Stock Annex: Sprat (*Sprattus sprattus*) in subdivisions 22–32 (Baltic Sea)

Stock-specific documentation of standard assessment procedures used by ICES.

Stock	Sprat (*Sprattus sprattus*) in subdivisions 22–32 (Baltic Sea)
Working Group	Baltic Fisheries Assessment Working Group (WGBFAS)
Last Benchmark	Benchmark Workshop on Baltic Pelagic stocks (WKBBALTPEL, ICES, 2023c)
Date last benchmark	13–17 February 2023 (previous benchmark in 2013 (ICES, 2013) and inter-benchmark in 2020 (ICES, 2020))
Last update	April 2023
Last updated by	Jan Horbowy, Stefanie Haase, Olavi Kaljuste
Main modifications	SAM (Nielsen and Berg, 2014) model was used instead of the previously used XSA. New estimates of natural mortality (M) from the WGSAM 2023 Baltic Sea SMS keyrun (ICES, 2023a) were included. Historic sprat catches were corrected based on the new Danish catch data. New BIAS indices (including Gulf of Finland) were used in parallel with the old BIAS index. New reference points were calculated based on the new stock assessment results.

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A General

A.1 Stock definition

Sprat is distributed mainly in the open sea areas of the entire Baltic Sea though high concentrations of YOY appear in coastal areas (especially in mixed fresh water from rivers and sea waters), primarily in autumn and in the 1st quarter of the year. These areas are also preferred by juvenile herring in the same season. During the year, mixed sprat and herring shoals often occur in both open sea and coastal areas.

Based on the ICES WGs and ACFMs advice sprat in the Baltic Sea has been assessed as a single unit within the ICES subdivisions 22–32 since 1992. In the 1980s and in the early 1990s, attempts were made to distinguish different Baltic sprat stocks/populations, but significant evidence about sprat stock heterogeneity was not found.

A.2 Fishery

The main part of the sprat catches is taken by pelagic single and pair trawling (using a mesh size of 16 mm in the codend). In addition there are demersal trawling activities for Baltic sprat in some parts of the Baltic. The sprat fishery is carried out all year but the main fishing season is in the first half of the year in most countries. In the northern part of the Baltic, ice cover is a limiting factor for all fishing operations.

In some countries Baltic sprat is fished by two types of fleets, small cutters (17–24 m length) with engine power up to 300 h.p., and medium size cutters (25–27 m length) with engine power up 570 h.p. In some countries a third type of vessel is engaged in sprat fishery, i.e. large vessels, over 40 m length with engine power of 1050 h.p. The large vessels have trawls with high vertical opening and operate in the areas deeper than 50 m. According to national regulation (e.g. in Russia) they are obliged to use sorting machines to separate herring from sprat. This fleet targets sprat for human consumption during 1st and 2nd quarters. During summer this fleet targets sprat for reduction purposes and bycatches of small herring increases.

Up to now the annual sprat quota was not exhausted in most countries, whereas the herring quota was fully utilized. This created a strong incentive to misreport herring as sprat.

The questionnaire prepared by WGBFAS in 2012 revealed that the main misreporting takes place in industrial fisheries; however, the national landing figures are adjusted according to the sampling results.

A.3 Ecosystem aspects

Stock trends in Baltic sprat have been driven mainly by released predation by cod and high (although varying) recruitment success since the 1990s (Köster *et al.*, 2003; Casini *et al.*, 2008). The latter may be related to the unusual high state of the North Atlantic Oscillation (NAO), resulting in unusually high temperature conditions. Variations in temperature may be large enough to affect sprat biology (Kalejs and Ojaveer, 1989). Sprat in the Baltic Sea is located near the northern limit of the species' geographic distribution (Muus and Nielsen, 1999), which ranges from the Black Sea to southern central Norway. Low temperatures can therefore be expected to be detrimental for production and survival in the Baltic Sea. Laboratory experiments have shown that cold water prevents hatching of sprat eggs from the North and Baltic Seas (Thompson *et al.*, 1981; Nissling, 2004). Field studies show that the temperatures which suppress sprat egg development in the laboratory also occur in the Baltic Sea at times, places and depths where sprat eggs occur (MacKenzie and Köster, 2004). Comparison of interannual variability in sea temperatures at the main sprat spawning time (May) with sprat recruitment shows a statistically significant positive relationship (MacKenzie and Köster, 2004). The same temperatures that affect sprat recruitment are themselves influenced by winter severity indices, including ice coverage in the Baltic Sea and a winter index (January–February) of the North Atlantic Oscillation (MacKenzie and Köster, 2004).

Another mechanism through which the increase in temperature may have affected sprat recruitment is a change in the food available. Sprat larvae have a strong preference for the copepod *Acartia* spp. (Voss *et al.*, 2003), which has drastically increased since the 1990s in parallel to the increase in temperature (Möllmann *et al.*, 2000). This may have led to higher larval survival in general.

Besides an increase in temperature, the unusual climatic situation during the 1990s has resulted in a change in the circulation pattern and thus in the drift pattern of sprat larvae (Hinrichsen *et al.*, 2003). Recent investigation using 3d-hydrodynamic modelling have shown that retention vs. dispersion in the Baltic deep basins have a strong influence on recruitment success of sprat (Baumann *et al*,. 2004).

Besides recruitment, a further important ecosystem-related aspect of sprat in the Baltic is the decrease in growth during the 1990s (Grygiel and Wyszynski, 2003; Götze and Gröhsler, 2004). This has been related to the decrease in abundance of the copepod *Pseudocalanus* sp., one of the most important food items of sprat during spawning in spring (Szypuła *et al.*, 1997; Möllmann *et al.*, 2004), and density-dependent processes mediated by the strong intra-specific competition due to the large stock size after the early 1990s (Casini *et al.*, 2006).

After the mid-1990s, the distribution of sprat has shifted considerably towards the northeastern areas of the Baltic Sea and and the autumn hydro-acoustic surveys revealed low abundances of sprat in the southern Baltic (WGBFAS, 2012). This seems to have triggered a spatial density-dependent process, with a decrease in condition and mean weights mainly in the northeastern areas. As the cod stock is distributed mainly in the southern Baltic, the overlap of cod and sprat stocks is much lower than previously (Casini *et al.*, 2011). It is not clear yet whether the shift in sprat distribution to northeastern areas during the past decades is an effect of release from cod predation, which has been basically nil in this area after the early 1990s (Casini *et al.*, 2011).

B Data

B.1 Commercial catch

In 1997, sprat catches were at a record high of 529 400 t for the whole Baltic, and have since decreased to the level of 300 000–400 000 t in 2000–2010. Since 2011, sprat catches have varied between 200 000 and 300 000 t.

Sprat catches are mainly utilized for the industrial purposes and smaller part of them goes for the human consumption. After the implementation of the landing obligation in 2015, the discards of sprat are assumed not to exist. Historically, discards in most countries have probably been small because even small and lower quality fish could be used for production of fishmeal and feeding in animal farms. In fisheries directed at human consumption, however, young fish were discarded with higher rates in the years when strong year classes are recruiting to the fishery. The amount of this discarding was unknown.

The species composition of the mixed catches is defined from logbooks and, partly, by observers on board larger commercial vessels in compliance with the special agreement between institute and vessel owners. In some countries e.g. in Denmark and Sweden, data about catch composition and other biological data are delivered by fisheries inspection in harbours and by managers of fish stock exchange.

B.2 Biological

Weight-at-age in the stock is assumed to be the same as weight-at-age in the catch.

The natural mortality coefficients used for assessment varied between years and ages depending on size of cod stock and ranging mostly within 0.3–0.8. These estimates were taken from updated SMS run (Stochastic Multispecies Simulations, Lewy and Vinther, 2004; ICES, 2023a).

The SMS estimates of M are not updated every year. Thus, if the M from SMS is not available for a given year, then M for the missing year is:

a) Assumed as last year estimates of SMS in first year for which there are no M estimates,

b) Estimated from regression of mean M against biomass of cod ≥20 cm in next years for which there are no M estimates. Next, age effects are used to obtain M by ages in the missing year. Such regression explains 90% of the M variance.

Both proportion of natural mortality (M_{prop}) and proportion of fishing mortality (F_{prop}) before spawning are set to 0.4.

In the years 1974–2003 knife-edge maturity-at-age 3 was used for this stock. At the assessment in 2002, a new maturity ogive was introduced for the whole time-series. This ogive is based on the distribution of age at first spawning estimated for the last 20 years. The preliminary analysis of the maturity data at the benchmark workshop did not provide reasons to change the maturity parameters. However, it is advised to look at maturity data in more detail and using statistical models.

B.3 Surveys

To tune SAM, two surveys were available: the October acoustic survey (BIAS) and the May acoustic survey (BASS). They resulted in four tuning fleets:

- fleet1: October acoustic survey (BIAS) in the years 2000-2022 (gaps in years 2001-2005 and 2008) covering the ages 1-8 and subdivisions 22-29+32,

- fleet2: October acoustic survey (BIAS) in the years 1991-2008 covering the ages 1-8 and subdivisions 22-29 (years from this fleet which overlapped with above fleet1 were excluded),

- fleet3: May survey (BASS) in the years 2001-2022 covering the ages 1-8 and subdivisions 24-26+28,

- fleet4: October (BIAS) survey covering the age 0 sprat and subdivisions 22-29+32 in 2010-2022; the age 0 series was shifted to represent the age 1 the following year.

The survey indices were corrected for area coverage. However, in 2016 the May survey (BASS) only covered ca. 50% of planed areas, so the 2016 survey estimates from BASS we not used in the assessment as recommended by the WGBIFS (ICES, 2023b). Due to the low area coverage also the 1993, 1995, and 1997 BIAS survey estimates we not used in the assessment as recommended by the WGBIFS (ICES, 2023b).

B.4 Commercial cpue

Very limited data on fishing effort and cpue have been provided to WGBFAS. Taking into account that survey estimates of sprat stock are relatively good, while available commercial CPUE data were very limited and may be considered not relevant for tuning of pelagic stocks, no attempts to include CPUE data in the assessment were undertaken.

B.5 Other relevant data

For some years the NAO index was used to predict recruitment in prediction year in short-term forecast. The statistical relationship between sprat recruitment and NAO explained ca. 25% of recruitment variance. In 2007, that approach was ceased due to lack of expertise in the WG.

C Historical stock development

Model used: SAM; Software used: *stockassessment* package in R

Benchmark assessment in 2023 (WKBBALTPEL (ICES, 2023c)).

The survey data presented in Section B.3 are used for tuning the assessment model. The age-0 survey indices are forward shifted to represent age 1 at the beginning of next year, because the first age group in the assessment is age 1. The survey data are corrected for area coverage.

Basic Model Options:

- 4 tuning fleets were used.
- Catchability depended on year-class strength at age 1 for all fleets.
- Catchability plateau was set at age 6 (ages 6-8 assume the same q).
- Recruitment was modelled as random walk.
- Covariance structure for each fleet was set as “ID” (independent

More details are contained in SAM configuration file presented at the end of this Stock Annex

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Caton	Catch in tonnes	1974–last data year		Yes
Canum	Catch-at-age in numbers	1974–last data year	1–8+	Yes
Weca	Weight-at-age in the commercial catch	1974–last data year	1–8+	Yes
West	Weight-at-age of the spawning stock at spawning time.	1974–last data year	1–8+	Yes-assumed to be the same as weight-at-age in the catch
Mprop	Proportion of natural mortality before spawning	1974–last data year	1–8+	No-set to 0.4 for all ages in all years
Fprop	Proportion of fishing mortality before spawning	1974–last data year	1–8+	No-set to 0.4 for all ages in all years
Matprop	Proportion mature at age	1974–last data year	1–8+	No-the same ogive for all years, averaged over noisy long time-series (1981–2002)
Natmor	Natural mortality	1974–last data year	1–8+	Yes-estimated from most recent SMS or (if SMS is not updated): a) assumed as last year estimates of SMS in first year for which there are no M estimates b) from regression of M against biomass of cod ≥20 cm in next years for which there are no M estimates

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	International acoustic (BIAS) in SD 22–29 and 32	2000–last data year	1–8+
Tuning fleet 2	International acoustic (BIAS) in SD 22–29 (years for which fleet 1 is available are excluded)	1991–2008	1–8+
Tuning fleet 3	International acoustic (BASS) in SD 24–26 & 28	2001–last data year	1–8+
Tuning fleet 4	International acoustic (BIAS) in SD 22–29 and 32	2010–last data year	0

D Short-term projection

Model used: Age structured

Software used*:* *forecast* procedure of *stockassessment* package in R

Initial stock size: Taken from the SAM. The recruitment at age 1 for year in which assessment is conducted is estimated within SAM. The recruitment in next two years is resampled from historical SAM estimates covering period from 1991 onwards.

Natural mortality: Average of the three last years in assessment or last year value if trend in mortality is observed.

Maturity: The same ogive as in the assessment is used for all years

F and M before spawning: The same values as in assessment

Weight-at-age in the stock: Assumed to be the same as weight-at-age in the catch

Weight-at-age in the catch: Average weight of the three last years in assessment or last year value if trend in weight-at-age is observed.

Exploitation pattern: Average of the three last years in assessment. Unscaled if no clear trend in F_{bar} (3–5) is observed, otherwise scaled to F_{bar} level of the last assessment year.

Intermediate year assumptions: Usually both F *status quo* and TAC constraint options are presented and the option preferred by the WG is indicated.

Stock–recruitment model used: None.

Procedures used for splitting projected catches: Not relevant.

E Medium-term projections

Not considered appropriate for this stock.

F Long-term projections

Not considered appropriate for this stock.

G Biological reference points

The following MSY and PA reference points were re-estimated at benchmark assessment in 2023.

Reference Point	Value	Rationale
B_{lim}	459 000t	The SSB producing 50% of maximal recruitment from the Beverton and Holt S-R function.
B_{pa}	541 000t	Blim*$e^{sigmaSSB*1.645}$; sigmaSSB = 0.1
MSY $B_{trigger}$	541 000t	B_{pa}
F_{msy}	0.34	Estimated by EqSim
$F_{msyUpper}$	0.35	The F which produces 95% of the MSY landings was estimated by EqSim at 0.44. As Fp05 was estimated at 0.35, the $F_{msy\text{-}upper}$ was capped at 0.35.
$F_{msyLower}$	0.25	Estimated by EqSim as the F producing 95% of the landings at F_{msy}
F_{lim}	0.58	Estimated by EqSim as the F with 50% probability of SSB being less than B_{lim}
F_{pa}	0.35	$F_{p.05}$, F which leads to 95% probability of SSB being above B_{lim}

H Other issues

None.

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SAM configuration file

```
#
$minAge
# The minimium age class in the assessment
 1
$maxAge
# The maximum age class in the assessment
 8
$maxAgePlusGroup
# Is last age group considered a plus group for each fleet (1 yes, or 0 no).
 1 1 1 1 0
$keyLogFsta
# Coupling of the fishing mortality states (normally only first row is used).
   0   1   2   3   4   5   6   6
  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1
$corFlag
# Correlation of fishing mortality across ages (0 independent, 1 compound symmetry, 2 AR(1), 3 separable AR(1).
2
$keyLogFpar
# Coupling of the survey catchability parameters (nomally first row is not used, as that is covered by fishing mortality).
  -1  -1  -1  -1  -1  -1  -1  -1
   0   1   2   3   4   5   5   5
   6  7   8   9   10   11   11   11
  12 13 14  15  16  17  17  17
  18  -1  -1  -1  -1  -1  -1  -1
$keyQpow
# Density dependent catchability power parameters (if any).
  -1  -1  -1  -1  -1  -1  -1  -1
  0  -1  -1  -1  -1  -1  -1  -1
  1  -1  -1  -1  -1  -1  -1  -1
  2  -1  -1  -1  -1  -1  -1  -1
 3  -1  -1  -1  -1  -1  -1  -1
$keyVarF
# Coupling of process variance parameters for log(F)-process (nomally only first row is used)
   0   0   0   0   0   0   0   0
  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1
  -1  -1  -1  -1  -1  -1  -1  -1
```

-1 -1 -1 -1 -1 -1 -1 -1

$keyVarLogN

Coupling of process variance parameters for log(N)-process

0 1 1 1 1 1 1 1

$keyVarObs

Coupling of the variance parameters for the observations.

0 0 0 0 0 0 0 0

1 1 1 1 1 1 1 1

2 2 2 2 2 2 2 2

3 3 3 3 3 3 3 3

4 -1 -1 -1 -1 -1 -1 -1

$obsCorStruct

Covariance structure for each fleet ("ID" independent, "AR" AR(1), or "US" for unstructured). | Possible values are: "ID" "AR" "US"

"ID" "ID" "ID" "ID" "ID"

$keyCorObs

Coupling of correlation parameters can only be specified if the AR(1) structure is chosen above.

NA's indicate where correlation parameters can be specified (-1 where they cannot).

#1-2 2-3 3-4 4-5 5-6 6-7 7-8

NA NA NA NA NA NA NA

NA NA NA NA NA NA NA

NA NA NA NA NA NA NA

NA NA NA NA NA NA NA

-1 -1 -1 -1 -1 -1 -1

$stockRecruitmentModelCode

Stock recruitment code (0 for plain random walk, 1 for Ricker, 2 for Beverton-Holt, and 3 piece-wise constant).

0

$noScaledYears

Number of years where catch scaling is applied.

0

$keyScaledYears

A vector of the years where catch scaling is applied.

$keyParScaledYA

A matrix specifying the couplings of scale parameters (nrow = no scaled years, ncols = no ages).

$fbarRange

lowest and higest age included in Fbar

3 5

$keyBiomassTreat

To be defined only if a biomass survey is used (0 SSB index, 1 catch index, 2 FSB index, 3 total catch, 4 total landings and 5 TSB index).

-1 -1 -1 -1 -1

$obsLikelihoodFlag

Option for observational likelihood | Possible values are: "LN" "ALN"

"LN" "LN" "LN" "LN" "LN"

$fixVarToWeight

If weight attribute is supplied for observations this option sets the treatment (0 relative weight, 1 fix variance to weight).

0

$fracMixF

The fraction of t(3) distribution used in logF increment distribution

0

$fracMixN

The fraction of t(3) distribution used in logN increment distribution

0

$fracMixObs

A vector with same length as number of fleets, where each element is the fraction of t(3) distribution used in the distribution of that fleet

0 0 0 0 0

$constRecBreaks

Vector of break years between which recruitment is at constant level. The break year is included in the left interval. (This option is only used in combination with stock-recruitment code 3)

$predVarObsLink

Coupling of parameters used in a prediction-variance link for observations.

-1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1

-1 -1 -1 -1 -1 -1 -1 -1

NA NA NA NA NA NA NA NA