et al. 2022.

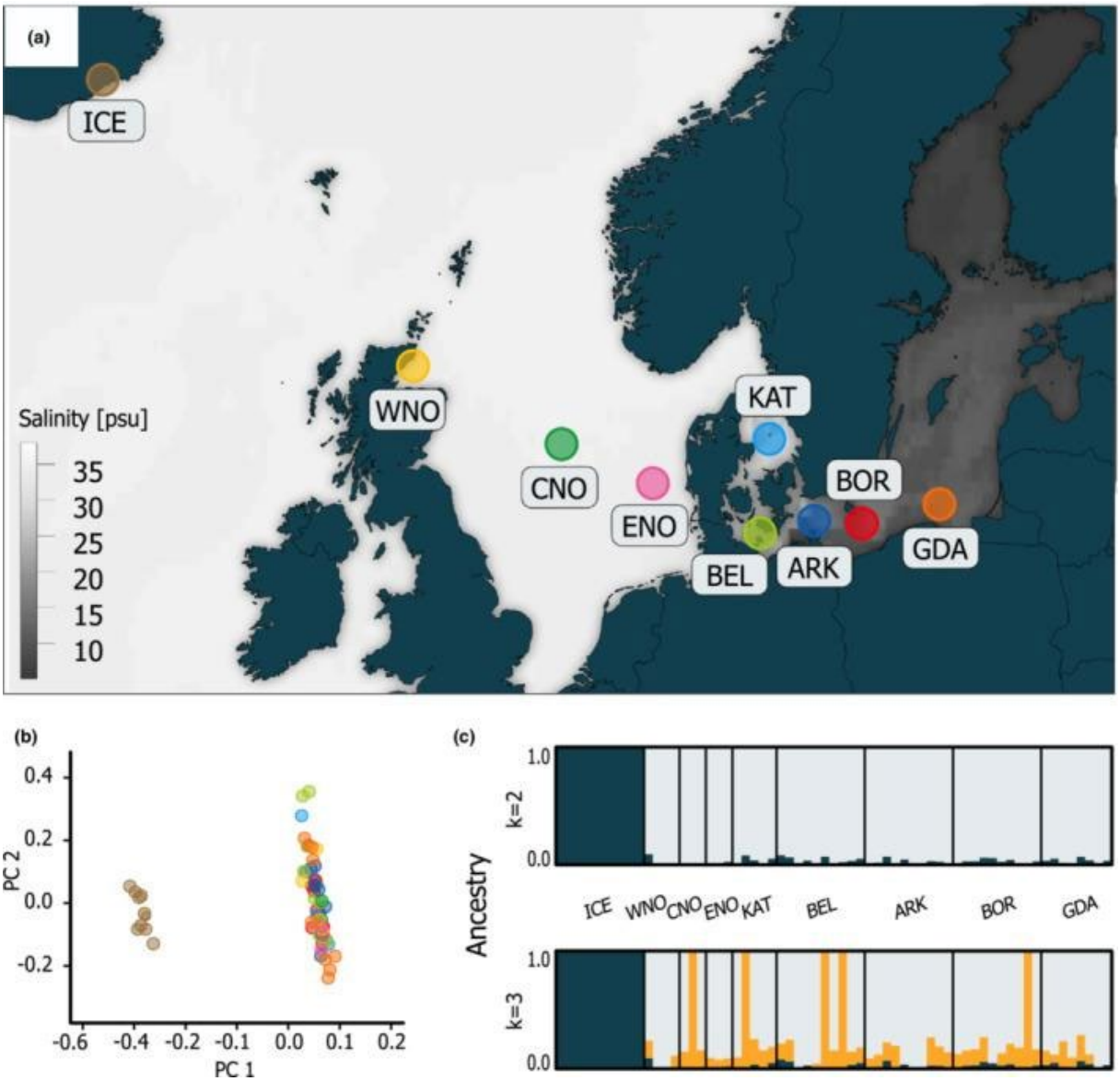


Fig. 1. Population structure analysis from a total of 63 European plaice samples based on 83,011 genome-wide distributed single nucleotide polymorphisms (SNPs) (Weist et al. 2022). (a) Map of sampling locations of plaice individuals included in this study (see also Table S1). (b) Principal component analysis (PCA) of population differentiation. Individuals are color-coded corresponding to the sampling locations in (a). (c)

Genetic clustering according to an analysis with admixture for *k* = 2 (above; most likely number of putative ancestral populations) and *k* = 3 (below). Genetic clusters are represented by different colors with vertical bars showing the ancestry proportion for each individual genotype.

The results of Weist et al. (2022) are supporting earlier findings by Le Moan et al. (2019, 2021) who compared genome-wide population structure using sets of RAD-sequencing SNPs with the spatial structure of Structural variant (SV) polymorphisms.
Their data show genomic heterogeneity of the European plaice population structure and discovered two putative SVs displaying allele frequency differentiation following the salinity gradient from the North Sea into the Baltic Sea.
Based on pairwise F_{ST} analyses by Weist et al (2022) on the pruned/neutral marker, subtle differentiation between plaice from Central and Western North Sea (CNO, WNO) versus the eastern Baltic Sea samples (ARK, BOR, GDA) was detected (see Table 1), refining the results of Le Moan et al (2021). No genetic differentiation among Baltic samples was detected.

Table 1. Estimates of genome-wide differentiation between samples of European plaice based on 83,011 SNPs (Weist et al. 2022)

	ICE	WNO	CNO	ENO	KAT	BEL	ARK	BOR	GDA
ICE		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
WNO	**0.019**		1	1	1	0.684	1	<0.001	<0.001
CNO	**0.021**	0.002		1	<0.001	1	<0.001	<0.001	<0.001
ENO	**0.015**	−0.003	0.000		1	1	1	1	1
KAT	**0.019**	0.001	**0.003**	0.000		1	1	1	0.072
BEL	**0.019**	0.001	0.001	−0.004	0.000		0.072	0.648	1
ARK	**0.020**	0.001	**0.002**	−0.003	0.001	0.001		0.072	1
BOR	**0.019**	**0.001**	**0.004**	−0.001	0.001	0.001	0.001		1
GDA	**0.018**	**0.002**	**0.005**	−0.001	0.002	0.000	0.000	0.000	

**Note*: Pairwise F_{ST} estimates are presented below the diagonal and corresponding *p*-values above the diagonal. Significant estimates are indicated in bold.

These studies were building on an earlier multi-disciplinary study by Ulrich et al. (2017) on plaice from the Eastern North Sea to the Baltic Sea involving genetic and biological analyses. While the focus was on the transition zone (Skagerrak and Kattegat), the Baltic Sea was also covered. Samples from the Western Baltic and Eastern Baltic were available and enhanced findings from a former study (Ulrich et al., 2013), which did not consider comparison within the Baltic Sea. The genetic results of Ulrich et al. (2017) suggested "the existence of different genetic populations in the North Sea, the transition zone and the Baltic Sea. The results from the AMOVA analysis, with samples grouped according to the patterns observed in Fig. 3 (i.e., three groups represented by the samples [North Sea], [Kattegat, West Skagerrak, Skagerrak] and [Western Baltic, Eastern Baltic], respectively, supported this pattern." However, both studies did not include samples from the Belt Sea, which was also recognized as an issue by WKPLE (ICES 2015), adding uncertainty to the stock splitting that was suggested by WKPESTO in 2012.

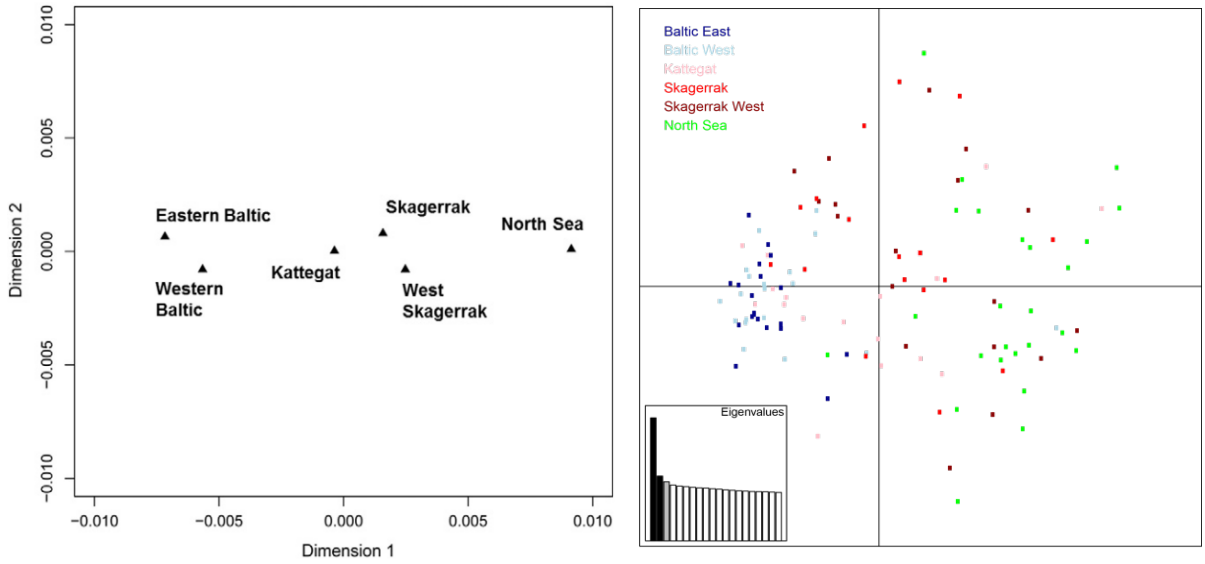


Fig. 3: Results of the genetic study conducted by Ulrich et al., 2017 Left Figure: Multidimensional scaling plot of pairwise estimates of genetic population differentiation (FST). Right Figure: Eigenvalue plots of the samples of plaice.

Ulrich et al. (2017) also investigated growth parameters in adult plaice based on otolith growth. The samples also did not indicate any differences in growth of plaice between the Western and Eastern Baltic Sea, but also none between Kattegat and the Belt Sea.

Table 2: Results of the pairwise comparison of back calculated growth between areas at two different spatial scales: Top: management areas scale (all fish). Bottom: at the scale of ICES (2012) Eastern and Western areas within Skagerrak and Kattegat (females only): Bold numbers represent geographically adjacent areas. Statistically different areas (p b 0.05) are marked with an asterisk.

	Skagerrak	Kattegat	Belt Sea	Western Baltic Sea	Eastern Baltic Sea
North Sea	**0.005***	<0.001	<0.001	<0.001	<0.001
Skagerrak		<**0.001***	<0.001	0.617	0.900
Kattegat			**1.000**	<0.001	<0.001
Belt Sea				<**0.001***	<0.001
Western Baltic Sea					**0.998**

	West Skag.	East Skag.	West Kat.	East Kat.
North Sea	**0.041***	0.274	<0.001	<0.001
West Skag.		**0.978**	<0.001	<0.001
East Skag.			**0.001***	0.129
West Kat.				**0.565**

Stock assessments and survey indices comparisons

Similar trends in ICES stock assessments

Plaice in SDs 21-23 is assessed by an age-based SAM model, which also has been conducted for plaice in SDs 24-32 (although advice was given on the relative SSB and relative R development). The SAM stock

assessments of the two Baltic Sea plaice stocks ple2123 and ple2432 show very similar trends since the beginning of the time series in 2002, indicating similar stock developments. Similar trends can be seen in SSB, F, and R development. Especially the outstanding recruitment peaks in recent years and the rise in SSB are characteristics equally seen in both “stocks” (Figure 4).

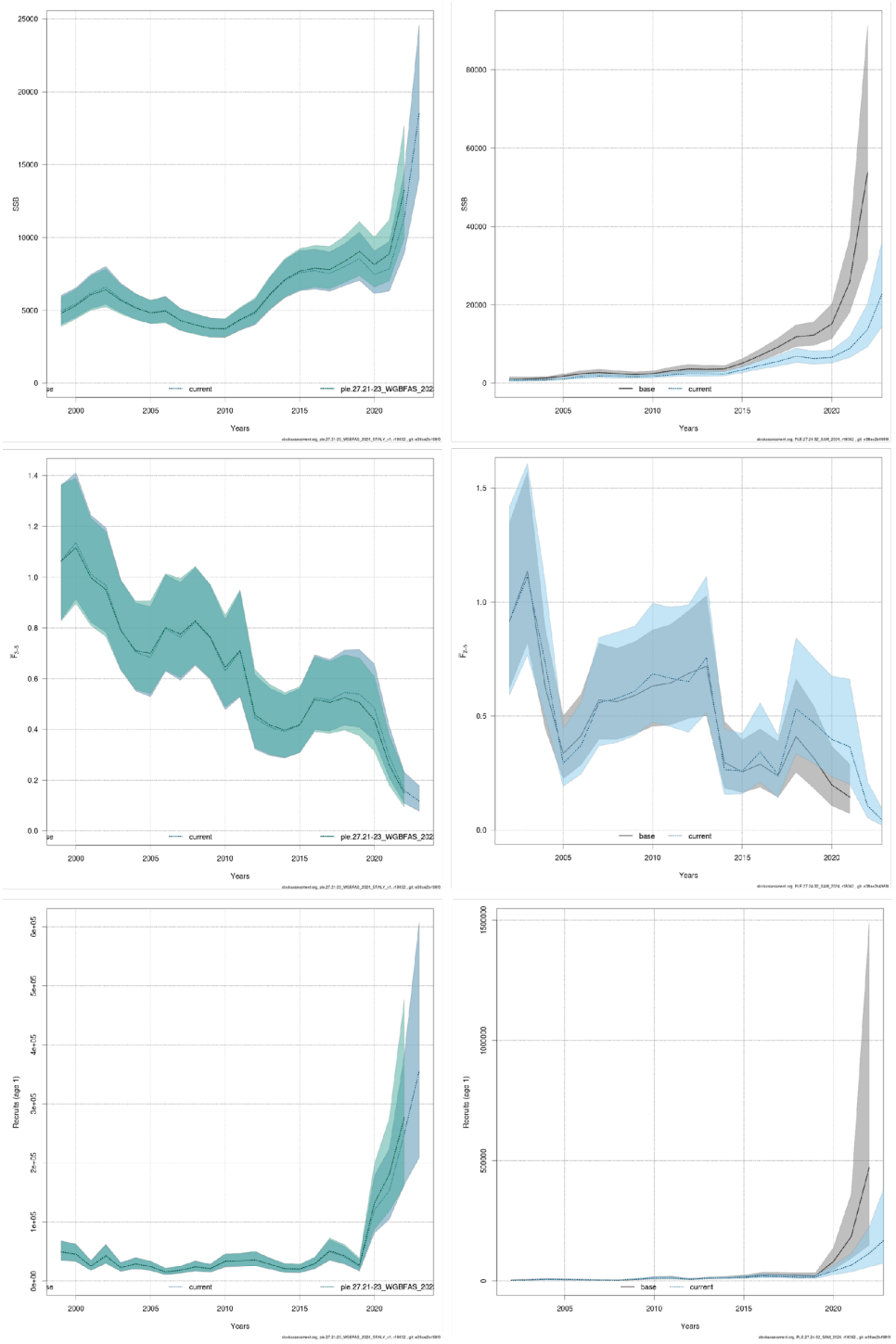


Fig. 4. Direct comparison of the most recent SAM outputs (ple21-23 on the left, ple 24-32 on the right). Note that the SAM assessment of ple24-32 has not been approved as an assessment method by ICES and input parameters in 2024 were not checked, as the assessment and advice is based on a SPiCT assessment since 2022.

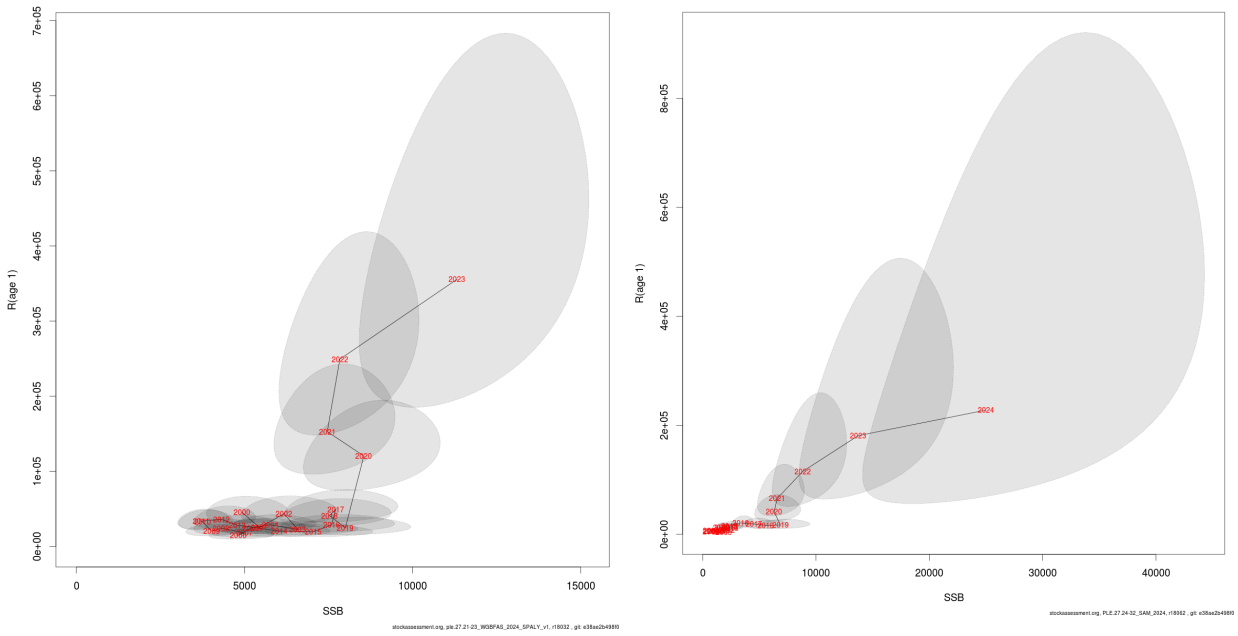


Fig. 5. Direct comparison of the most recent SAM outputs (ple21-23 on the left, ple 24-32 on the right). Spawner-recruitment relationships in the two stocks. Note that the SAM assessment of ple24-32 has not been approved as an assessment method by ICES and input parameters in 2024 were not checked, as the assessment and advice was based on a SPiCT assessment since 2022.

Survey trends

The International Bottom Trawl Survey (IBTS) covers the North Sea (Subarea 4) and the Transition area (Division 3.a. including the Skagerrak 3.a.20 and Kattegat 3.a.21) and is conducted two times per year in Quarter 1 and 3 (Q1, Q3). The Baltic International Trawl Survey (BITS) covers the entire Baltic Sea and Kattegat (3.a.21) and is also conducted twice per year, in Q1 and Q4. Both surveys are conducted using the same sampling protocols and data are publicly available at the International Survey database DATRAS, hosted by ICES (https://datras.ices.dk).

Survey CPUE indices for plaice at length per haul from before 2001 are standardized to the standard TV3 trawl used by all vessels since 2001 by multiplying with a conversion factor. Then the mean age at length per depth stratum and sub-division are calculated and weighted with the surface area (m2) of the stratum. From these means, the mean catch-at-age per sub-division and then the mean catch per index area are calculated.

Calculations:

- CPUE per length (l) and haul (H) are multiplied with the conversion factor (conf) for the gear to give CPUE adjusted for gear performances (conf)

$$confCPUE_{H,l} = CPUE_{H,l} * conf$$

- Age is allocated to the length distribution as described above.

- Number per length (l) (1 cm group) per haul is summed by year, quarter, sub-division and depth stratum (DS) and divided with total hauls in the depth stratum.

The indices are currently compiled for each stock outside of DATRAS, using the CPUE per age per area (subdivision) and combined according to the stock boundaries.

The CPUE survey indices display very similar trends between the two stocks ple21-23 and ple24-32 (Figure 6). Both stocks slowly increased in the early 2000s and rapidly increased in the late 2010s.

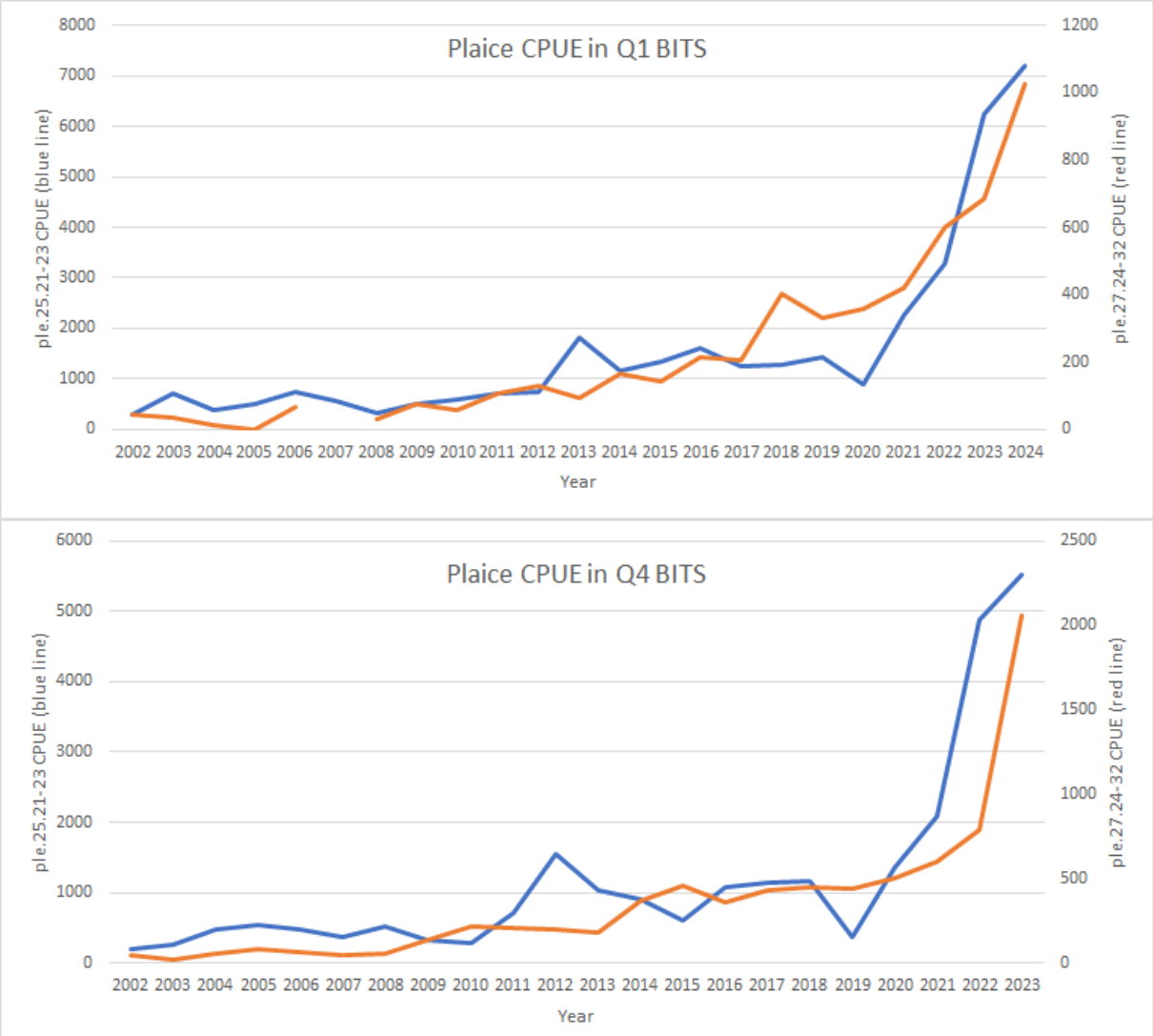


Fig. 6. Comparison of the cpue by age indices (age classes 1 to 7) between the two plaice stocks, ple.27.21-23 (blue line, left axis)and ple.27.24-32 (red line, right axis) in the two surveys BITS Q1 (upper graph) and BITS Q4 (lower graph)

Survey distribution maps of the two most recent BITS (Q4 in 2023 and Q1 in 2024) do not display any spatial separation between plaice in the Belt Sea and Sounds and Arkona Sea (Fig. 7). In both quarters, plaice seems to be concentrated in the Belt Sea, extending into southern Kattegat and the Arkona Sea.

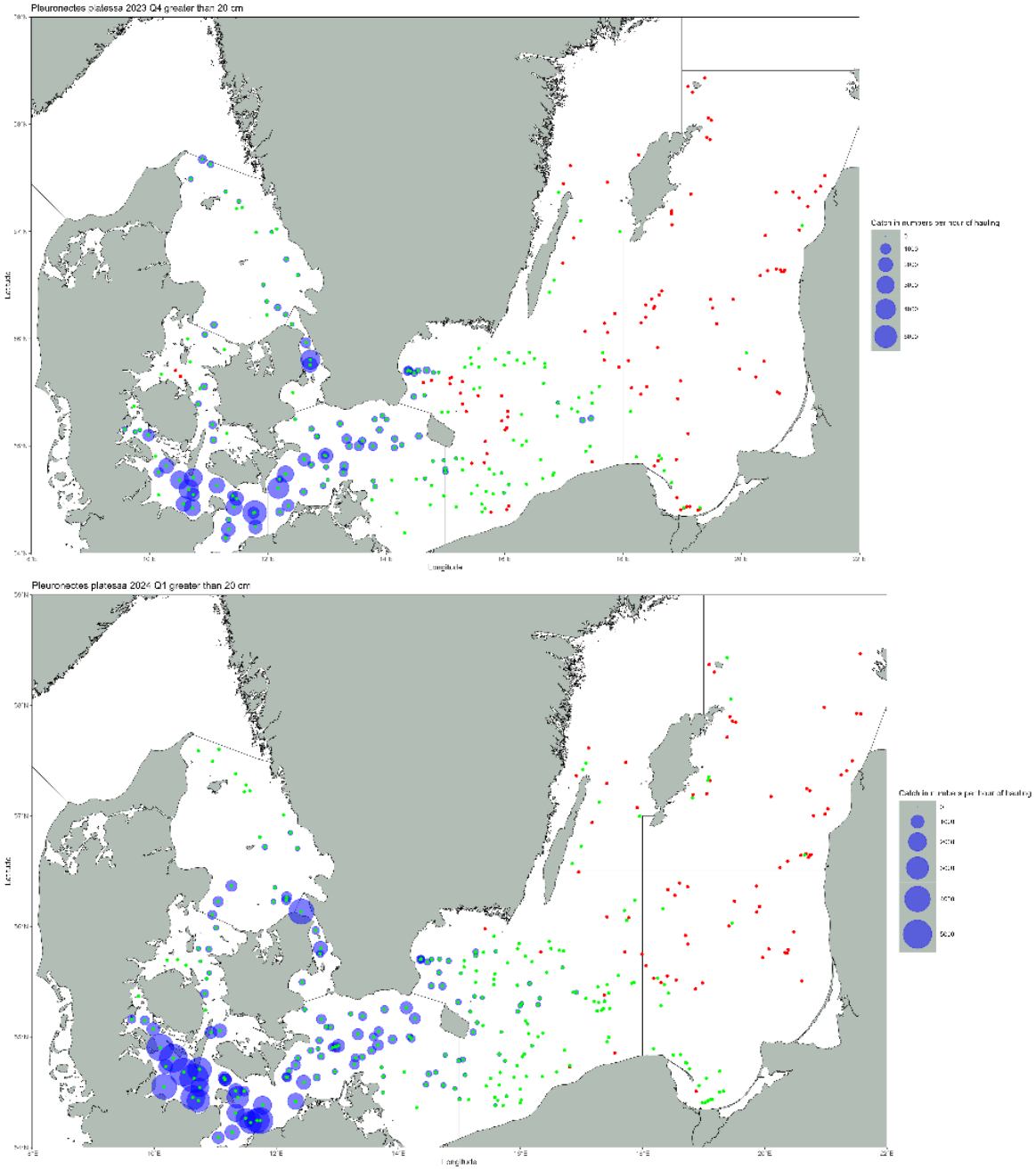


Fig. 7. Distribution maps of the most recent surveys (BITS in Q1 2024 and Q4 2023), raised to numbers per hour. Red dots indicate stations with zero plaice catches. Green dots indicate stations with very low numbers caught (threshold <10 individuals) and no raising to CPUE was conducted.

More distribution maps, covering the assessment time series from 2002 to recent (2024 Q1, preliminary), divided by length groups (juveniles <20cm and adult >20cm) and by survey (Q1 and Q4) are given in **Annex 1**.

Migration and tagging studies

Recaptures from tagging experiments conducted by the Thünen-OF since 2017 in SD22 and SD24 suggest that plaice mainly stay in the same subdivision. However, plaice tagged in the south of SD24 seem to

conduct spawning migrations in Q1 towards the deeper areas around Bornholm (Bornholms Gatt and Bornholm basin, i.e., northeast part of SD24 and western part of SD25). Plaice tagged in SD22 and on Darss Sill (western part of SD24) were recaptured in SD22; but there was also one individual that was tagged in Pomeranian Bay (SD24) and recaptured in Lübeck Bay (SD22) while another individual tagged nearby Pomeranian Bay was recaptured in SD25 (Fig. 8). Growth of recaptured adult plaice was generally low, ranging from rarely 4 cm/yr to usually something between 1 and 2 cm/yr.

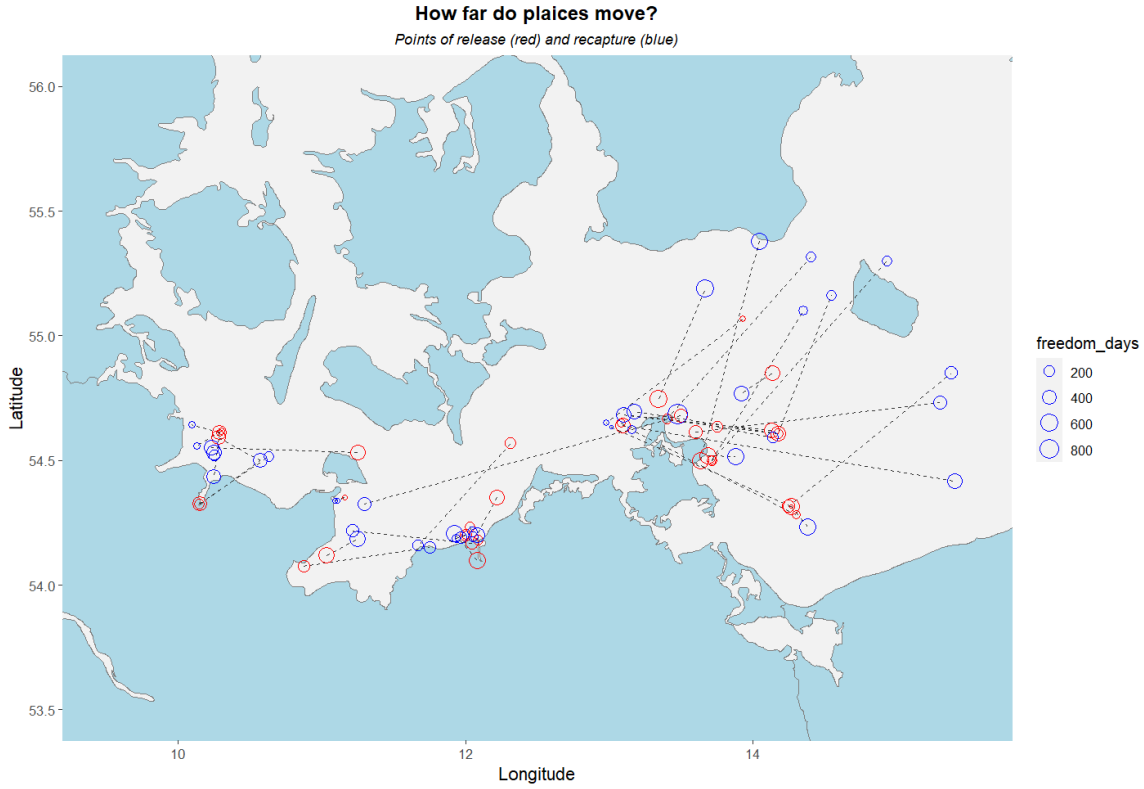


Fig. 8. Overview of plaice recaptures since 2017. Circle size indicates the days at liberty. Red dots: release location, blue dots: recapture location. Krumme U, unpublished data.

Historic tagging studies show a similar pattern with plaice displaying seasonal migration between the basins (during spawning time) and the slopes (feeding grounds). However, in almost all tagging studies, some plaice were recaptured in other areas that are not part of their assigned stock boundary, sometimes even more than 20% of the plaice were recaptured outside the subdivision in which they were released (Nielsen et al., 2007, ICES 2007).

Nielsen and co-authors worked up recapture data from more than 13.000 tagged plaice (of a total of over 40.000 tagged fish) in the North Sea, Skagerrak, Kattegat and Baltic Sea for an extensive working document of WGNSSK in 2006 (ICES 2007). The analyzed recaptures are covering more than 300 releases over a time span of >60 years (1903 to early 1964) and while most of the tagging studies have been conducted in the North Sea and the transition area, several tagging results are presented for the Baltic Sea as well, showing migrations from the Arkona Sea into the Belt Sea (Fig. 9). Most of the tagging studies in the Western Baltic (including SD24) have been conducted in the mid- to end-1950s, while the two tagging studies east of Bornholm (SD25) have been conducted in 1956 and 1957, respectively.

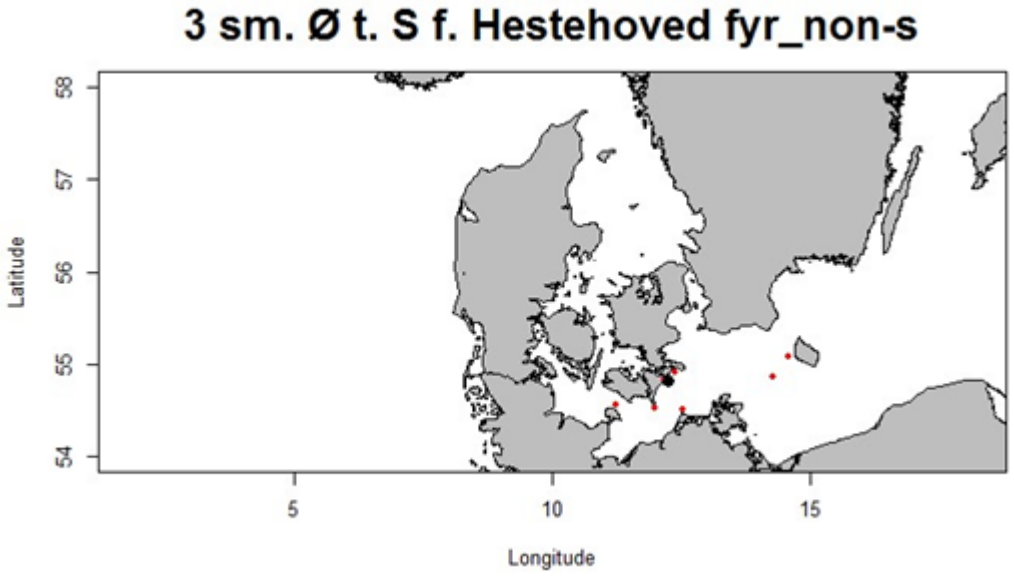
Based on a calibration with fishing effort within the area, these data revealed a stable migration pattern over the years (Table 4). There was in general a high level of resident behavior observed within the various sub-areas, and especially in the Belt and Western Baltic (between SDs 22-24!), in Kattegat and in the North Sea, where up to 90% of the fish were recaptured in the same area in which they were released.

However, most of these were recaptured within the tagging year. Residency in the Eastern Baltic (SDs 25-32) proved to be low, because about 39% of recaptures occurred in SDs22-24.

Table 4: Migration rates (in column percentage) between management areas, using Danish tagging experiments during the period 1903-1964. Data adjusted for fishing effort. Bold: residency.

	Tagging management area			
Recapture management area	22-24	25-32	IIIa	IVabc
22-24	**97**	39	2	0
25-32	0	**61**	0	0
IIIa	3	0	**95**	10
IVabc	0	0	3	**90**

The Baltic Sea was poorly covered by marked releases, only , but even the few recaptures available regularly displayed exchanges across the administrative borders of the two current stocks (Figure 9), with plaice released east of Hestehoved (SD22) being recaptured west of Bornholm Island, in SD24.



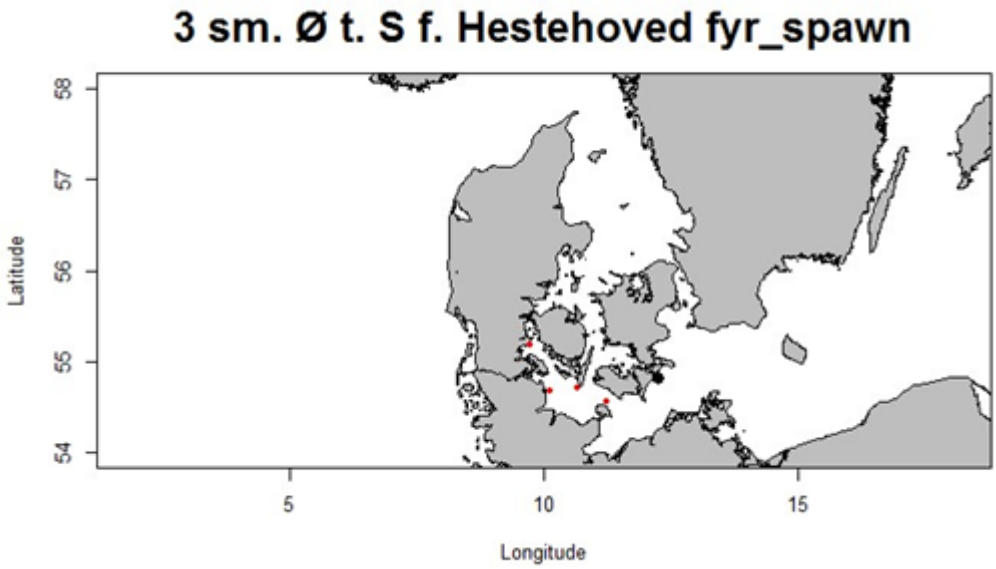


Figure 9: Plaice tagging results from Nielsen et al. (2006, as WD for ICES 2006) in the Baltic Sea. Black dot: release station, red dots: recapture location of non-spawning (upper figure) and spawning (lower figure) plaice.

Results from another historic tagging study are available for this report which focused on plaice in the Baltic Sea. Strodtmann (1918) reported recaptures results from tagging experiments with plaice from SD22, SD24 and SD25 from the period 1905 to 1907. These recaptures were neither considered in WKPESTO (2012) nor in Ulrich et al. (2013, 2017). The publication of Strodtmann (1918) is in German and was re-discovered during the data compilation workshop of WKBPLAICE in June 2024. These historic results from almost 120 years ago clearly show that 1) plaice display the same annual movement pattern since decades (use of deeper basins mainly during spawning time in quarter 1, use of shallower slope areas during the rest of the year to feed), 2) there is no evidence suggesting any effective divide between plaice in SD24 and SD22, or between plaice in SD24 and SD 23, neither today nor more than 100 years ago. Or conversely, the historical tagging experiments clearly call into question how WKPESTO (2012) could recommend and ACOM later on accept a stock separation of plaice in the Baltic Sea.

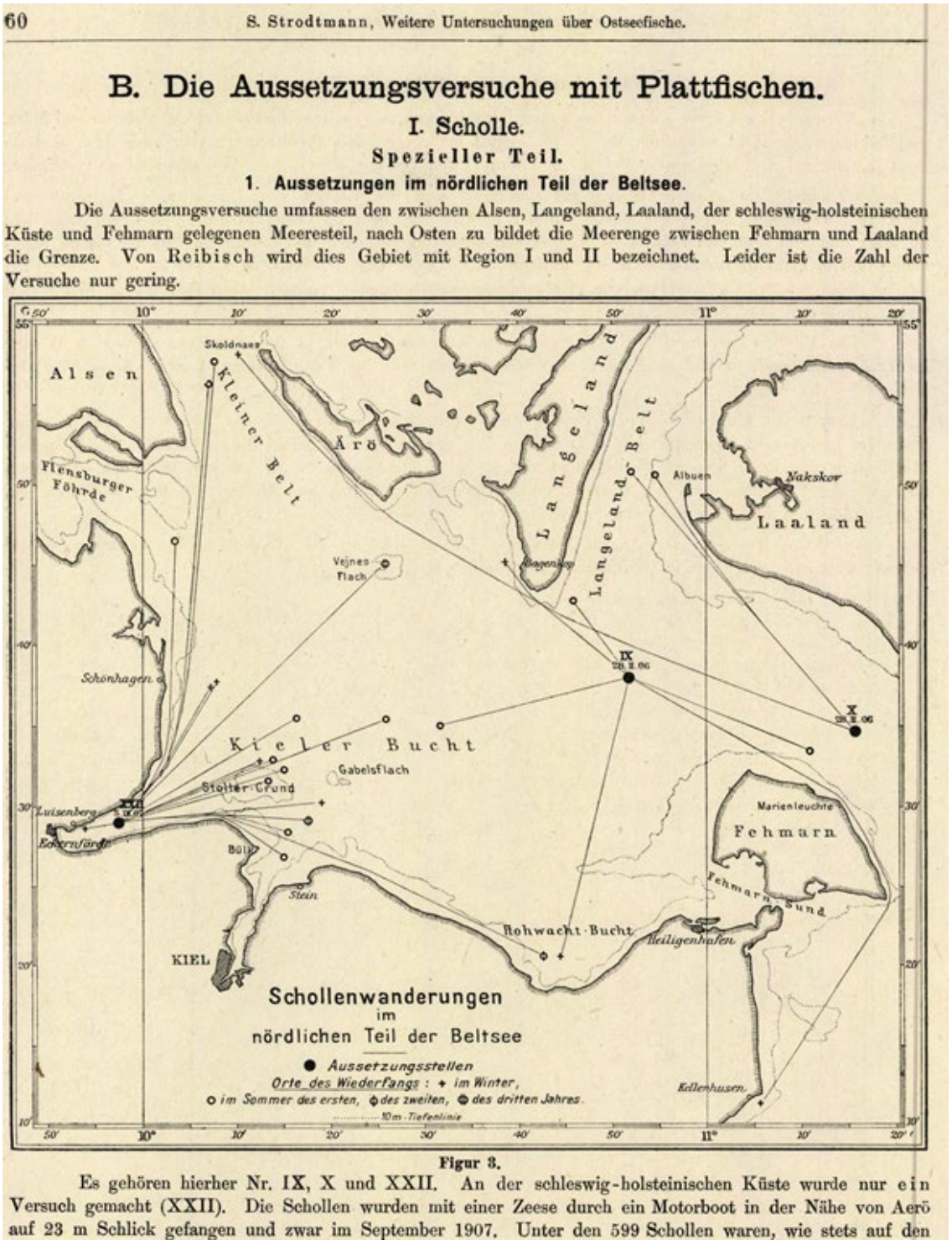


Fig. 10. Recaptures of plaice released in February 28th, 1906 (Fehmarnsund, south of Langeland) and September 5th, 1907 (Eckernförde Bay, caught by trawl at 23 m water depth on muddy ground). Map from Strodtmann (1918).

In the Belt Sea (SD 22) recaptures showed that plaice moved from the spawning grounds (deeper areas in Fehmarnbelt and south of Langeland) to shallower areas outside the spawning ground (Fig. 11). Recapture rates ranged between 0.4 and 15%. Selected growth rates that were reported are: 2 cm/yr for two recaptures,2 cm in 18 months and 2,5 cm in 6,5 years.

Fig. 11. Recaptures of plaice released on March 1st, 1906 (off Pelzerhaken). Map from Strodtmann (1918).

In Mecklenburg Bay marked plaice were released in Neustädter Bucht, close to Pelzerhaken.

Recapture rates within the first winter post-release were high, ranging between 40 and 61%. “This is proof that a very intensive plaice fishery took place the further you go into the bay, the more intensive the fishing” (translated text from Strodtmann 1918).

“Most of the animals were recaptured in the bay itself, but quite a few have made their way to the Mecklenburg coast, and we have recovered animals from almost all the fishing villages. Also, from the Kadettrinne, the area between Gedser and Darsser Ort, some were returned (5). Even lower was the number further east, one from Moen and 2 from Stralsund. Not a single one had migrated into the Baltic proper. The plaice also proved to be a stable fish here, even after years (one after six years) it does not move away from its sea area” (translated text from Strodtmann 1918). These historic recaptures clearly show that there was a regularly link between spawning fish in SD22 (Mecklenburg Bay) and feeding grounds in SD24 (Darss sill).

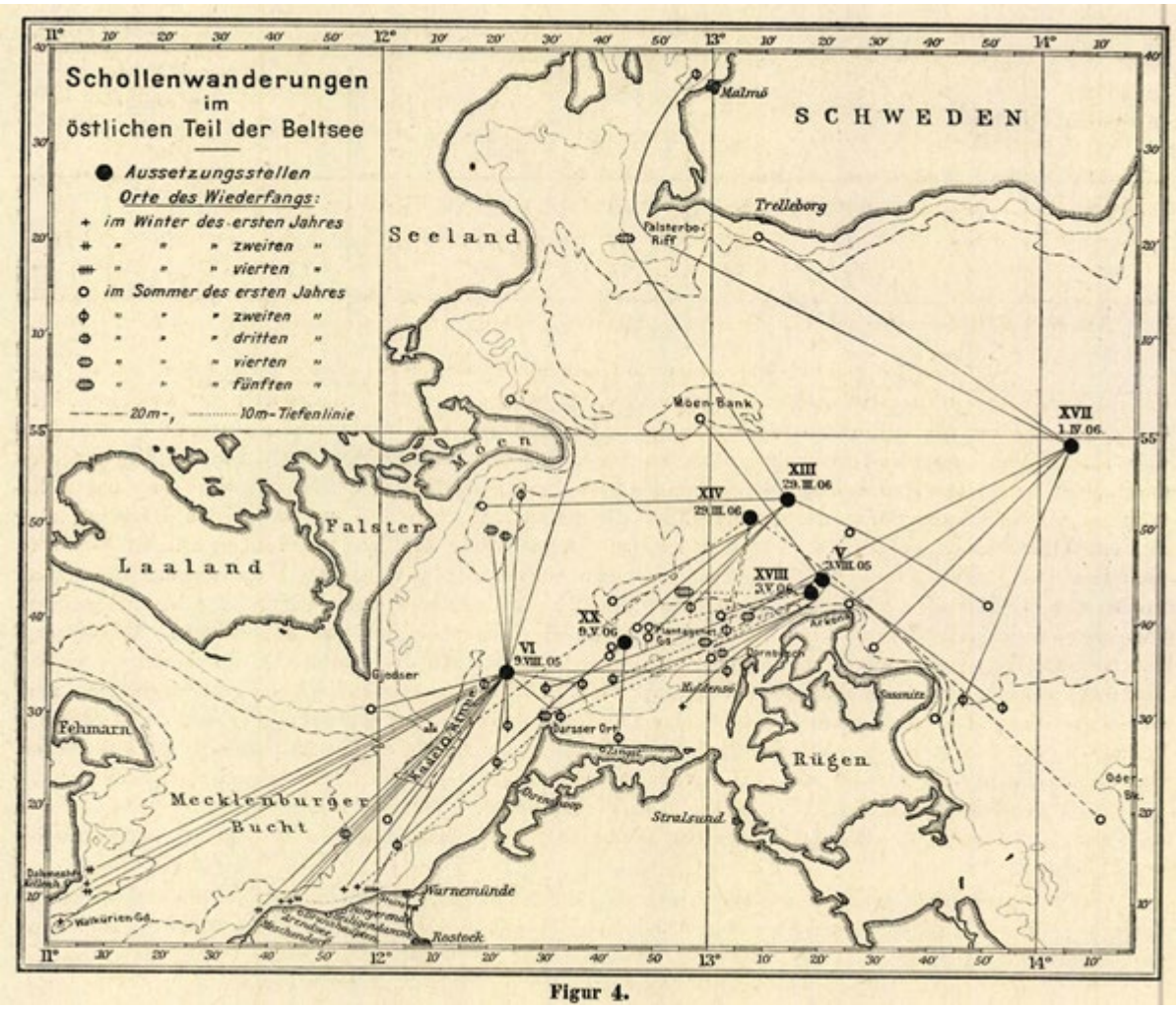


Fig. 12. Recaptures of plaice released in SD24; east of Kadettrinne on Darss sill at September 9t, 1905, in 1905/06 north off Rügen island, and April 1st 1906 in the Arkona basin. Map from Strodtmann (1918).

Figure 12 "gives an overview of the movements of the plaice released in the eastern part of the Belt Sea beyond the Darsser Ort-Gedser line and in the Rügen Basin. The release at the Kadettrinne, slightly east of it, at a depth of 20 m and on a sandy bottom is remarkable. Initially, all the animals, with one exception, were only recaptured after a longer period of time, after 6 months to 4 years. Nevertheless, 5 were recaptured within a radius of 10 seamiles. Of those that have traveled further, only one went to the east, 27 sm. to Hiddensö, but 13 went to the west to the various sites of the Mecklenburg Bay. 4 were recaptured in a northerly direction near the island of Moen.

The majority (9) of the fish that moved to the west fell victim to winter fishing, while east of the Gedser-Warnemünde line they were all caught in the summer. What is more striking is the high percentage of recovered females - 34 % of the released ones, while only 4% of the males were recaptured" (translated text from Strodtmann 1918).

Maximum reported growth rate of the tagging in this area was 4 cm /yr, but usually growth comprised 1,5-2 cm/yr.

Plaice tagged in the central Arkona basin moved into SD23 and many fish released on Darss sill moved into SD22, thus clearly violating the (untested) assumption of WKPESTO (2012) that SD24 is separated from SD22 and SD23.

"Further to the east, we have only carried out tagging in the Bornholm Basin. In the Gdansk Basin, the plaice is already too sparse to obtain useful results" (translated text from Strodtmann 1918). Unfortunately, no recapture map from the recapture distribution around Bornholm basin is available in Strodtmann (1918). Plaice were released at 95 m depth in the Bornholm basin and "the animals first have to travel 60 or more sea miles until they arrive at areas where fishing occurs. The vast majority were caught" south of the Bornholm basin and had thus moved "in a southerly and south-easterly direction, only one had migrated to Rügen" (translated text from Strodtmann 1918). Plaice released at another location around 60-75m deep spread across a wider area (east, south and west) but most traveled south and west (e.g. Oderbank and off Rügen).

"The theory of Reibisch that there was a lively exchange of plaice between the individual regions in terms of large and regular migrations from west to east take place, is conclusively refuted by the results of our tagging. It is true that within the individual basins there is a regular shift of the plaice populations within the individual regions. In late summer and fall, the animals move to the deeper areas, complete their spawning period in more saline depths, then in the spring move to the shallower, warmer parts of the sea" (translated text from Strodtmann 1918).

Strodtmann (1918) further concluded that "the plaice in the Baltic Sea is to a much greater degree a distinctly resident fish than in the North Sea. The migration of the animals from one region to another is in any case quite insignificant. They stay in the same area for years. Likewise, the Danish investigations have also shown that there is no significant migration of plaice from the southern Kattegat neither through the Belts nor through the Sound" (translated text from Strodtmann 1918).

At that time they even did exchange experiments that pointed to genetically determined difference in growth performance between plaice from the North Sea and the Baltic Sea: "We have moved plaice from the Baltic Sea to the North Sea (see Reichard (23)), but the animals have not grown any more here than in the Baltic, while conversely plaice, which the sea fishing association brought over from the North Sea to the Baltic Sea, exceeded the Baltic Sea plaice in growth despite the unfavorable conditions: the best proof that it is not external circumstances alone that are decisive here, but internal are decisive here, but internal causes play a role. (Translated text from Strodtmann 1918).

What would be the next steps in relation to WKBPLAICE

If plaice in the Baltic is considered as one stock, the following tasks need to be completed before the benchmark in October 2024:

- Merging survey data and create a combined index with annual length-weight relationships (delta GAM model after Berg et al., 2013)
- Merging commercial data
    - Landings and estimated discards, including BMS landings
    - Biological data and catch composition (numbers-at-age, weight-at-age, etc.)
- Have all other relevant data match the new assessment unit
- Calculating new reference points for the stock
- Determine if the TAC is still fixed for SD22-32 and Plaice in the Kattegat (SD21) separately
- Conducting assessment runs and sensitivity analyses for the merged stock

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