
An historic fishery collapse driven by socioeconomic and environmental factors

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Supplementary information

1) Study Area



Fig. S1. Map of the western Baltic Sea, indicating major sites of importance for autumn-spawning herring fishery, processing, and trade in the Late Middle-Ages.

The first major fish market in the Baltic region was established on the island of Rügen in the 12th century. Rügen herring was shipped over several hundreds of kilometres on the river Oder to Poland and to Moravia, furthermore via Hamburg and then along the Elbe to Central Germany. However, competition arose from the emerging Sound fishery. Major fairs and trading posts were Skanör, Falsterbo, Dragør and Kronborg Len.

Salt for conservation was shipped from the salt works in Lüneburg via Lübeck, one of the most important cities in the Hanseatic League.

2) Description of BESA (bio-economic stock assessment) method

This section summarizes the more elaborate description as detailed in the original publication (Lancker et al. 2023). A freely accessible example code is provided on GitHub to illustrate how BESA can be used (<https://github.com/klancker/BESA.git>).

BESA exploits two traits that are well known to hold in unregulated, commercial fisheries. First, fishers fish as long as it is profitable, i.e. as long as the price they can earn for another fish exceeds the cost to fish it. Second, this cost increases when the size of the fish stock decreases. Taken together, this means that in years where the price is high, the stock size will be reduced farther down, whereas in years with low prices, fishers will already stop fishing at higher stock sizes. This price variation is to some extent exogenous, it stems for example from varying consumer affluence, and changes in the market for substitutes, such as meat. BESA exploits this variation and uses the price dynamics for inference on the latent biomass dynamics.

In line with the classic Gordon-Schaefer model (Gordon 1954, Schaefer 1957), BESA assumes a logistic biomass growth function with natural growth rate r and carrying capacity K . The stock in a subsequent period, B_{t+1} , is given as the surplus between growth and harvest H_t , and subject to a multiplicative, unit mean, log-normally distributed error, $\exp(\eta_t)$:

$$B_{t+1} = \exp(\eta_t) \left(B_t + rB_t \left(1 - \frac{B_t}{K} \right) - H_t \right)$$

To incorporate climate impacts, we assume that the temperature anomaly ($TEMP$) affects the natural growth rate, which we model as a quadratic function:

$$r = r_0 + \tau_1 TEMP + \tau_2 TEMP^2$$

Fishers fish under open access, such that profit is driven to zero, i.e. revenues at price P_t equal costs. Costs are modeled as inversely proportional to the stock size, but linear in harvests. BESA assumes that the zero-profit condition holds in expectation, but is subject to a unit mean, log-normally distributed error $\exp(\epsilon_t)$. This reflects e.g. weather induced shocks on harvesting costs (Lancker et al. 2019). Furthermore, we allow for changes in costs over time, such as decreases due to technological progress or increases due to economic growth and associated wage increases, by including a time trend. To summarize, costs are given by (with cost scaling parameter c and time denoted by t) $\frac{\exp(\epsilon_t)(c + trend * t)}{B_t}$. This means that costs decrease non-linearly in stock size. Thus, the zero-profit condition is:

$$P_t H_t = \frac{\exp(\epsilon_t)(c + trend * t)}{B_t} H_t$$

As the stock size decreases, fishing becomes more costly: It only makes sense to reduce the equilibrium stock size further, when the price for fish is sufficiently high. As such, stronger fishing incentives, represented by a higher price that fishers can earn per fish, feedback to fish biomass: The resulting biomass at which fishers stop fishing is lower in periods with a higher price. Thus, the price works as a signal for stock size, even though it is a noisy signal due to economic and environmental stochasticity.

Importantly, while this condition is rooted in classic bio-economic theory (Gordon 1954, Schaefer 1957, Smith 1969), BESA additionally assumes that the zero-profit-condition holds instantaneously at all times, except for deviations represented by the error term. That is, we assume that short-run dynamic adjustments to equilibrium are well-behaved and small enough in relevance that they can be captured by this error term while the measurement equation delivers interpretable information regarding stock size. This means that our method is best suited for fisheries with a relatively high speed of adjustment.

These assumptions fit the fishery in question well. Effort tends to adjust faster in fisheries with a high number of part-time fishers that adapt their effort to profitability, where there are no constraints imposed by capital, and with a relatively high biological turnover in biomass (Li & Smith 2021). The historical fishery in this paper was a derby fishery, with little to no capital requirements, mainly consisting of farmers who seasonally arrive to partake in the fishery according to profitability (Jahnke 2009). Moreover, a high intrinsic growth and fish that reach maturity at a relatively young age, as is characteristic of small pelagic species, increases the likelihood that the equilibrium is quickly reached after shocks.

Over the analysed time horizon, to the best of our knowledge, there were no restrictions that would directly limit harvest, such as a quota, a season restriction, or similar. There were also no restrictions that directly relate to harvest quantities, such as a tax per unit of catch. Thus, we are confident that the fishery was not subject to the modern understanding of optimal or rights-based management. We do not think that there were any regulations that restricted entry or harvest and would therefore lead to rent generation, violating the zero-profit condition.

There were, however, individual cases of gear regulations, indicating a soft type of regulated open access (Homans & Wilen 1997), for certain parts of the fishery. For example, bottom trawl nets were prohibited from 1371 onwards in the Sound (Jahnke 2009). A complaint from 1386 suggests that the mesh size of nets was also regulated (HR I 2, no. 320, § 7, p. 380). Likewise, there was some taxation of fishers, but it was a lump sum tax, not a per unit tax (Jahnke 2009). Such regulations would alter the cost function and potentially catchability, and might also be partly responsible for avoiding collapse, but should not lead to a violation of the zero-profit-condition (Homans & Wilen 1997).

A regulation that could potentially violate this assumption was the kongekøb, a first-purchase-right of the king to landed herring in the Sound at a price lower than the market price. However, as outlined in Lehmann et al. (2021), this was likely exercised on only four of 60 days in a season, and covering not more than 3.6% of catches overall, such that we must assume it to be too small in relevance to have regulated a large scale, regionally broad fishery.

We estimate a state space model with the zero-profit condition as observation equation and the biomass dynamics given above as process equation, using annual time series of prices

and harvest in logs. We estimate parameters r , K , c as well as the unobserved time series of biomass as a share of the carrying capacity ($\frac{B_t}{K}$) (e.g. following Millar & Meyer 2000, Winker et al. 2018). The state space model can be estimated for any given starting value by use of an extended Kalman filter, which lets us calculate the log-likelihood directly. This model is then combined with Bayesian estimation and run in Stan (Stan Development Team 2022a), using the R package rstan (Stan Development Team 2022b). We run 20,000 samples for each of 8 chains, with a thinning parameter of 5 and 6000 warm-up iterations. As such, we can for example estimate the maximum sustainable yield ($MSY = \frac{rK}{4}$) as well as depletion levels, i.e. biomass relative to carrying capacity. To calculate those values, we simulate the joint posterior distribution and calculate means and highest density intervals for each point in time.

For the Bayesian estimation, we choose priors as follows: For r and K , for lack of better information, we run the harvest data in the well-known CMSY method (Froese et al. 2017) and calculate log-normal priors from the resulting distribution of viable values for each r and K . A prior for the initial depletion level is modelled as a beta-distribution, and found by assuming a symmetric prior distribution, that falls with 95% confidence between 0.5 and 0.95. Furthermore, we use a relatively uninformative log-normal prior for the cost parameter c , with standard deviation 1 and the mean calculated from the zero-profit condition in the initial period, using the prior means for the remaining parameters. For the climate impact, we use flat, normal, mean-zero priors for both parameters, τ_1 and τ_2 . Finally, flat priors are assumed for the two error terms and the variability of the initial depletion level. See

Tab. S2. for a list of priors used.

Apart from the mathematical assumptions above, BESA builds on the premise that the price data reflects an important incentive for fishers to fish, i.e. that the collected data and its variation is not dominated by sources of variation that occur later in the value chain, by market power of fishery, by cross-regional data aggregation, or by choices regarding deflation. This also means that the method would not work for a fishery where harvest is limited by regulation, which however we are not concerned about in the case of the historical herring fishery. In the case of our four price time series, to confirm that long run price incentives to fishers of Baltic herring were comparable across the price time series, we tested for cointegration using the Johansen test (Johansen 1991). Cointegration means that there is a meaningful long-run relationship between different time series. We confirm the existence of a cointegration relationship (trace statistic = 22.1147, test statistic at 5% level of significance: 29.68). This is typically considered as a sign of market integration, e.g. through trade (Asche et al. 1999, Lancker & Bronnmann 2022) – that is, all four price time series should carry the same long run signals for fishers. However, local price series may reflect differential dynamics in the short run, stemming from impacts such as transport cost shocks, which is why comparing across locations can give a complementary picture, ruling out certain sources of uncertainty.

As is typical for state space models, estimates for the parameters r , c , and K are known to be somewhat interdependent, and identification requires sufficient variation in the dataset. This challenge does not extend to key estimates of interest, MSY and depletion levels (i.e. biomass relative to carrying capacity) (Lancker et al. 2023). It can, however, lead to inflated estimates of absolute biomass levels. Typically, the additional price data in BESA mitigates this challenge as opposed to harvest only models, like CMSY, that for this very reason implement strict (log-)uniform priors for r and K , such as in our case r between 0.2 and 0.8. BESA can typically forego implementation of strict limits for r and K . However, in this case, we observe that confounding of r and K likely happens in the England model. Namely, we observe that results for the Hamburg, Brabant and Utrecht models all lead to similar r and K estimates that are also in line with expectations from the literature, while the England model estimates a very low r and a high K if left unconstrained, leading to extremely high values of absolute biomass. We suspect that this is due to the very long time-horizon used for the England model, and the comparably weak variation in the data. For the results shown here, we therefore restrict carrying capacity K to the range [240kt, 960kt] in the England model. We find these limits by using the CMSY prior range for r (0.2, 0.8) and using the CMSY estimate for MSY to translate this into a range for the carrying capacity.

A limitation is that BESA ignores the demographic structure, as it belongs into the class of surplus production models at biomass level. Another limitation is that, outside of the included trend and climate anomaly, BESA assumes stationarity of parameters, in particular parameter c , representing fishing cost and technology. Concerns remain that short term

positive or negative developments in fishing cost and technology have an impact. The trend captures large scale, general dynamics outside of biomass, but is still a constrained measure to the problem of potential non-stationarity of the cost parameter, in a similar way as other model parameters may not be stationary. To some degree, the inter-model comparison across different time series, that likely reflect short term different cost dynamics, can provide complementary results that help to reduce this uncertainty. However, future research could improve our understanding of historical dynamics by adding covariates that better capture changes in gear restrictions and fishing technology. For example, technological change might not be Hicks-neutral, such that it might affect the relative inputs of different factors of production, or it might affect the relationship between effort and the fish stock e.g. through better methods to locate fish, which is not reflected in a simple trend on the cost parameter. Further assumptions and limitations are discussed in detail in Lancker et al. (2023).

BESA results: Details and diagnostics

Tab. S1 presents details and diagnostics for the four main models (England - ENGL, Hamburg - HH, Brabant - BRA, and Utrecht - UT) whose results are discussed in the manuscript. We find that, compared to the priors from CMSY, BESA suggests a lower natural growth rate r and a higher carrying capacity K . The reason for this correction is that the model favoured by CMSY is incompatible with the price time series, as it suggests an increasing biomass at times where the price increases would imply stronger incentives to fish. In that way, BESA works similarly to other state space models that complement harvest with effort time series, to account for changing economic incentives. Baseline MSY (for climate anomaly = 0) is estimated 5-16 kt below the CMSY prior. Whereas Hamburg, Brabant and Utrecht models attribute greater productivity to an increased r and a reduced K , the England model shows the opposite pattern. The parameter c is estimated very differently between the four models, which could be due to the different time series length, but could also simply reflect differences in the fleets of the different locations. Depletion trajectories, temperature impacts, and MSY levels are all estimated very similarly across the four models. It is difficult to determine a credible range for carrying capacity for the stock(s) that likely sustained the catches described here, since autumn spawning herring today is not the dominant resource sustaining catches anymore. Area wise, the catches likely came from herring stocks in the western Baltic Sea, mixed with Skagerrak and Kattegat stocks (today's ICES subdivisions 20–24). For that area and spring spawning herring, ICES (2024) reports high spawning stock biomass around 300 kt in the 1990s, which was heavily fished. If we interpret the stock at that time as lying around BMSY (in an environmentally already polluted state), this would indicate a carrying capacity of around 600 kt, which is in line with the estimates from the Brabant and Utrecht models, and a bit below the estimates from the Hamburg and England models. Our estimate for the natural growth rate, r , which is around 0.21, is a bit lower than the 0.44 reported in FishBase for *Clupea harengus*, which could be a result of climatic impacts given the climate sensibility of autumn spawning herring (Rechlin 1991), but may

also be attributable to the general difficulty in identifying r and K separately from each other.

Fig. S2 shows the estimated development of stock sizes (BESA analysis) across time, based on the four available price data time series. Pairwise Pearson correlation coefficients fall between 0.61 and 0.94, all significant at the 1% level – we conclude that the development of the stock is similarly estimated from all four location datasets. Differences in levels across the four time series can be explained mainly by the different periods they cover, which reflect different average environmental conditions and observed aggregate harvest levels.

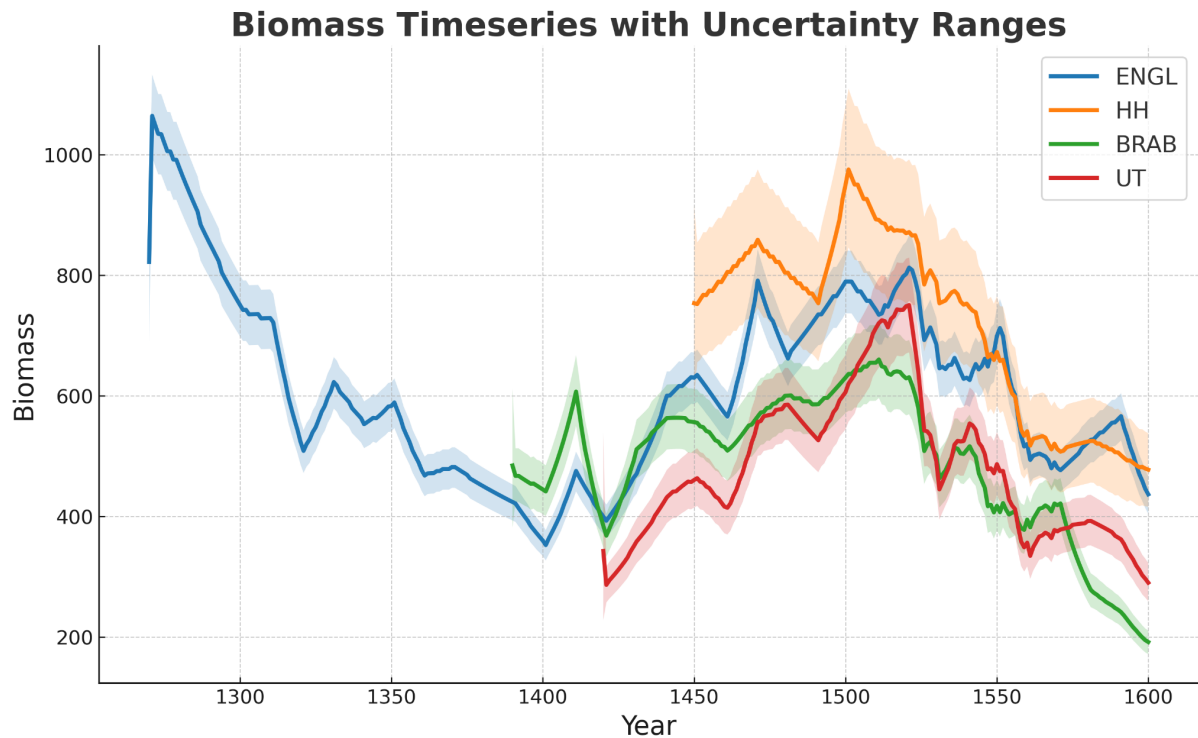


Fig. S2. Biomass ('000 tons) of western Baltic autumn-spawning herring during 1270-1600, based on the bio-economic stock assessment model BESA and estimates derived from four different time series of price data. Lines represent the mean values of the estimated posterior distributions, surrounded by the shaded areas indicating the associated 95% highest-density intervals. The price time series vary in length; Estimates reflect four separate calculations of the same indicator from different price time series applied to the same catch data and should not be summed. ENGL: England; HH: Hamburg; BRAB: Brabant; UT: Utrecht. Estimated from $n=331$ (England), $n=151$ (Hamburg), $n=211$ (Brabant) and $n=181$ (Utrecht) annual observations.

The temperature anomaly has a positive and concave effect on the natural growth rate (see Fig. S3). A pseudo R^2 based on comparing observation error variance indicates that inclusion of the climate anomaly as a covariate improves model fit. This is confirmed by likelihood ratio tests. The improvement is greater for the Brabant and Utrecht models than for the England and Hamburg models.

Concerning model diagnostics, no problems were detected regarding maximum tree depth, step size effectiveness, or divergences. The table shows that only for the Utrecht and England models, a low number of divergences (48 and 75 of 22,400) occurred. Trace-plots

were used to confirm chain convergence, which was not a problem in any of the models. This is also confirmed by the R-hat diagnostic that compares between-chain with within-chain estimates, where the maximum value was 1 in each model. Pairs-plots were used to investigate identification issues: No severe issues were found, though the plots do show a slight interdependence between r and K as well as between c and K , a characteristic difficulty as discussed above. All plots are available upon request.

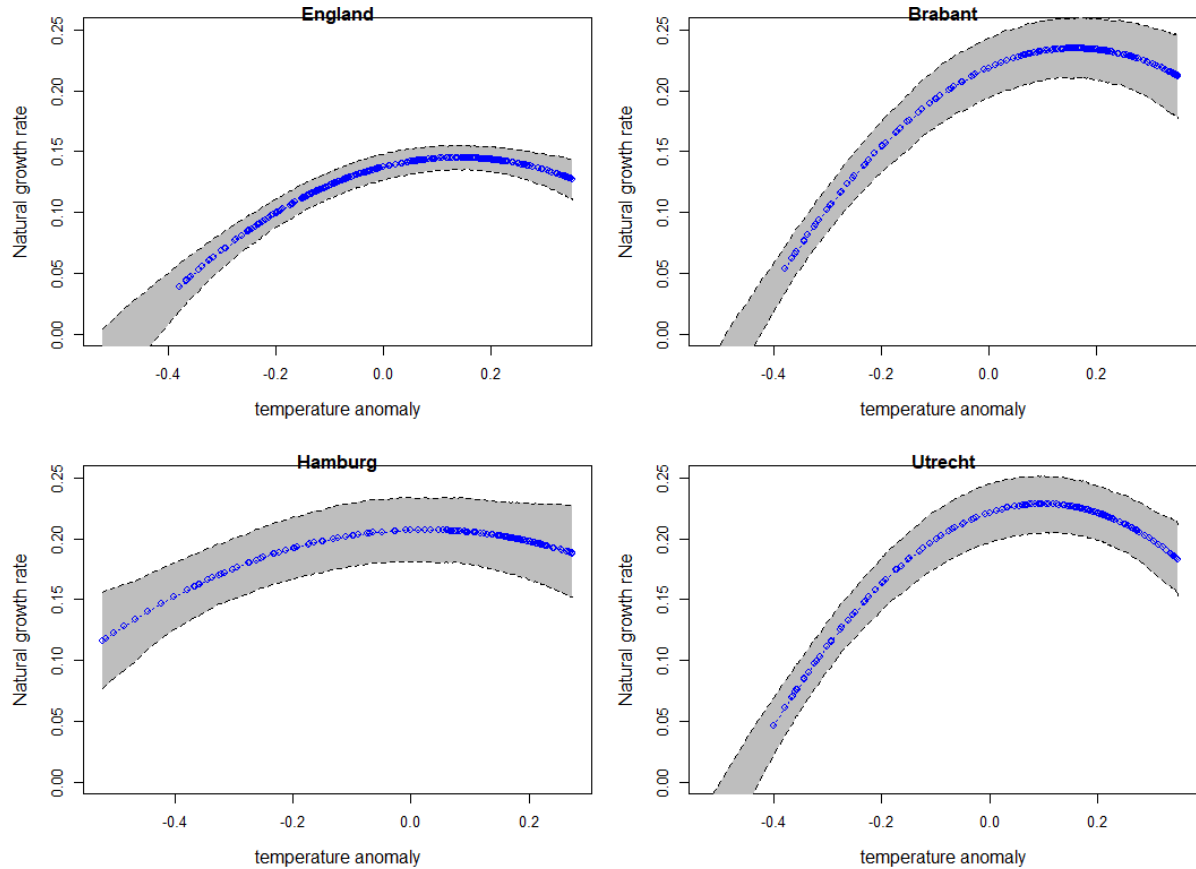


Fig. S3: Natural growth rate r , plotted over the observed range of temperature anomalies, as estimated in the four main models. Dotted lines indicate the means of the estimated posterior density, while shaded areas represent the associated highest-density intervals. Estimated from $n=331$ (England), $n=151$ (Hamburg), $n=211$ (Brabant) and $n=181$ (Utrecht) annual observations.

Tab. S1. Parameters, and diagnostics for the four main models, i.e. England (ENGL), Hamburg (HH), Brabant (BRA), and Utrecht (UT); Values include 95% highest-density intervals (HDI). Priors for r and K were obtained from a CMSY run advised for BESA in Lancker et al. (2023), resulting in the following means: $r = 0.35$, and $K = 542.02$ ('000 tons). The reported pseudo R^2 is computed as 1 minus the ratio of observation error variances between a model with and without inclusion of the climate anomaly.

Parameter/ value	ENGL			HH			BRA			UT		
	mean	95% HDI		mean	95% HDI		mean	95% HDI		mean	95% HDI	
Years in time period	331			151			211			181		
c	68,052.68	63,295.43	72,776.46	61,831.52	53,736.60	70,346.04	55,798.06	50,460.74	61,378.46	44,324.52	39,693.57	49,026.08
r0	0.14	0.13	0.15	0.21	0.18	0.23	0.22	0.19	0.24	0.22	0.20	0.25
tau1	0.11	0.08	0.14	0.01	-0.05	0.08	0.20	0.15	0.25	0.15	0.10	0.20
tau2	-0.39	-0.52	-0.27	-0.31	-0.52	-0.09	-0.62	-0.80	-0.44	-0.73	-0.92	-0.54
K	936.12	895.01	960.00	984.97	863.37	1,109.78	710.02	649.96	773.60	748.92	681.78	817.82
cost trend	-0.03	-2.00	1.90	0.00	-1.94	1.99	-0.20	-2.15	1.76	-0.10	-2.06	1.83
std err. (observation)	0.0009	0.0000	0.0021	0.0012	0.0000	0.0030	0.0014	0.0000	0.0034	0.0015	0.0000	0.0038
std. err. (process)	0.0250	0.0229	0.0271	0.0209	0.0179	0.0241	0.0303	0.0270	0.0337	0.0315	0.0276	0.0355
divergentsams	48			0			0			75		
max. Rhat	1			1			1			1		
pseudoR^2 with versus w/o climate anomaly	0.10			0.13			0.43			0.43		

BESA: Robustness checks

Results are robust to several changes for all four models.

For example, we tested all four models with a flatter prior for the initial biomass size (by varying the prior for initial depletion via a beta distribution with 95% confidence limits of 0.2 and 0.9) and found consistent results.

Concerning climate impacts, we tested the models with no effect of the temperature anomaly, with breaks in the natural growth rate r instead of direct impacts of the temperature, as well as with a linear specification for the temperature anomaly. This analysis confirmed the robustness of findings obtained with the reference configuration.

Furthermore, we tested all models without a trend on cost parameter c . The results remain robust. In particular, the path of depletion over time shows no relevant changes, as expected, since the estimated cost trend is not economically significant.

All results can be provided upon request.

3) Stan code for the main model and priors

```
/*----- Data -----*/
/* Data block: unpack the objects that will be input as data */
data {
  int TT; // Length of state and observation time series
  vector[TT] pt; // Log price observations
  vector[TT] Ht; // Level Harvest observations
  vector[TT] TEMP; // Temperature anomaly observations
  // lognormal and normal prior inputs (first mu, second sig)
  real mur; // transformation made for better numerical performance, mur=1/4r
  real sigr;
  real sigK;
  real musigeps;
  real sigsigeps;
  real musigeta;
  real sigsigeta;
  real sigc;
  real mutau1;
  real sigtau1;
  real mutau2;
  real sigtau2;
  // inputs for beta distribution of starting depletion
  real F11;
  real F12;
  // fixed inputs
  real m; // expected value for K, multiplier for better numerical performance
  real mc; // expected value for c, multiplier for better numerical performance
}
/*----- Parameters -----*/
parameters {
  real<lower=0> r; // parameter in process equation
  real<lower=240/m, upper=960/m> K; // parameter in process equation, ENGL
  //real<lower=0> K; // parameter in process equation
  real<lower=0> sigeps; // standard deviation of the observation equation error
  real<lower=0> sigeta; // standard deviation of the process equation error
  real<lower=0> c; // parameter in observation equation
  real<lower=0, upper=1> Xs; // initial state of depletion
  real<lower=0> Z1; // initial state variance
  real tau1; // temperature response 1
  real tau2; // temperature response 2
  real trend;
```

```

}

// transform some parameters for better numerical performance or to output (MSY)
transformed parameters {
  real sigepstrue;
  real sigetattrue;
  real truer;
  real truek;
  real truec;
  real MSY;
  sigepstrue=sigeps/4;
  sigetattrue=sigeta/4;
  truer=r/4; // reversing transformations made for better numerical performance
  truek=K*m; // reversing transformations made for better numerical performance
  truec=c*mc; // reversing transformations made for better numerical performance
  MSY=truer*truer/4;
}
/*----- Model -----*/
/* Model block: defines and runs the model */
model {
  // Initialization of variables
  vector[TT+1] xt; // state variable time series
  vector[TT+1] Zt; // variance of xt
  vector[TT] xtt; // intermed state var time series
  vector[TT] vt; // residual time series
  vector[TT] Ft; // variance of vt
  vector[TT] Ztt; // intermed state var variance
  vector[TT] Jtt; // Jacobian
  real llik_obs[TT];
  real llik;

  // Prior distributions:
  target+=lognormal_lpdf(c|log(1),sigc);
  target+=lognormal_lpdf(r|log(mur),sigr);
  target+=lognormal_lpdf(K|log(1),sigK);
  target+=normal_lpdf(sigeps|musigeps,sigsigeps);
  target+=normal_lpdf(sigeta|musigeta,sigsigeta);
  target+=beta_lpdf(Xs|F11,F12);
  target+=lognormal_lpdf(Z1|log(0.01),1);
  target+=normal_lpdf(tau1|mutau1,sigtau1);
  target+=normal_lpdf(tau2|mutau2,sigtau2);
  target+=normal_lpdf(trend|0,1);

```

```

// initial:
Zt[1]=Z1; // initial variance
xt[1]=log(Xs); // initial state
target+= -0.5*TT*log(2*3.14159); // log likelihood constant part

// Extended Kalman filter part loop
for (t in 1:TT){
vt[t]=pt[t]-log(truec+trend*t)+log(K*m)+xt[t]; // residual
Ft[t]= Zt[t]+pow(sigepstrue,2); // variance of residual
// Each step, add this part to loglikelihood:
llik_obs[t] = -0.5*(log(Ft[t])+pow(vt[t],2)/Ft[t]); // log likelihood

xtt[t]=xt[t]-(Zt[t]*vt[t])/Ft[t]; // corrected state estimate
Ztt[t]=pow(sigepstrue,2)*Zt[t]/Ft[t]; // variance of corrected state estimate
xt[t+1]=log((1+truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(xtt[t])-
(truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(2*xtt[t])-Ht[t]/truek); // a priori state estimate
for next period
Jtt[t]=((1+truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(xtt[t])-
2*(truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(2*xtt[t]))/((1+truer+tau1*TEMP[t]+tau2*TEMP
P[t]^2)*exp(xtt[t])-(truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(2*xtt[t])-Ht[t]/truek); //
Jacobian
Zt[t+1]=pow(Jtt[t],2)*Ztt[t]+pow(sigetatrue,2); // a priori estimate for state variance for
next period
}
llik = sum(llik_obs); // log likelihood is the sum over all the parts
target+=llik; // add the log likelihood to the target
}

// the next part only serves to make quantities available for R output afterwards
/*----- Generated quantities (for output)-----*/
generated quantities {
vector[TT+1] xt;
vector[TT+1] Bt; // biomass time series
vector[TT] vt;
vector[TT] Ft;
vector[TT+1] Zt;
vector[TT] xtt;
vector[TT] Ztt;
vector[TT] Jtt;
real log_lik[TT];
real llik;

```

```

vector[TT] MSYvec;
vector[TT] rtemp;

// initial:
Zt[1]=Z1;
xt[1]=log(Xs);
Bt[1]=exp(xt[1])*truek;

// Kalman filter part loop
for (t in 1:TT) {
vt[t]=pt[t] -log(truec+trend*t)+log(truek)+xt[t];
Ft[t]= Zt[t]+pow(sigepstrue,2);
log_lik[t] = -0.5*(log(Ft[t])+pow(vt[t],2)/Ft[t]);
xtt[t]=xt[t]-(Zt[t]*vt[t])/Ft[t];
Ztt[t]=pow(sigepstrue,2)*Zt[t]/Ft[t];
xt[t+1]=log((1+truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(xtt[t])-
(truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(2*xtt[t])-Ht[t]/truek);
Jtt[t]=((1+truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(xtt[t])-
2*(truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(2*xtt[t]))/((1+truer+tau1*TEMP[t]+tau2*TEMP
P[t]^2)*exp(xtt[t])-(truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*exp(2*xtt[t])-Ht[t]/truek);
Zt[t+1]=pow(Jtt[t],2)*Ztt[t]+pow(sigetatrue,2);
Bt[t+1]=exp(xt[t+1])*truek;
MSYvec[t]=(truer+tau1*TEMP[t]+tau2*TEMP[t]^2)*truek/4;
rtemp[t]=(truer+tau1*TEMP[t]+tau2*TEMP[t]^2);
}
llik = sum(log_lik);
}

```

Tab. S2. Priors used in BESA main estimation.

parameter	distribution	item	value
transformed r ¹	lognormal	mu sigma	1.41797 0.09991891 (based on CMSY)
K	lognormal	mu sigma	1 (at multiplier m : 542.0222) 0.09991891 (based on CMSY)
cost parameter c	lognormal	mu sigma	$\exp(\text{pt}[1] + (\log(1) + \log(m)))$ 1
starting depletion	beta	F11 F12	9.03 2.74
climate effect tau1	normal	mu sigma	0 1
climate effect tau2	normal	mu sigma	0 1
obs. error	normal	mu sigma	0.5 1
process err.	normal	mu sigma	0.5 1

¹ Note that this is a transformed version for BESA. The actual estimate for the natural growth rate r is $\frac{1}{4}$ the transformed r .

4) Loop analysis

Tab. S3. Pathways through which climate cooling (CC) affects the herring stock (HS) and herring harvest (HA). The table summarizes the pathways by listing names of the variables involved and signs of direct interactions (i.e. positive: $\rightarrow$ and negative: $\rightarrow$); length of the chains (i.e. number of links) and sign of the net effect they carry, obtained through the product of the signs of each link, are indicated.

Pathways	Length	Sign
<i>Impact on herring stock (HS)</i>		
CC $\rightarrow$ AG $\rightarrow$ PO $\rightarrow$ WF $\rightarrow$ HA $\rightarrow$ HS	5	1
CC $\rightarrow$ AG $\rightarrow$ PO $\rightarrow$ EC $\rightarrow$ HA $\rightarrow$ HS	5	1
CC $\rightarrow$ AG $\rightarrow$ PO $\rightarrow$ EC $\rightarrow$ DE $\rightarrow$ HA $\rightarrow$ HS	6	1
CC $\rightarrow$ AG $\rightarrow$ PO $\rightarrow$ EC $\rightarrow$ WA $\rightarrow$ HA $\rightarrow$ HS	6	1
CC $\rightarrow$ AG $\rightarrow$ DE $\rightarrow$ HA $\rightarrow$ HS	4	-1
CC $\rightarrow$ HS	1	-1
<i>Impact on herring harvest (HA)</i>		
CC $\rightarrow$ AG $\rightarrow$ PO $\rightarrow$ WF $\rightarrow$ HA	4	-1
CC $\rightarrow$ AG $\rightarrow$ PO $\rightarrow$ EC $\rightarrow$ HA	4	-1
CC $\rightarrow$ AG $\rightarrow$ PO $\rightarrow$ EC $\rightarrow$ DE $\rightarrow$ HA	5	-1
CC $\rightarrow$ AG $\rightarrow$ PO $\rightarrow$ EC $\rightarrow$ WA $\rightarrow$ HA	5	-1
CC $\rightarrow$ AG $\rightarrow$ DE $\rightarrow$ HA	3	1
CC $\rightarrow$ HS $\rightarrow$ HA	2	-1

5) Climate and stock depletion data

Tab. S4. Temperature anomalies after interpolation and smoothing as plotted in Fig. 1; BESA estimates of stock depletion ('000 tons) as well as 95% Highest Density Interval (HDI) for price series from England, Brabant, Utrecht, and Hamburg, and CMSY depletion estimates with 95% HDI.

Year	Climate	CMSY			England			Hamburg		Brabant		Utrecht	
		Est.	95% HDI		Est.	95% HDI		Est.	95% HDI	Est.	95% HDI	Est.	95% HDI
1270	-0.086	0.72	0.49	0.95	0.88	0.74	0.99						
1271	-0.083	0.76	0.55	0.96	1.14	1.09	1.19						
1272	-0.082	0.79	0.59	0.95	1.12	1.07	1.17						
1273	-0.082	0.81	0.65	0.96	1.11	1.05	1.15						
1274	-0.085	0.83	0.69	0.96	1.10	1.05	1.15						
1275	-0.090	0.85	0.72	0.95	1.09	1.04	1.14						
1276	-0.097	0.87	0.75	0.95	1.07	1.03	1.12						
1277	-0.106	0.88	0.78	0.95	1.07	1.02	1.12						
1278	-0.115	0.89	0.81	0.94	1.06	1.01	1.11						
1279	-0.124	0.89	0.82	0.94	1.06	1.01	1.11						
1280	-0.133	0.90	0.84	0.94	1.05	1.00	1.09						
1281	-0.140	0.90	0.85	0.93	1.03	0.98	1.08						
1282	-0.145	0.90	0.86	0.93	1.02	0.97	1.07						
1283	-0.148	0.91	0.87	0.93	1.00	0.96	1.05						
1284	-0.149	0.91	0.88	0.93	0.99	0.95	1.04						
1285	-0.148	0.91	0.88	0.93	0.98	0.93	1.02						
1286	-0.145	0.91	0.89	0.92	0.97	0.92	1.01						
1287	-0.141	0.91	0.89	0.92	0.94	0.90	0.99						
1288	-0.136	0.91	0.89	0.92	0.93	0.89	0.98						
1289	-0.131	0.91	0.89	0.92	0.92	0.88	0.97						
1290	-0.126	0.91	0.89	0.92	0.91	0.87	0.96						
1291	-0.122	0.91	0.89	0.92	0.90	0.86	0.94						
1292	-0.119	0.90	0.89	0.92	0.89	0.85	0.93						
1293	-0.118	0.90	0.89	0.91	0.88	0.84	0.92						
1294	-0.117	0.90	0.89	0.91	0.86	0.82	0.90						
1295	-0.118	0.90	0.89	0.91	0.85	0.81	0.89						
1296	-0.119	0.90	0.88	0.91	0.84	0.80	0.88						
1297	-0.121	0.89	0.88	0.90	0.83	0.79	0.87						
1298	-0.122	0.89	0.88	0.90	0.82	0.78	0.86						
1299	-0.122	0.89	0.87	0.90	0.81	0.77	0.85						
1300	-0.122	0.88	0.87	0.89	0.80	0.76	0.84						
1301	-0.120	0.88	0.86	0.89	0.79	0.76	0.83						
1302	-0.117	0.87	0.86	0.89	0.79	0.76	0.83						
1303	-0.112	0.87	0.85	0.88	0.79	0.75	0.82						
1304	-0.107	0.87	0.85	0.88	0.79	0.75	0.83						
1305	-0.101	0.87	0.85	0.88	0.79	0.75	0.83						
1306	-0.094	0.86	0.85	0.88	0.79	0.75	0.83						
1307	-0.088	0.86	0.85	0.88	0.78	0.74	0.82						
1308	-0.081	0.86	0.84	0.88	0.78	0.74	0.82						
1309	-0.075	0.86	0.84	0.88	0.78	0.74	0.82						
1310	-0.068	0.86	0.84	0.88	0.78	0.74	0.82						
1311	-0.062	0.86	0.84	0.88	0.77	0.73	0.81						
1312	-0.055	0.86	0.84	0.87	0.74	0.71	0.78						
1313	-0.049	0.86	0.84	0.88	0.71	0.68	0.75						
1314	-0.042	0.86	0.84	0.88	0.69	0.66	0.73						
1315	-0.035	0.86	0.84	0.87	0.67	0.63	0.70						

1316	-0.029	0.86	0.84	0.87	0.64	0.61	0.67
1317	-0.023	0.86	0.84	0.87	0.62	0.59	0.65
1318	-0.018	0.86	0.84	0.87	0.60	0.57	0.63
1319	-0.013	0.86	0.84	0.87	0.58	0.55	0.61
1320	-0.010	0.85	0.84	0.87	0.56	0.53	0.59
1321	-0.008	0.85	0.84	0.87	0.54	0.51	0.57
1322	-0.008	0.85	0.84	0.87	0.56	0.53	0.58
1323	-0.009	0.85	0.84	0.87	0.56	0.53	0.59
1324	-0.012	0.85	0.84	0.87	0.58	0.55	0.61
1325	-0.015	0.85	0.84	0.87	0.59	0.55	0.62
1326	-0.019	0.85	0.84	0.87	0.60	0.57	0.63
1327	-0.024	0.85	0.84	0.87	0.61	0.58	0.64
1328	-0.028	0.85	0.83	0.87	0.62	0.59	0.65
1329	-0.034	0.85	0.83	0.87	0.64	0.61	0.67
1330	-0.041	0.85	0.83	0.87	0.65	0.62	0.68
1331	-0.049	0.85	0.83	0.87	0.67	0.63	0.70
1332	-0.059	0.85	0.83	0.87	0.66	0.63	0.69
1333	-0.071	0.85	0.83	0.87	0.65	0.62	0.68
1334	-0.084	0.85	0.83	0.87	0.64	0.61	0.68
1335	-0.099	0.85	0.83	0.87	0.64	0.60	0.67
1336	-0.115	0.85	0.83	0.87	0.63	0.60	0.66
1337	-0.132	0.85	0.83	0.87	0.62	0.59	0.65
1338	-0.150	0.85	0.83	0.87	0.61	0.58	0.65
1339	-0.168	0.85	0.83	0.87	0.61	0.58	0.64
1340	-0.186	0.85	0.83	0.87	0.60	0.57	0.63
1341	-0.203	0.85	0.83	0.87	0.59	0.56	0.62
1342	-0.219	0.85	0.83	0.87	0.59	0.56	0.63
1343	-0.233	0.85	0.83	0.87	0.60	0.57	0.63
1344	-0.244	0.85	0.83	0.87	0.60	0.57	0.63
1345	-0.251	0.85	0.83	0.87	0.60	0.57	0.63
1346	-0.252	0.85	0.83	0.87	0.61	0.57	0.64
1347	-0.248	0.85	0.83	0.87	0.61	0.58	0.64
1348	-0.238	0.85	0.83	0.87	0.62	0.58	0.65
1349	-0.225	0.85	0.83	0.87	0.62	0.59	0.65
1350	-0.208	0.85	0.83	0.87	0.62	0.59	0.66
1351	-0.189	0.85	0.83	0.87	0.63	0.60	0.66
1352	-0.169	0.85	0.83	0.87	0.61	0.58	0.65
1353	-0.148	0.85	0.83	0.87	0.60	0.57	0.63
1354	-0.127	0.85	0.83	0.87	0.58	0.55	0.61
1355	-0.106	0.85	0.83	0.87	0.57	0.54	0.60
1356	-0.085	0.85	0.83	0.87	0.56	0.53	0.59
1357	-0.064	0.85	0.83	0.87	0.54	0.52	0.57
1358	-0.044	0.85	0.83	0.87	0.53	0.51	0.56
1359	-0.024	0.85	0.83	0.87	0.52	0.50	0.55
1360	-0.006	0.85	0.83	0.87	0.51	0.48	0.54
1361	0.010	0.85	0.83	0.87	0.50	0.47	0.53
1362	0.024	0.85	0.83	0.87	0.50	0.48	0.53
1363	0.036	0.85	0.83	0.87	0.50	0.48	0.53

1364	0.045	0.85	0.83	0.87	0.50	0.48	0.53			
1365	0.051	0.85	0.83	0.87	0.51	0.48	0.53			
1366	0.056	0.85	0.83	0.87	0.51	0.48	0.53			
1367	0.058	0.85	0.83	0.87	0.51	0.48	0.54			
1368	0.060	0.85	0.83	0.87	0.51	0.48	0.54			
1369	0.060	0.85	0.83	0.87	0.51	0.48	0.54			
1370	0.061	0.85	0.83	0.87	0.51	0.49	0.54			
1371	0.062	0.85	0.83	0.87	0.51	0.49	0.54			
1372	0.063	0.85	0.83	0.87	0.51	0.48	0.54			
1373	0.064	0.85	0.83	0.87	0.51	0.48	0.54			
1374	0.065	0.85	0.83	0.87	0.50	0.48	0.53			
1375	0.066	0.85	0.83	0.87	0.50	0.47	0.53			
1376	0.067	0.85	0.83	0.87	0.49	0.47	0.52			
1377	0.068	0.85	0.83	0.87	0.49	0.46	0.52			
1378	0.070	0.85	0.83	0.87	0.49	0.46	0.51			
1379	0.071	0.85	0.83	0.87	0.49	0.46	0.51			
1380	0.072	0.85	0.83	0.87	0.48	0.46	0.51			
1381	0.074	0.85	0.83	0.87	0.48	0.45	0.50			
1382	0.075	0.85	0.83	0.87	0.48	0.45	0.50			
1383	0.075	0.85	0.82	0.86	0.47	0.45	0.50			
1384	0.076	0.85	0.83	0.86	0.47	0.45	0.50			
1385	0.075	0.85	0.83	0.86	0.47	0.44	0.49			
1386	0.075	0.85	0.83	0.86	0.46	0.44	0.49			
1387	0.074	0.85	0.83	0.87	0.46	0.44	0.49			
1388	0.073	0.85	0.83	0.87	0.46	0.43	0.48			
1389	0.074	0.85	0.83	0.87	0.46	0.43	0.48			
1390	0.076	0.85	0.83	0.87	0.45	0.43	0.48	0.68	0.55	0.85
1391	0.079	0.85	0.83	0.87	0.45	0.43	0.47	0.66	0.63	0.69
1392	0.085	0.85	0.83	0.86	0.44	0.42	0.47	0.66	0.63	0.69
1393	0.094	0.85	0.83	0.87	0.43	0.41	0.46	0.65	0.63	0.68
1394	0.105	0.85	0.83	0.86	0.43	0.40	0.45	0.65	0.62	0.68
1395	0.119	0.85	0.83	0.86	0.42	0.40	0.44	0.64	0.62	0.67
1396	0.135	0.85	0.83	0.87	0.41	0.39	0.43	0.64	0.61	0.67
1397	0.152	0.85	0.83	0.86	0.40	0.38	0.43	0.64	0.61	0.67
1398	0.170	0.85	0.83	0.86	0.40	0.38	0.42	0.64	0.61	0.66
1399	0.188	0.85	0.83	0.87	0.39	0.37	0.41	0.63	0.60	0.66
1400	0.206	0.85	0.83	0.87	0.38	0.36	0.41	0.63	0.60	0.65
1401	0.224	0.85	0.83	0.87	0.38	0.36	0.40	0.62	0.59	0.65
1402	0.242	0.85	0.83	0.86	0.39	0.37	0.41	0.64	0.61	0.67
1403	0.261	0.85	0.83	0.86	0.40	0.38	0.42	0.66	0.63	0.69
1404	0.278	0.85	0.83	0.87	0.41	0.39	0.43	0.68	0.65	0.71
1405	0.295	0.85	0.83	0.87	0.42	0.40	0.44	0.70	0.67	0.73
1406	0.310	0.85	0.83	0.86	0.43	0.41	0.46	0.72	0.69	0.75
1407	0.324	0.85	0.83	0.86	0.45	0.42	0.47	0.74	0.71	0.77
1408	0.336	0.85	0.83	0.87	0.46	0.44	0.49	0.77	0.74	0.80
1409	0.345	0.85	0.83	0.87	0.48	0.45	0.50	0.80	0.76	0.83
1410	0.350	0.85	0.83	0.87	0.49	0.47	0.52	0.82	0.79	0.86
1411	0.352	0.85	0.83	0.87	0.51	0.48	0.53	0.85	0.82	0.89

1412	0.353	0.85	0.83	0.87	0.50	0.47	0.52				0.81	0.78	0.84			
1413	0.351	0.85	0.83	0.87	0.49	0.46	0.51				0.76	0.73	0.79			
1414	0.349	0.85	0.83	0.87	0.48	0.45	0.50				0.72	0.69	0.75			
1415	0.346	0.85	0.83	0.87	0.47	0.45	0.49				0.69	0.66	0.72			
1416	0.342	0.85	0.83	0.87	0.46	0.44	0.49				0.65	0.62	0.68			
1417	0.340	0.85	0.83	0.87	0.45	0.43	0.47				0.62	0.59	0.65			
1418	0.338	0.85	0.83	0.87	0.44	0.42	0.47				0.59	0.56	0.62			
1419	0.337	0.85	0.83	0.87	0.43	0.41	0.46				0.57	0.54	0.59			
1420	0.337	0.85	0.83	0.87	0.43	0.40	0.45				0.54	0.52	0.57	0.46	0.31	0.72
1421	0.339	0.85	0.83	0.87	0.42	0.40	0.44				0.52	0.49	0.54	0.38	0.36	0.40
1422	0.341	0.85	0.83	0.87	0.43	0.40	0.45				0.53	0.51	0.56	0.39	0.37	0.41
1423	0.344	0.85	0.83	0.87	0.43	0.41	0.46				0.55	0.53	0.58	0.40	0.38	0.42
1424	0.347	0.85	0.83	0.87	0.44	0.42	0.47				0.57	0.54	0.59	0.41	0.39	0.43
1425	0.349	0.85	0.83	0.87	0.45	0.43	0.47				0.59	0.56	0.61	0.42	0.39	0.44
1426	0.350	0.85	0.83	0.87	0.46	0.44	0.48				0.61	0.58	0.63	0.42	0.40	0.45
1427	0.349	0.85	0.84	0.87	0.47	0.44	0.49				0.62	0.60	0.65	0.43	0.41	0.46
1428	0.346	0.85	0.84	0.87	0.48	0.45	0.50				0.65	0.62	0.68	0.44	0.42	0.47
1429	0.342	0.85	0.84	0.87	0.49	0.46	0.51				0.67	0.64	0.70	0.46	0.43	0.48
1430	0.336	0.85	0.84	0.87	0.50	0.47	0.52				0.69	0.66	0.72	0.47	0.44	0.49
1431	0.329	0.85	0.84	0.87	0.50	0.48	0.53				0.72	0.69	0.75	0.48	0.45	0.50
1432	0.322	0.86	0.84	0.87	0.52	0.49	0.54				0.73	0.70	0.76	0.49	0.46	0.51
1433	0.314	0.86	0.84	0.87	0.53	0.50	0.55				0.73	0.70	0.76	0.50	0.47	0.52
1434	0.306	0.86	0.84	0.87	0.54	0.51	0.57				0.74	0.71	0.77	0.50	0.48	0.53
1435	0.297	0.86	0.84	0.87	0.55	0.52	0.58				0.75	0.72	0.78	0.51	0.49	0.54
1436	0.288	0.86	0.84	0.87	0.56	0.54	0.59				0.76	0.73	0.79	0.52	0.50	0.55
1437	0.277	0.86	0.84	0.87	0.58	0.55	0.61				0.77	0.73	0.80	0.54	0.51	0.56
1438	0.265	0.86	0.84	0.87	0.59	0.56	0.62				0.77	0.74	0.80	0.55	0.52	0.57
1439	0.250	0.86	0.84	0.88	0.61	0.58	0.64				0.78	0.75	0.81	0.56	0.53	0.58
1440	0.232	0.86	0.84	0.87	0.63	0.59	0.66				0.79	0.75	0.82	0.57	0.54	0.59
1441	0.210	0.86	0.84	0.87	0.64	0.61	0.67				0.79	0.76	0.82	0.58	0.55	0.60
1442	0.185	0.86	0.84	0.88	0.64	0.61	0.67				0.79	0.76	0.82	0.58	0.55	0.61
1443	0.158	0.86	0.84	0.88	0.65	0.62	0.68				0.79	0.76	0.82	0.59	0.56	0.62
1444	0.128	0.86	0.84	0.88	0.65	0.62	0.69				0.79	0.76	0.82	0.59	0.56	0.62
1445	0.097	0.86	0.84	0.88	0.66	0.63	0.69				0.79	0.76	0.82	0.60	0.57	0.62
1446	0.065	0.86	0.84	0.88	0.66	0.63	0.69				0.79	0.76	0.82	0.60	0.57	0.63
1447	0.033	0.86	0.84	0.88	0.66	0.63	0.70				0.79	0.76	0.82	0.61	0.58	0.63
1448	0.001	0.86	0.84	0.88	0.67	0.64	0.70				0.79	0.75	0.81	0.61	0.58	0.64
1449	-0.032	0.86	0.84	0.88	0.67	0.64	0.71				0.78	0.76	0.82	0.61	0.58	0.64
1450	-0.064	0.86	0.84	0.88	0.67	0.64	0.71	0.77	0.64	0.91	0.78	0.75	0.81	0.61	0.58	0.64
1451	-0.097	0.86	0.84	0.88	0.68	0.64	0.71	0.76	0.74	0.79	0.78	0.75	0.81	0.62	0.59	0.65
1452	-0.130	0.86	0.84	0.88	0.67	0.64	0.71	0.77	0.75	0.80	0.77	0.74	0.80	0.61	0.58	0.64
1453	-0.163	0.86	0.85	0.88	0.66	0.63	0.70	0.78	0.75	0.80	0.77	0.74	0.80	0.61	0.58	0.64
1454	-0.197	0.86	0.85	0.88	0.66	0.62	0.69	0.78	0.75	0.80	0.76	0.73	0.79	0.60	0.57	0.63
1455	-0.230	0.86	0.85	0.88	0.65	0.62	0.68	0.79	0.76	0.81	0.76	0.73	0.79	0.60	0.57	0.63
1456	-0.262	0.86	0.85	0.88	0.64	0.61	0.67	0.79	0.76	0.81	0.75	0.72	0.78	0.59	0.56	0.62
1457	-0.293	0.86	0.85	0.88	0.63	0.60	0.67	0.79	0.77	0.82	0.74	0.71	0.77	0.58	0.55	0.61
1458	-0.321	0.86	0.85	0.88	0.63	0.59	0.66	0.80	0.78	0.83	0.74	0.71	0.77	0.57	0.55	0.60
1459	-0.344	0.87	0.85	0.88	0.62	0.59	0.65	0.80	0.78	0.83	0.73	0.70	0.76	0.56	0.54	0.59

1460	-0.359	0.87	0.85	0.88	0.61	0.58	0.64	0.81	0.78	0.83	0.73	0.70	0.76	0.56	0.53	0.59
1461	-0.366	0.87	0.85	0.88	0.60	0.57	0.64	0.82	0.79	0.84	0.72	0.69	0.75	0.55	0.52	0.58
1462	-0.365	0.87	0.85	0.88	0.62	0.59	0.65	0.82	0.79	0.84	0.72	0.69	0.75	0.56	0.53	0.59
1463	-0.357	0.87	0.85	0.88	0.64	0.60	0.67	0.83	0.80	0.85	0.73	0.70	0.76	0.58	0.55	0.61
1464	-0.343	0.87	0.85	0.88	0.66	0.63	0.70	0.83	0.80	0.85	0.74	0.71	0.77	0.59	0.56	0.62
1465	-0.324	0.87	0.85	0.88	0.68	0.65	0.72	0.84	0.81	0.86	0.75	0.72	0.78	0.61	0.58	0.65
1466	-0.301	0.87	0.85	0.88	0.70	0.67	0.74	0.84	0.81	0.86	0.76	0.73	0.79	0.63	0.60	0.66
1467	-0.275	0.87	0.85	0.88	0.73	0.70	0.77	0.85	0.82	0.88	0.77	0.73	0.80	0.65	0.62	0.69
1468	-0.249	0.87	0.85	0.88	0.76	0.72	0.79	0.85	0.82	0.88	0.78	0.74	0.81	0.67	0.64	0.71
1469	-0.223	0.87	0.85	0.88	0.78	0.74	0.82	0.86	0.83	0.89	0.78	0.75	0.81	0.70	0.66	0.73
1470	-0.198	0.87	0.85	0.89	0.81	0.77	0.85	0.86	0.83	0.89	0.79	0.76	0.82	0.72	0.68	0.75
1471	-0.173	0.87	0.85	0.88	0.85	0.80	0.89	0.87	0.85	0.90	0.80	0.77	0.83	0.74	0.71	0.78
1472	-0.148	0.87	0.85	0.89	0.83	0.79	0.87	0.86	0.84	0.89	0.81	0.78	0.84	0.75	0.71	0.78
1473	-0.123	0.87	0.85	0.89	0.81	0.77	0.85	0.85	0.83	0.88	0.81	0.78	0.84	0.76	0.72	0.79
1474	-0.098	0.87	0.85	0.89	0.80	0.76	0.84	0.85	0.83	0.88	0.82	0.79	0.85	0.76	0.72	0.79
1475	-0.074	0.87	0.85	0.89	0.78	0.74	0.82	0.84	0.82	0.87	0.82	0.79	0.85	0.76	0.72	0.79
1476	-0.049	0.87	0.85	0.89	0.77	0.74	0.81	0.84	0.82	0.87	0.83	0.80	0.86	0.76	0.72	0.79
1477	-0.025	0.87	0.86	0.89	0.76	0.72	0.80	0.83	0.81	0.86	0.83	0.80	0.86	0.77	0.73	0.80
1478	0.000	0.87	0.86	0.89	0.75	0.71	0.78	0.83	0.81	0.86	0.84	0.81	0.87	0.77	0.74	0.80
1479	0.024	0.87	0.86	0.89	0.73	0.70	0.77	0.83	0.80	0.85	0.84	0.81	0.87	0.77	0.74	0.81
1480	0.047	0.87	0.86	0.89	0.72	0.68	0.76	0.82	0.79	0.84	0.85	0.81	0.88	0.78	0.75	0.82
1481	0.070	0.87	0.86	0.89	0.71	0.67	0.74	0.82	0.79	0.84	0.85	0.81	0.88	0.78	0.75	0.82
1482	0.091	0.87	0.86	0.89	0.72	0.69	0.76	0.81	0.78	0.83	0.85	0.82	0.88	0.77	0.74	0.81
1483	0.109	0.87	0.86	0.89	0.73	0.69	0.76	0.81	0.78	0.83	0.84	0.81	0.87	0.76	0.73	0.80
1484	0.125	0.87	0.86	0.89	0.73	0.70	0.77	0.80	0.77	0.82	0.84	0.81	0.87	0.76	0.72	0.79
1485	0.137	0.87	0.86	0.89	0.74	0.71	0.78	0.80	0.77	0.82	0.84	0.81	0.87	0.75	0.72	0.78
1486	0.146	0.87	0.86	0.89	0.75	0.71	0.79	0.79	0.77	0.82	0.83	0.80	0.86	0.74	0.71	0.77
1487	0.153	0.88	0.86	0.89	0.76	0.72	0.79	0.79	0.77	0.81	0.83	0.80	0.86	0.73	0.70	0.77
1488	0.159	0.88	0.86	0.89	0.76	0.73	0.80	0.78	0.76	0.81	0.83	0.80	0.86	0.73	0.69	0.76
1489	0.163	0.88	0.86	0.89	0.77	0.73	0.81	0.78	0.76	0.81	0.83	0.79	0.86	0.72	0.68	0.75
1490	0.167	0.88	0.86	0.89	0.78	0.74	0.82	0.77	0.75	0.80	0.83	0.79	0.86	0.71	0.68	0.74
1491	0.170	0.88	0.86	0.89	0.79	0.75	0.82	0.77	0.74	0.79	0.83	0.79	0.86	0.70	0.67	0.73
1492	0.174	0.88	0.86	0.89	0.79	0.75	0.82	0.79	0.76	0.81	0.83	0.80	0.86	0.72	0.68	0.75
1493	0.177	0.88	0.86	0.89	0.79	0.76	0.83	0.81	0.78	0.83	0.84	0.81	0.87	0.73	0.69	0.76
1494	0.180	0.88	0.86	0.89	0.80	0.76	0.84	0.83	0.80	0.85	0.84	0.81	0.87	0.74	0.71	0.77
1495	0.184	0.88	0.86	0.89	0.81	0.77	0.85	0.84	0.82	0.87	0.85	0.82	0.88	0.75	0.72	0.78
1496	0.188	0.88	0.86	0.89	0.82	0.78	0.86	0.86	0.84	0.89	0.86	0.82	0.89	0.76	0.73	0.80
1497	0.192	0.88	0.87	0.90	0.82	0.78	0.86	0.88	0.86	0.91	0.86	0.83	0.89	0.77	0.74	0.81
1498	0.196	0.88	0.86	0.89	0.83	0.79	0.87	0.91	0.88	0.93	0.87	0.84	0.90	0.79	0.76	0.83
1499	0.201	0.88	0.87	0.90	0.83	0.80	0.87	0.94	0.91	0.97	0.88	0.85	0.91	0.80	0.77	0.84
1500	0.205	0.88	0.87	0.89	0.84	0.80	0.88	0.96	0.94	0.99	0.89	0.86	0.92	0.81	0.77	0.84
1501	0.210	0.88	0.87	0.89	0.84	0.80	0.88	0.99	0.96	1.02	0.90	0.86	0.93	0.83	0.79	0.86
1502	0.215	0.88	0.87	0.90	0.84	0.80	0.88	0.98	0.95	1.01	0.90	0.86	0.93	0.84	0.80	0.87
1503	0.219	0.88	0.87	0.90	0.83	0.80	0.87	0.96	0.94	0.99	0.90	0.87	0.94	0.85	0.81	0.88
1504	0.224	0.88	0.87	0.90	0.83	0.79	0.87	0.96	0.94	0.99	0.90	0.87	0.94	0.87	0.83	0.91
1505	0.228	0.88	0.87	0.90	0.83	0.79	0.87	0.95	0.92	0.98	0.90	0.87	0.94	0.88	0.84	0.92
1506	0.230	0.88	0.87	0.90	0.82	0.78	0.86	0.94	0.91	0.97	0.91	0.88	0.95	0.89	0.85	0.93
1507	0.230	0.88	0.87	0.90	0.81	0.77	0.85	0.94	0.91	0.97	0.91	0.88	0.95	0.90	0.87	0.94

1508	0.228	0.88	0.87	0.90	0.81	0.77	0.85	0.93	0.90	0.96	0.92	0.89	0.95	0.91	0.88	0.95
1509	0.222	0.88	0.87	0.90	0.80	0.76	0.84	0.92	0.89	0.94	0.92	0.89	0.95	0.94	0.90	0.98
1510	0.213	0.88	0.87	0.90	0.79	0.76	0.83	0.91	0.88	0.93	0.92	0.89	0.95	0.95	0.91	0.99
1511	0.200	0.88	0.87	0.90	0.78	0.75	0.82	0.91	0.88	0.93	0.93	0.90	0.96	0.96	0.92	1.00
1512	0.185	0.88	0.87	0.89	0.79	0.75	0.83	0.90	0.87	0.93	0.91	0.88	0.95	0.97	0.93	1.01
1513	0.168	0.87	0.86	0.89	0.80	0.76	0.84	0.90	0.87	0.93	0.91	0.88	0.94	0.97	0.93	1.01
1514	0.149	0.86	0.84	0.88	0.80	0.76	0.84	0.89	0.86	0.92	0.90	0.86	0.93	0.95	0.91	0.99
1515	0.130	0.85	0.83	0.87	0.81	0.77	0.85	0.89	0.87	0.92	0.89	0.86	0.93	0.97	0.93	1.01
1516	0.111	0.84	0.82	0.86	0.83	0.79	0.87	0.89	0.86	0.91	0.90	0.87	0.93	0.98	0.94	1.02
1517	0.094	0.83	0.81	0.85	0.84	0.80	0.88	0.89	0.86	0.91	0.90	0.87	0.93	0.99	0.95	1.03
1518	0.079	0.83	0.81	0.85	0.84	0.80	0.88	0.89	0.86	0.91	0.90	0.87	0.93	0.99	0.95	1.03
1519	0.069	0.83	0.81	0.85	0.85	0.81	0.89	0.89	0.86	0.91	0.89	0.86	0.92	0.99	0.95	1.03
1520	0.063	0.82	0.80	0.84	0.86	0.82	0.90	0.88	0.86	0.91	0.89	0.85	0.92	1.00	0.96	1.04
1521	0.061	0.82	0.80	0.84	0.87	0.83	0.91	0.88	0.86	0.91	0.89	0.86	0.92	1.00	0.96	1.04
1522	0.062	0.82	0.80	0.84	0.86	0.82	0.91	0.88	0.85	0.91	0.87	0.84	0.90	0.95	0.92	0.99
1523	0.067	0.82	0.80	0.84	0.85	0.81	0.89	0.88	0.85	0.91	0.85	0.82	0.88	0.91	0.87	0.94
1524	0.075	0.82	0.80	0.84	0.82	0.79	0.86	0.87	0.84	0.89	0.82	0.79	0.85	0.86	0.82	0.89
1525	0.085	0.81	0.78	0.83	0.78	0.74	0.82	0.83	0.80	0.86	0.77	0.74	0.80	0.79	0.75	0.83
1526	0.095	0.77	0.74	0.80	0.74	0.70	0.78	0.80	0.77	0.82	0.72	0.69	0.75	0.72	0.69	0.76
1527	0.107	0.73	0.70	0.77	0.75	0.71	0.79	0.81	0.79	0.84	0.73	0.70	0.76	0.72	0.69	0.76
1528	0.118	0.71	0.67	0.75	0.76	0.73	0.80	0.82	0.79	0.85	0.74	0.71	0.77	0.71	0.68	0.75
1529	0.129	0.71	0.67	0.74	0.75	0.71	0.79	0.81	0.78	0.84	0.72	0.69	0.75	0.68	0.65	0.72
1530	0.140	0.71	0.68	0.75	0.73	0.70	0.77	0.80	0.78	0.83	0.71	0.68	0.74	0.66	0.62	0.69
1531	0.151	0.70	0.67	0.74	0.69	0.65	0.73	0.76	0.74	0.79	0.65	0.62	0.68	0.59	0.56	0.62
1532	0.162	0.69	0.65	0.72	0.69	0.66	0.73	0.77	0.74	0.79	0.66	0.63	0.69	0.61	0.58	0.64
1533	0.172	0.66	0.62	0.70	0.69	0.65	0.73	0.77	0.74	0.80	0.67	0.64	0.70	0.63	0.59	0.66
1534	0.183	0.64	0.60	0.68	0.70	0.66	0.73	0.78	0.75	0.80	0.69	0.66	0.72	0.64	0.61	0.67
1535	0.192	0.63	0.58	0.68	0.70	0.66	0.73	0.78	0.76	0.81	0.70	0.67	0.73	0.66	0.63	0.70
1536	0.201	0.64	0.59	0.68	0.71	0.67	0.74	0.79	0.76	0.81	0.72	0.69	0.75	0.69	0.66	0.73
1537	0.209	0.64	0.60	0.69	0.70	0.66	0.73	0.78	0.76	0.81	0.72	0.69	0.75	0.70	0.67	0.74
1538	0.215	0.65	0.61	0.69	0.68	0.65	0.72	0.77	0.74	0.79	0.71	0.68	0.74	0.70	0.67	0.73
1539	0.219	0.64	0.60	0.69	0.67	0.64	0.71	0.76	0.74	0.79	0.71	0.68	0.74	0.70	0.67	0.74
1540	0.220	0.63	0.59	0.67	0.67	0.64	0.71	0.76	0.74	0.79	0.72	0.69	0.75	0.72	0.69	0.75
1541	0.219	0.62	0.57	0.66	0.67	0.63	0.70	0.76	0.73	0.78	0.73	0.70	0.76	0.74	0.71	0.78
1542	0.217	0.61	0.57	0.66	0.68	0.65	0.72	0.75	0.73	0.78	0.71	0.68	0.74	0.74	0.70	0.77
1543	0.213	0.61	0.56	0.65	0.70	0.66	0.73	0.75	0.73	0.77	0.70	0.67	0.73	0.73	0.69	0.76
1544	0.209	0.60	0.56	0.65	0.69	0.65	0.72	0.73	0.70	0.75	0.66	0.64	0.69	0.70	0.66	0.73
1545	0.205	0.59	0.55	0.64	0.69	0.66	0.73	0.72	0.69	0.74	0.65	0.62	0.68	0.69	0.66	0.72
1546	0.202	0.58	0.53	0.62	0.71	0.67	0.74	0.70	0.68	0.73	0.63	0.60	0.66	0.67	0.64	0.71
1547	0.201	0.55	0.50	0.60	0.69	0.66	0.73	0.67	0.65	0.70	0.59	0.56	0.62	0.64	0.60	0.67
1548	0.202	0.52	0.47	0.57	0.71	0.68	0.75	0.68	0.66	0.70	0.59	0.56	0.62	0.64	0.61	0.67
1549	0.205	0.49	0.43	0.54	0.72	0.68	0.76	0.67	0.65	0.69	0.57	0.55	0.60	0.63	0.60	0.66
1550	0.211	0.47	0.41	0.53	0.75	0.71	0.79	0.68	0.66	0.71	0.59	0.56	0.61	0.65	0.62	0.68
1551	0.220	0.46	0.40	0.51	0.76	0.72	0.80	0.67	0.64	0.69	0.57	0.55	0.60	0.63	0.60	0.67
1552	0.230	0.46	0.40	0.52	0.75	0.71	0.78	0.67	0.65	0.69	0.59	0.57	0.62	0.63	0.61	0.67
1553	0.242	0.47	0.41	0.52	0.71	0.68	0.75	0.65	0.63	0.67	0.58	0.55	0.61	0.61	0.58	0.64
1554	0.254	0.47	0.42	0.53	0.68	0.64	0.71	0.63	0.61	0.65	0.57	0.54	0.59	0.57	0.54	0.60
1555	0.264	0.47	0.41	0.53	0.65	0.62	0.69	0.61	0.59	0.63	0.57	0.55	0.60	0.56	0.53	0.59

1556	0.271	0.47	0.41	0.53	0.64	0.61	0.68	0.61	0.59	0.63	0.58	0.55	0.60	0.55	0.52	0.58
1557	0.274	0.47	0.41	0.52	0.60	0.57	0.63	0.58	0.56	0.60	0.55	0.52	0.58	0.51	0.48	0.54
1558	0.273	0.46	0.40	0.52	0.57	0.54	0.60	0.55	0.53	0.57	0.54	0.51	0.56	0.48	0.45	0.51
1559	0.268	0.43	0.38	0.50	0.55	0.52	0.58	0.54	0.52	0.56	0.53	0.50	0.56	0.47	0.44	0.49
1560	0.257	0.40	0.35	0.48	0.56	0.53	0.59	0.55	0.53	0.57	0.56	0.53	0.58	0.48	0.45	0.50
1561	0.241	0.38	0.32	0.45	0.53	0.50	0.56	0.53	0.51	0.55	0.54	0.51	0.56	0.45	0.42	0.47
1562	0.223	0.37	0.30	0.44	0.54	0.51	0.56	0.54	0.52	0.56	0.56	0.53	0.58	0.47	0.44	0.49
1563	0.203	0.35	0.29	0.43	0.54	0.51	0.57	0.54	0.52	0.56	0.57	0.54	0.60	0.48	0.45	0.50
1564	0.182	0.35	0.28	0.43	0.54	0.51	0.57	0.54	0.52	0.56	0.58	0.56	0.61	0.49	0.46	0.51
1565	0.161	0.35	0.28	0.43	0.54	0.51	0.56	0.54	0.52	0.56	0.58	0.56	0.61	0.49	0.47	0.52
1566	0.139	0.35	0.28	0.44	0.53	0.51	0.56	0.54	0.52	0.56	0.59	0.56	0.62	0.50	0.47	0.52
1567	0.118	0.35	0.28	0.45	0.53	0.50	0.56	0.53	0.51	0.55	0.58	0.56	0.61	0.49	0.47	0.52
1568	0.096	0.34	0.27	0.45	0.51	0.48	0.54	0.52	0.50	0.54	0.57	0.55	0.60	0.49	0.46	0.51
1569	0.075	0.34	0.27	0.45	0.52	0.49	0.55	0.53	0.51	0.55	0.59	0.57	0.62	0.50	0.48	0.53
1570	0.054	0.33	0.26	0.45	0.51	0.49	0.54	0.52	0.50	0.54	0.59	0.56	0.62	0.50	0.47	0.53
1571	0.034	0.32	0.24	0.44	0.51	0.48	0.54	0.52	0.50	0.54	0.59	0.57	0.62	0.51	0.48	0.53
1572	0.013	0.32	0.23	0.45	0.51	0.49	0.54	0.52	0.50	0.54	0.57	0.54	0.59	0.51	0.48	0.53
1573	-0.007	0.31	0.22	0.45	0.52	0.49	0.55	0.52	0.50	0.54	0.54	0.52	0.56	0.51	0.48	0.54
1574	-0.028	0.30	0.21	0.45	0.52	0.50	0.55	0.52	0.50	0.54	0.52	0.49	0.54	0.51	0.48	0.54
1575	-0.048	0.30	0.20	0.45	0.53	0.50	0.56	0.53	0.51	0.55	0.49	0.47	0.52	0.52	0.49	0.54
1576	-0.069	0.29	0.18	0.46	0.53	0.51	0.56	0.53	0.51	0.55	0.47	0.45	0.50	0.52	0.49	0.54
1577	-0.089	0.29	0.17	0.47	0.54	0.51	0.57	0.53	0.51	0.55	0.46	0.43	0.48	0.52	0.49	0.54
1578	-0.110	0.29	0.16	0.48	0.55	0.52	0.58	0.53	0.51	0.55	0.44	0.42	0.46	0.52	0.49	0.55
1579	-0.130	0.29	0.15	0.49	0.55	0.52	0.58	0.53	0.51	0.55	0.42	0.40	0.44	0.52	0.49	0.55
1580	-0.150	0.30	0.14	0.51	0.56	0.53	0.59	0.53	0.51	0.55	0.41	0.39	0.42	0.52	0.50	0.55
1581	-0.171	0.30	0.14	0.52	0.56	0.53	0.59	0.53	0.51	0.55	0.39	0.37	0.41	0.52	0.50	0.55
1582	-0.191	0.31	0.12	0.54	0.56	0.53	0.59	0.53	0.51	0.55	0.39	0.37	0.40	0.52	0.49	0.55
1583	-0.212	0.32	0.12	0.57	0.57	0.54	0.60	0.53	0.51	0.55	0.38	0.36	0.40	0.52	0.49	0.54
1584	-0.232	0.34	0.11	0.59	0.58	0.54	0.60	0.53	0.51	0.55	0.37	0.36	0.39	0.51	0.49	0.54
1585	-0.253	0.35	0.10	0.62	0.58	0.55	0.61	0.52	0.50	0.54	0.37	0.35	0.39	0.51	0.48	0.54
1586	-0.273	0.38	0.11	0.65	0.58	0.55	0.61	0.52	0.50	0.54	0.36	0.35	0.38	0.51	0.48	0.53
1587	-0.294	0.40	0.12	0.69	0.59	0.56	0.62	0.52	0.50	0.54	0.36	0.34	0.38	0.50	0.48	0.53
1588	-0.314	0.44	0.12	0.71	0.59	0.56	0.62	0.52	0.50	0.54	0.36	0.34	0.37	0.50	0.47	0.53
1589	-0.335	0.47	0.13	0.74	0.59	0.56	0.62	0.51	0.49	0.53	0.35	0.33	0.37	0.49	0.47	0.52
1590	-0.357	0.51	0.17	0.78	0.60	0.57	0.63	0.51	0.49	0.53	0.35	0.33	0.36	0.49	0.46	0.51
1591	-0.378	0.55	0.20	0.81	0.60	0.57	0.64	0.51	0.49	0.53	0.34	0.32	0.35	0.48	0.46	0.51
1592	-0.400	0.60	0.23	0.84	0.58	0.55	0.61	0.50	0.48	0.52	0.33	0.32	0.35	0.47	0.45	0.50
1593	-0.422	0.64	0.28	0.86	0.57	0.54	0.60	0.50	0.48	0.52	0.32	0.31	0.34	0.46	0.44	0.48
1594	-0.444	0.69	0.33	0.88	0.55	0.52	0.58	0.50	0.48	0.52	0.31	0.30	0.33	0.45	0.43	0.47
1595	-0.466	0.73	0.38	0.90	0.54	0.51	0.57	0.50	0.48	0.51	0.30	0.29	0.32	0.44	0.42	0.46
1596	-0.486	0.77	0.44	0.91	0.52	0.49	0.55	0.49	0.47	0.51	0.30	0.28	0.31	0.43	0.40	0.45
1597	-0.503	0.80	0.50	0.92	0.50	0.48	0.53	0.49	0.47	0.51	0.29	0.27	0.30	0.42	0.39	0.44
1598	-0.516	0.83	0.55	0.93	0.49	0.46	0.52	0.49	0.47	0.51	0.28	0.27	0.29	0.40	0.38	0.43
1599	-0.522	0.86	0.61	0.94	0.48	0.45	0.50	0.49	0.47	0.50	0.27	0.26	0.29	0.40	0.38	0.42
1600	-0.522	0.89	0.67	0.95	0.47	0.44	0.49	0.48	0.47	0.50	0.27	0.26	0.28	0.39	0.37	0.41

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6) Short description on timeseries construction, based on Lehmann et al. 2021. (see full translated article below)

Herring catch volumes in the western Baltic Sea, 1200–1650

To determine the total herring catch volume in the western Baltic Sea 1200-1650, the yields of the fisheries in Scania, on Rügen, at the Limfjord, on Bornholm, and in the Szczecin Lagoon are considered. However, catches from Scania by far dominated the total output from ca. 1300 onwards, with only marginal contributions from other catch sites. Reliable information on trade volumes, providing benchmark values, can be found in pound-toll accounts (military levy of the Hanseatic towns), Danish tax accounts, and the kongekøb (payment in kind). However, these data exist only for individual towns and market sites, and only for specific years, so they must be extrapolated on the basis of market shares, preferably using tax data. The benchmark values determined in this way are validated using economic indicators, climate data, and political framework conditions. The gaps between the benchmark values were filled by extrapolation, using data on production factors (salt) as well as economic indicators (prices), and climate data as reference points. The reliability of the data is assessed as follows:

- Original tax data: certain [+++++]
- Extrapolations based on tax data: highly reliable [++++]
- Estimates based on tax data: reliable [+++]
- Assumptions based on other data (e.g. salt as production factor): highly probable [++]
- Plausibility-checked assumptions: probable [+]

The results are rounded down using a conservative approach and assessed overall with regard to their reliability. Figure SI1 provides an overview on the estimation process.

Herring Catch Volume Determination Process

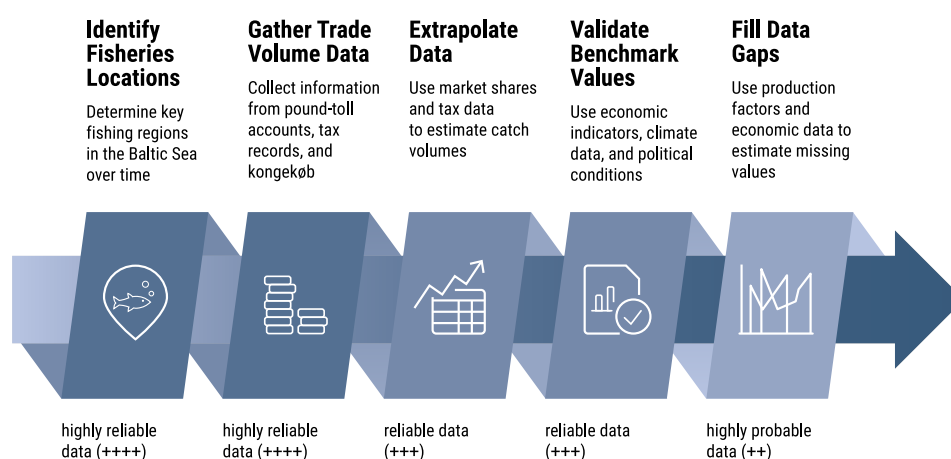


Fig. SI4: Conceptual figure on timeseries reconstruction approach.

Quantification of catch volumes is based on the historical unit “Tonne Rostocker Band (TRB)” as accounting basis. One TRB equals 100 kg of fresh fish (based on Jahnke (2000), Holm (2001)) [++++ - highly reliable data]. For assessment of the kongekøb we need to assess the number of fishes per historic unit “wal”. We assume that 15 wal equals 1,200 fish per TRB (based on Schäfer (1927)) [++++ - highly reliable data].

Establishment of the time series is then based on benchmark years and data-driven extrapolation (see figure SI2), as described below.

Herring Catch Volume Estimation in the Western Baltic Sea (1200–1650)

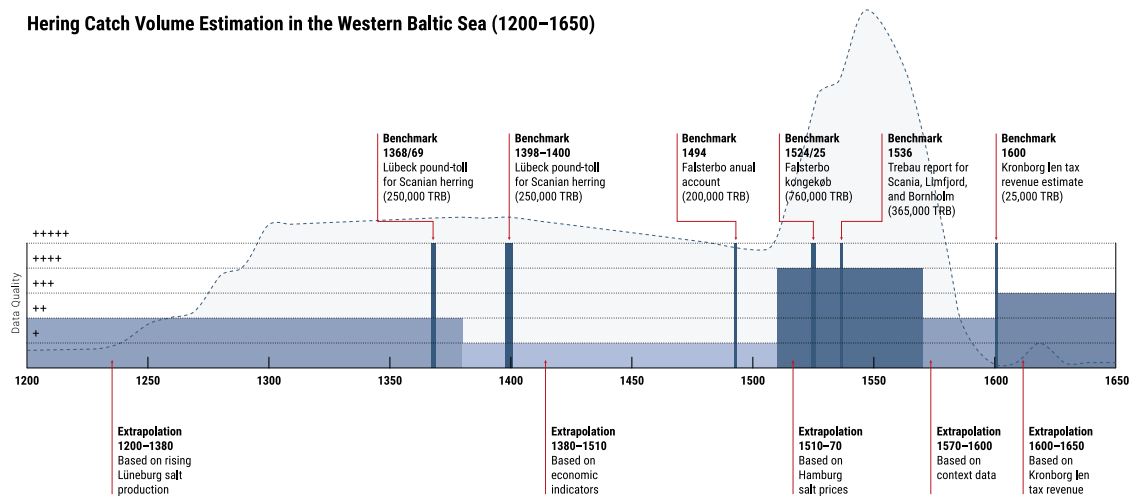


Fig. SI5: Overview on data quality of different periods of the time-series, including benchmark years, major data sources, extrapolation methods and data reliability. Expert judgement.

1. Benchmark values

(i) 1368/69 and 1398–1400 (late 14th century):

- a) Lübeck pound-toll for Scanian herring (Weibull (1967), Lechner (1935)): Ø 68,370 TRB [+++++]
- b) Extrapolation of Scanian production based on Lübeck's share of the pound-toll (Ø 59%; Weibull (1922)): 116,841 TRB [++++]
- c) Plus 50,000 TRB for direct trade to the West (Holm (1996)), rendered plausible by Flemish import data (Degrijse (1957)) [+++]
- d) Plus Scanian kongekøb (3.6%; Schäfer (1927); 8,700 TRB), of which only two-thirds are considered due to resale of kongekøb to merchants: 6,000 TRB (Jahnke (2000)) [++++]
- e) Plus Rügen herring: Lübeck pound-toll for herring from Stralsund 1368/69: 1,186 TRB (Lechner (1935)); exemptions from trade restrictions 1393: 3,152.5 TRB (Wehrmann (1867)): Ø 2,169 TRB, extrapolated as under (b), but with lower direct trade (c) and without kongekøb (d): 5,000 TRB [+++]
- f) Plus Limfjord herring based on kongekøb 1518 (higher at the Limfjord than in Scania): in 1518, 528 TRB were levied on 2,616 TRB in Aalborg (17%; Jahnke (2000), Holm (2001)), extrapolated to all Limfjord markets (Holm (1996)): 4,000 TRB; since Limfjord fisheries were still developing in the late 14th century (Jahnke (2000)), only 2,000 TRB are used [++]
- g) Plus Bornholm herring based on fishery tax of 1597/1607 (1 wal per fisherman): 1,458 and 567 TRB respectively; 1,000 TRB used [+++]
- h) Plus Szczecin Lagoon herring, no values available, 1,000 TRB used [+
- i) Rounded down to 250,000 TRB (conservative approach) [+++]

(ii) 1494 (late 15th century):

- a) Annual account of 1494 for Falsterbo: 47,323 TRB (Schäfer (1927)) [+++++]
- b) Extrapolation of Scanian production based on Falsterbo's share (1536: 27%): 176,000 TRB, derived from the customs officer Trebau's report [++++]
- c) Plus compensation for catch decline in 1494 (Hirsch (1855)): 12,000 TRB [++]
- d) Plus two-thirds kongekøb (as in 1 d) [++++]
- e) Plus smaller market fisheries (1 e–h) [++]
- f) Rounded down to 200,000 TRB, considered plausible given the decline of Lübeck pound-toll 1492–95 (Bruns (1908)) and economic indicators (Bullion famine, salt prices, population figures, as in III 1.) [+++]

(iii) 1524/25:

- a) Kongekøb for Falsterbo (Register paa the Slott): 7,703 TRB, corresponding to a catch of 200,000 TRB [+++++]
- b) Extrapolation as in 2 b.: 750,000 TRB, supported by catch volumes in Holland and Bohuslän (Akveld (2003), Poulsen (2008)) and economic indicators (as in III 1.) [++++]
- c) Plus smaller market fisheries (1 e–h), with 4,000 TRB used for Limfjord fisheries [++]
- d) Rounded down to 760,000 TRB [++++]

(iv) 1536:

- a) Report of customs officer Trebau for Scania, Limfjord, and Bornholm (as in 1 f and g): 360,000 TRB [+++++]
- b) Plus smaller market fisheries (1 e, h) [++]
- c) Rounded down to 365,000 TRB [++++]

(v) 1600:

- a) Estimate based on tax revenue for Kronborg len (North Zealand), number of fishermen in Scania from the Danish census of 1771 (Holm (1996), Holm (2001)), and productivity per fisherman according to kongekøb (Register paa the Slott): 10,000 TRB, supported by the documented decline of the fishery (Jahnke (2000)) and the reversal of trade flows (Christensen (1941)) [+++]
- b) Plus smaller market fisheries (1 e–h), which likely benefited from the collapse of the Sound fishery; mid-17th century Limfjord fisheries briefly reached 30,000 TRB (Holm (1996)) [+++]
- c) Rounded (for around 1600) to 25,000 TRB [+++]

2. Extrapolations

(i) 1200–late 14th century based on rising Lüneburg salt production (Witthöft (1976)), and supported by trends in Lübeck salt imports, population, and prices (Malanima (2010), Bairoch (1988), Abel (1978), Hitzbleck (1971), Hirsch (1858)) [++]

(ii) Late 14th century–1510 based on economic indicators (as in 1.): stagnation due to agrarian crisis, Bullion famine, and climate change (IPCC (2013), Mann (2009)) [+]

(iii) 1511–1569:

- a) Based on Hamburg salt prices (North (1990)) [+++++]
- b) Starting from yields of 1524/25 and 1536 [++++]
- c) Inflation-adjusted using salt-herring price trends (Hitzbleck (1971)) [++]
- d) Supported by Lüneburg salt deliveries (Witthöft (1976)), catch volumes in Holland and Bohuslän (as in II 3 b), economic indicators (as in 1.), climate change (as in 2.), and political history (Jahnke (2000)) [+++]

(iv) 1570–1600: no values; 1572 decline of the fishery in Skanör and Falsterbo due to shifting dunes (Jahnke (2000)); based on market share (as in II 2 b) and the subsequent decline of the fishery, and supported by the reversal of trade flows (as in II 5 a) and climate change (as in 2.) [++]

(v) 1600–1650: extrapolation based on tax revenue for Kronborg len and number of fishermen in Scania from the Danish census of 1771 (as in II 5 a.) [+++]

7) Detailed description on timeseries development based on Lehmann et al., 2021 “De vorbisteringhe deß heringheß uth deme Sunde” -Indizien für eine vorindustrielle Überfischung des Ostseeherings. *Hansischen Geschichtsblätter* (Band 139/2021). ISSN 0073-0327, ISBN 978-3-940677-09-9 (2021). AI-supported translation of original German peer-reviewed publication. With the permission of the journal.

De vorbisteringhe deß heringheß uth deme Sunde

Evidence for preindustrial overfishing of herring in the Baltic Sea area

Oliver Lehmann, Jörn O. Schmidt and Rüdiger Voss

Abstract: Salted herring became one of the most important commodities during the times of the Hanseatic League. C. 1200, fishery centred in the Oresund (Sound fishery). Sources to project yields on are fragment (e.g. toll-books, chronicles). Reviewing sources in the light of data on factors that influenced production: salt, labour, general economy (demographics, money-supply, prices, and market-volume), legal frameworks (privileges, market-orders), sales channels, political situations (trade conditions) and temperatures, we constructed a trend of estimated outputs of the western Baltic herring-fisheries (1200–1650). Thus, we found indications that the collapse of the Sound fishery, c. 1580, was triggered by overfishing. Applying marine and fisheries science on our findings (development of stocks and size of fish caught), we show that the autumn spawning herring, which was the basis of the Sound fishery, must have been sustainably damaged then, contributing to its practical extinction in recent times.

1. Introduction

For almost 300 years (c. 1280–1570), fishing in the Øresund and off Scania (the Sound fishery) was Europe's most important salted herring producer. Scanian herring was traded from the British Isles through Central and Eastern Europe to Northern Italy. The fishing villages developed into 'international' trading centres (Scania Fairs). Around 1580, however, the area was abruptly abandoned. The centre of fishing shifted to the North Sea. From then on, Dutch herring dominated the market². In the Baltic Sea, only the Limfjord (Aalborg) was still fished to any significant extent³. And in the Sound, the previous catch volumes were not reached again until the 1950s⁴.

Why was herring fishing in the western Baltic Sea abandoned so suddenly? Did – as chroniclers suspected⁵ – the fish migrate to the North Sea? A change in the migration pattern cannot be ruled out⁶. As will be shown in this article, the evidence suggests that the collapse of the Sound fishery was the result of overfishing.

It is generally assumed that the total trade volume of the Sound fishery amounted to approximately 200,000–300,000 tons of Rostock tonnage (TRB) per year⁷. The starting point for this estimate is Lübeck's import volumes at the end of the 14th century (Lübeck pound customs books 1368, 1398–1400)⁸, which, following Weibull, were extrapolated based on the Scanian pound customs accounts for the years 1368/69⁹. A trade volume of 200,000–300,000 TRB corresponds to a catch of at least 20,000–30,000 metric tons (t)¹⁰. For comparison: the current catch volumes in the western Baltic Sea are 15,000–25,000 t per year. However, that doesn't mean much. In the 1980s, up to 100,000 tons per year were landed¹¹, but this was known to overfish stocks.

In general, evidence of overexploitation of fish stocks can only be identified by looking at the development of catches or trade volumes. A time series is therefore required. However, the sources are

² Poulsen 2008, S. 40 ff.

³ Holm 2016, S. 17; ders. 1996, S. 194.

⁴ Thurow 1997, S. 451.

⁵ CS 28, § 1436, S. 226 f.

⁶ Poulsen 2008, S. 212.

⁷ Hill 2006, S. 724.

⁸ Weibull 1967, p. 66.

⁹ Weibull 1922, pp. 18.

¹⁰ Holm/Bager 2001, p. 108.

¹¹ ICES 2020a, p. 8 f.

fragmentary. Reliable data on trade volumes (e.g., from customs records) are available only for individual cities or trade fair locations, and even then only for individual years. In addition, information on the royal right of first refusal (for herring) at the trade fairs (*kongekøb*) can be used. The extent of the in-kind payment allows for inferences about the number of fishermen and their productivity, which allows for further extrapolations. The samples can then be linked to other time series, e.g., on the production factor salt (trade volumes, prices). This creates a trend in catch volumes for the entire study period (1200–1650). Bearing in mind that such a combination of extrapolation and interpolation is subject to considerable uncertainty, the results must be checked for plausibility at every opportunity. To do this, the factors that may have influenced salted herring production must be considered. In addition to the general economic situation and the political and ecological conditions (temperatures¹²), these include, in particular, the availability of production factors (salt, labour), as well as the legal situation, trade practices, and distribution channels of the Sound fishery. The latter are described in detail by Schäfer and Jahnke. Extensive material is also available on economic indicators, for example on demographics¹³, on salted herring¹⁴, on grain¹⁵, on salt prices¹⁶, on the capacity and trade volumes of the Lüneburg saltworks¹⁷. However, this information has not yet been used, or only partially used¹⁸, to determine the yields of the historical herring fisheries in the western Baltic Sea.

While a trend does not necessarily represent an accurate time series, a rough assessment from a fisheries perspective is already possible based on the magnitude of trade or catch volumes, for example, by comparing it with the recommendations of the *International Council for the Exploration of the Sea* (ICES)¹⁹, which form the basis for modern catch quotas. However, such a comparison requires expert classification. In particular, it is necessary to clarify whether and how the ecological conditions for herring in the western Baltic Sea have changed since the late Middle Ages or the early modern period. Furthermore, the development of the size of the fish caught must be examined. This is because size allows conclusions to be drawn about the age structure of the stocks and thus about fishing pressure. Last but not least, the fact that the spawning behaviour of the herring population has apparently changed will have to be investigated. In the Baltic Sea, modern herring fishing is based on spring spawning, i.e., on herring, which reaches its maximum weight before laying eggs in the spring. However, according to the trade fair period (August 15 to October 9)²⁰, it must have been autumn spawners that were caught in the Sound at that time. However, the economic importance of autumn spawners is so small today that even their populations are no longer recorded²¹. The article is structured as follows: First, the historical trade unit, the "Rostock Band," is examined in more detail. All estimates are based on this. Next, the magnitude of the trade volumes of the Sound fishery are determined, namely for the period of its rise (13th century), Hanseatic dominance (late 14th century), stagnation (15th century), late prosperity (1524–71), and decline (late 16th century). In conclusion, the trend established on this basis will be evaluated from a fisheries science perspective, and the evidence for overfishing will be assessed in an overall perspective. This article was written as part of the project "Marine ecological-economic systems in the Western Baltic

¹² IPCC 2013, p. 419, Fig. 5.12, black line (reconstruction of the historical temperature anomaly in Europe from 1500 to 1850); also Mann 2009, p. 1257, Fig. 1B (Atlantic Multidecadal Oscillation).

¹³ Malanima 2010, pp. 5–6; Bairoch 1988, p. 297 (as the average of both estimates for the main sales areas of Scanian herring: Poland, Germany, the Netherlands, Belgium, England, Scotland, and Scandinavia).

¹⁴ Hitzbleck 1971, p. 324 ff., based on various price collections (p. 6 ff.), including those by Rogers (England) and Elsas (Germany), for Hamburg, Hanover, Braunschweig, Holzstedt, Frankfurt, Speyer, Würzburg, Augsburg, England, Brabant, Leiden, Utrecht, Amsterdam, Kraków, Danzig, Vienna, Klosterneuburg, and Alsace in silver, as well as for Munich in gold. While price developments on the individual markets show similarities, the price level sometimes differs considerably, apparently depending on the trade distance (transportation costs, customs duties). Therefore, the index was not calculated based on the level, but rather on the price changes on the individual markets. This was done – in order to make data fragments usable – initially for the base period 1541–50, for which most quotations are available. The index was then based on the unweighted average of price changes.

¹⁵ Abel 1978, p. 306 ff., as an average of the price changes (cf. fn. 13) for wheat in England, Belgium, France, and Northern Italy, as well as for rye in Holland, Germany, Austria, and Poland (in silver).

¹⁶ Hirsch 1858, pp. 258 ff. (for Danzig); North 1990, p. 190 (for Hamburg); for conversion to silver: Jesse 1928, pp. 209 ff.

¹⁷ Witthöft 1976, p. 77, 83 ff., 95.

¹⁸ Holm/Bager 2001, p. 109; Holm 1996, S. 190 f., 196 f.

¹⁹ ICES 2017, p. 1 (for 2018, since then ICES has recommended the cessation of fishing, most recently ICES 2020a, p. 1).

²⁰ Schäfer 1927, p. XCIX; based on entries in the Pound Customs Act 1409, Jenks suspects that the herring season actually ran until November 1 or even 11 (Jenks 2012, p. XXXII).

²¹ ICES 2020b.

Sea and beyond: Shifting the baselines to a regime of sustainability (marEEshift), funded by the Federal Ministry of Education and Research. It is based on the results of the working paper "Estimates on the Herring Harvested in the Western Baltic Sea, c. 800–1800," which was presented at the annual meeting of the International Council for the Exploration of the Sea (ICES 2018) in Hamburg and at the conference "Territories and durability of maritime resource exploitation: adapting to change, changing for adapting" at the Institut Brestois des Sciences de l'Homme et de la Société, Université de Bretagne Occidentale.

2. The barrel ,Rostocker Band‘

During Hanseatic times, salted herring was traded in barrels. The standard measure was the 'Rostocker Band' (TRB) tonne (Rostocker Band) introduced at the end of the 14th century²². It held just under 120 litres. The ratio of herring to saltwater was 2:1, resulting in a net fish weight of approximately 80 kg per TRB. Approximately 3/17 of this was lost during fish processing²³. According to this, one TRB corresponded to a catch weight of 97 kg. Holm/Bager estimate 100 kg (0.1 t) per TRB²⁴. This is adopted here.

Considerable quantities of salt were required for fish processing. For every 22–24 loads of herring (12 TRB each), seven loads of Lüneburg salt were used. This represents a salt content of approximately 23%. If Baien salt was used, seven loads were only sufficient to process 17–19 loads (28%)²⁵. Baien salt is seawater salt extracted from the Atlantic coast and has entered the Baltic Sea market since the mid-14th century as a cheaper, albeit inferior, alternative to Lüneburg salt²⁶.

The number of herrings per ton is controversial. Hitzbleck has compiled 22 estimates, including ten literary opinions (including Elsas: 1,000–1,200 for Dutch herring, Tomfohrde: 1,000 for Scanian herring, and 800 for Bohuslän herring), three-ton counts (in 1483 in Sélestat: 446 for half a ton, in 1573 and 1582 in Strasbourg: 898 and 1,317, respectively), and data from account books (in 1540 for Würzburg: 1,300, and in 1728–1765 for Hanover: 780–1,020). The range of estimates ranges from 640 for Bohuslän (Marstrand, 16th century) to 1,360–1,520 (17–19 whales of 80 herring each) for Scanian herring (1485 in Gdansk). Hitzbleck himself calculates 1,000, but notes that it is almost impossible to calculate the contents of the barrel based on the number of herrings it contains²⁷. Based on a profit statement for herring traded in Halberstadt, Jahnke assumes a minimum of 830–840 for the TRB²⁸. Holm assumes 840²⁹. This roughly corresponds to the figures in *The Noubre of Weights* (1463)³⁰ and *The Book of Rates* (1558)³¹. According to this, the herring barrel in England was calculated at 833 (10,000 per load). Nevertheless, it was English merchants who complained to the Hanseatic League in 1378 that the number of herrings per ton barely reached 900, whereas it had traditionally been 1,000–1,200³². The fact that the figures for the actual number of herrings per ton differ is primarily due to the fact that different tonnage measurements were used in the different fishing areas, for example, in the Netherlands: 141.1 litres (sea pack), in Bohuslän: 122.5 litres, and in England and Scotland: 127 litres³³. Furthermore, the number depended on the average catch size: the smaller the fish, the higher the number. The size of the fish, in turn, depended on

- the stock being fished; for example, herring in the North Sea may have tended to be larger than in the Baltic Sea³⁴,

²² Witthöft 2006, pp. 745 f.; HR I 2, No. 266, § 5, p. 323.

²³ Poulsen 2008, p. 141.

²⁴ Holm/Bager 2001, p. 108.

²⁵ Jahnke 2000, p. 220.

²⁶ Lamschus 2006, p. 623.

²⁷ Hitzbleck 1971, pp. 316 ff.

²⁸ Jahnke 2000, p. 220, footnote 18.

²⁹ Holm/Bager 2001, p. 109.

³⁰ Jenks 1992, p. 304.

³¹ Willan 1967, p. 33.

³² HR I 3, No. 102, p. 89.

³³ Poulsen 2008, pp. 47 ff., 141; Hitzbleck 1971, pp. 315 f.

³⁴ In 2018, the average weight of herring caught in the North Sea (autumn spawning) was 133 g; for the spring spawning herring in the Baltic Sea in 2019, it was only 107 g (ICES 2020b, pp. 74, 345).

- the time of harvest – sometimes pre-seasonal and therefore inferior catches were also processed (zomerghud)³⁵ – and
- the age structure of the stock or catch (Chapters 5 and 8).

In addition, tampering with the contents of the barrels during distribution was possible. To preserve the fish, the brine had to be renewed from time to time³⁶. For this purpose, the fish was repackaged, which provided opportunities for fraud. Against this background, the barrel counts cited by Hitzbleck must be viewed with the reservation that suspicion of fraud may have prompted the review. In general, there may have been a tendency to conceal profits from long-distance trade by reducing the size of the barrels. The Hanseatic League responded to this, among other things, by introducing the Rostock Volume standards. However, since complaints persisted, the legal and factual impact of standardization may have been limited³⁷.

The question of the number of herrings per TRB thus remains open. But it can be left aside here. The decisive factor for the upcoming extrapolations is not how many herring per TRB actually reached consumers, but rather how many units the TRB was valid for according to Danish customs. This is the basis for the assessment of duties, especially the royal right of pre-emption (kongekøb). In connection with the kongekøb of 1524/25, Hermann Tellemann, Lübeck's bailiff in Falsterbo, calculated the TRB at 1,200 units (15 whales)³⁸. This figure was evidently also the basis for the taxation of fishermen on Bornholm in 1607. At that time, a total of seven tons of herring was collected from 105 fishermen. If one calculates the ton as 1,200 herring, each fisherman ("per oar") would have had to pay 80 herring, i.e., exactly one whale³⁹. This is unlikely to have been a coincidence, nor was it a coincidence that the kongekøb of three whales (240 herring) per fisherman and usually five fishermen per boat amounted to exactly one TRB per boat (Chapter 4). Thus, the figure of 1,200 herring per TRB can be seen as at least the legal fiction of the Danish tax authorities, which will therefore be used as the basis for the following calculations.

3. Rise (13th century)

The first major market fishing industry in the Baltic Sea developed on Rügen. Initially, Kolberg salt was used to process herring, and from the mid-12th century, Lüneburg salt was used. The latter was brought by merchants from Bardowick. After Bardowick's decline (1189), Lübeck took over the business. The city soon controlled fish processing on Rügen. However, access to the fishery remained regulated by the sovereign. Jahnke dates the heyday of Rügen fishing to around 1260. At that time, Rügen herring was traded via the Oder to Poland and Moravia, and also via the Elbe to central Germany. By 1290, however, the island had already lost its importance as a fishing centre⁴⁰.

By the end of the 12th century, a fishing and trading centre had also emerged in the Øresund. Due to disputes over the Danish throne, the Sound fishery soon came under the influence of Lübeck. The city also asserted its market power in Scania as the main importer of Lüneburg salt. Subsequently, the Sound fishery developed more dynamically than its Pomeranian predecessor. This may have been due, among other things, to the liberal market regulations of the Scanian fairs. By virtue of the Danish fishing rights, in principle, anyone was permitted to fish for herring in the Sound⁴¹.

This mobilized labour. Year after year, the Scanian fairs (Skanör, Falsterbo, Malmö, Dragör, and others) attracted numerous seasonal workers, especially Danish farmers who, after the harvest, became fishermen⁴².

How high were the yields? Direct data are lacking. Sources that allow an extrapolation of the trade volumes of the Rügen fishery and the early Sound fishery are only available for the end of the 14th

³⁵ Schäfer 1927, p. 11; UBStL 4, No. 137, pp. 131 and 132.

³⁶ Jahnke 2000, p. 222.

³⁷ Schäfer 1927, pp. LXV et seq., see also HR I, 6, No. 68, § 20, p. 60; No. 397, § 53, p. 377.

³⁸ Register paa the Slott, p. 313.

³⁹ Holm/Bager 2001, p. 112, as well as in Kronborg Len (ibid., p. 110).

⁴⁰ Jahnke 2000, pp. 15 ff.

⁴¹ Ebd., p. 39 ff., 47 ff., 64 ff.

⁴² Jahnke 1997a, p. 300 ff., 306 f.

century, when the latter had long since dominated the market. Until then, only backward calculations are possible. Given the high salt demand of the herring fisheries, the development of the capacity of the Lüneburg saltworks can be considered a benchmark for this. In the 13th century, this tripled (1205: 5,208 t, 1227: 6,566 t, 1244: 8,543 t, 1273: 12,070 t, 1291/1301: 15,333 t), whereas in the 14th century it stagnated (1388: 15,122 t)⁴³.

Since the end of the 12th century, Lüneburg salt held a near-monopoly in the Baltic Sea region. Distribution was dominated by Lübeck, especially of so-called summer or ship salt, which covered the autumn demand peak of the Sound fishery (August 15 to October 9). In 1368/69, the city imported 7,661 tons. This was roughly half of Lüneburg's production capacity⁴⁴. In 1368, one-third, and in 1369, half, of Lübeck's salt exports went to Scania⁴⁵. How much of this was used in fish processing is not entirely clear, especially since the Scanian fairs were also a salt market. What is certain is that it was not enough to cover the Sound fishery's demand⁴⁶. This results in a simple rough calculation: As discussed in Chapter 1. The quantity of herring processed in Scania in 1368 amounted to approximately 262,000 metric tons (Table 1). This would have required a good 8,200 tons (60,000 tons at 136 kg each⁴⁷) of Lüneburg salt (23%). While further salt deliveries from other cities (e.g., Wismar) or other saltworks (e.g., Oldesloe) can be assumed, even these would probably not have been enough to close the gap of several thousand metric tons.

It can therefore be assumed that Baien salt was already being traded on a significant scale in the Baltic Sea in 1368. Further details are unknown. In the second half of the 16th century, the market share of Baien salt exceeded that of Lüneburg salt by five times⁴⁸. Between 1562 and 1657, an average of 45,000–50,000 tons per year passed through the Sound⁴⁹. Against this background, it is quite possible that early Baien salt imports already amounted to several thousand metric tons. By 1427, salt imports from the West were already so significant that the price of salt quadrupled as a result of the capture of the Hanseatic Baien fleet⁵⁰.

However, if imports of salt from the Baltic Sea already had a significant market share in the Baltic Sea by the end of the 14th century, is the development of the capacity of the Lüneburg saltworks still suitable for retrospectively calculating the trade volumes of the Rügen fishery and the early Sound fishery? Shouldn't it then be assumed that salted herring production also increased from the mid-14th century onwards, namely in proportion to the amount of salt added, so that the retrospective calculations would have to be adjusted accordingly?

That the Sound fishery grew in the second half of the 14th century is highly unlikely, given the plague that was raging in Europe at the time⁵¹. The first wave of plague hit Lübeck in 1349/50. A quarter of the population died⁵². And the disease returned at regular intervals from then on⁵³, for example in 1358 and 1367⁵⁴. The price of salted herring rose significantly compared to grain, which could have provided incentives for an increase in catches. On the other hand, fishermen may also have fallen victim to the plague, so a decline in production is also a possibility, which would equally explain the price increase, partly as a result of higher wages. The general assumption is that the reason for the price increase is that assets, especially real estate⁵⁵, were concentrated among the survivors as a result of inheritance, giving them increased purchasing power, which was used, among other things, to consume higher-quality foods, such as fish⁵⁶. Be that as it may, overall, demographics do not suggest that the Sound fishery grew significantly as a result of increasing imports of salt from the bay in the second half of the 14th century. It

⁴³ Witthöft 1976, p. 77, whereby the capacity cannot be used to directly determine the actual production.

⁴⁴ Ebd., p. 4, 13, 66, 105.

⁴⁵ Hill 2006, p. 724.

⁴⁶ Irsigler 2006, p. 708.

⁴⁷ Witthöft 1976, p. 27.

⁴⁸ Lamschus 2006, p. 623.

⁴⁹ Witthöft 1976, p. 110.

⁵⁰ Hirsch 1858, p. 258.

⁵¹ Weigl 2012, p. 52.

⁵² Graßmann 2008, p. 183.

⁵³ Weigl 2012, p. 53.

⁵⁴ Wolf 2006, S. 563.

⁵⁵ Graßmann 2008, p. 184.

⁵⁶ Hitzbleck 1971, p. 14.

is more likely that parts of the 'fishing industry' simply switched to cheaper seawater salt.

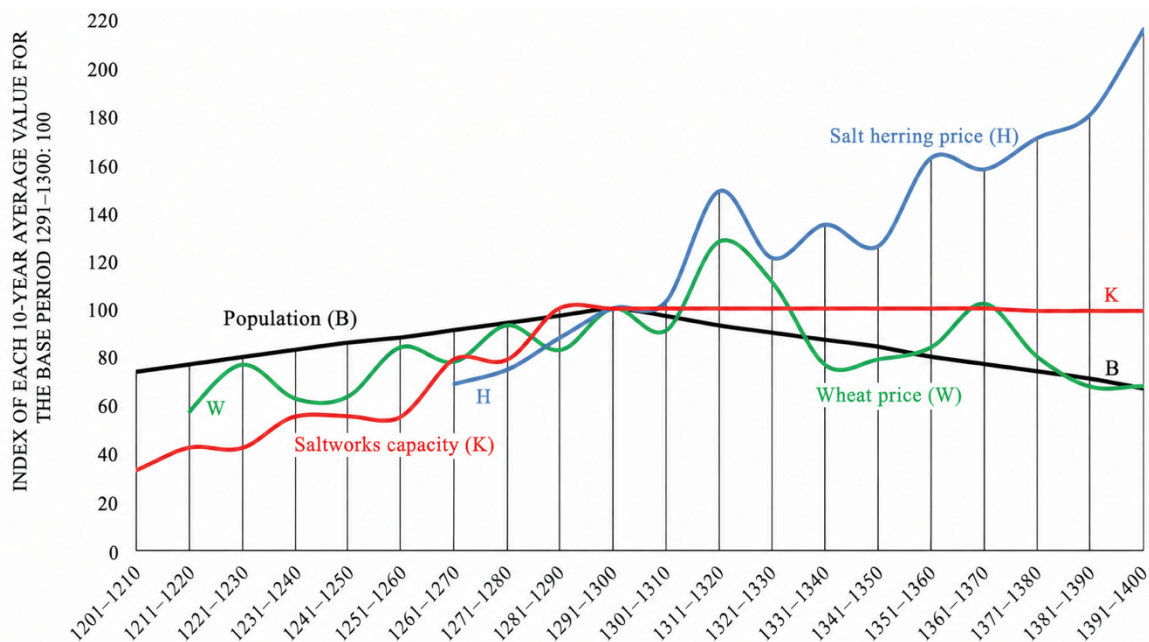


Fig. 1: Indices for the development of population and capacity of the Lüneburg saltworks, as well as the English prices for salted herring and wheat in silver (1200–1400). Sources: see footnotes 12, 13, and 14, as well as Witthöft 1976, p. 77.

The theory that salted herring production in the western Baltic Sea correlated with the development of the capacity of the Lüneburg saltworks is even more plausible for the 13th century through economic indicators: a growing population led to increased demand, higher prices, and thus to an expansion of production (Fig. 1). Accordingly, the first peak of herring fishing in the western Baltic Sea can be dated to around 1300. This is consistent with Jahnke's finding that salted herring had already become an everyday food at that time, at least in England (Fig. 2)⁵⁷. However, falling temperatures (Little Ice Age, Fig. 8) as well as famine (1315–22)⁵⁸ and plague (see above) temporarily put an end to the boom.

4. Hanseatic dominance (end of the 14th century)

Despite all the Hanseatic League's political and military successes at the end of the 14th century (Peace of Stralsund), these were times of crisis. As a result of the plague, agricultural production declined. Cultivated land was abandoned (deserted lands)⁵⁹. The economy suffered from the consequences of the late medieval agrarian crisis. There was also a shortage of coin metal (Great Bullion Famine). The medieval silver and gold mines were almost exhausted, and precious metal reserves flowed eastward due to a permanently negative foreign trade balance⁶⁰. The precious metal shortage led to coin depreciation and a shortage of cash. The resulting deflation caused the economy to stagnate, particularly in the Hanseatic economic zone, where, apart from the bond market, the possibility of creating money through credit instruments was still barely used⁶¹.

How much Scanian herring was traded at that time? Sources are available for Lübeck. According to the pound customs books, the city imported 66,558, 71,043, and 66,877 TRB between 1398 and 1400. Weibull estimates approximately 76,000 TRB for 1368. Following Weibull, Lübeck's import volume can be extrapolated based on the accounting of the Scanian pound customs for the years 1368/69. This extrapolation assumes that the trading conditions of the Wendish and Prussian cities at the Scanian fairs were similar to those of Lübeck. According to this, approximately 206,000 TRB of salted herring were

⁵⁷ Jahnke 2008, p. 160.

⁵⁸ Weigl 2012, p. 51, Abel 1978, p. 47.

⁵⁹ Weigl 2012, p. 68 f.

⁶⁰ North 2009, p. 38 ff.

⁶¹ North 2006, p. 756 f.

transhipped in the Hanseatic Baltic ports in 1368. More reliable than the estimate for 1368 are the import volumes for 1398–1400⁶². Extrapolating these based on the Scanian pound duty of 1368/69 is, however, fraught with uncertainty due to the chronological discrepancy of 30 years. Given the poor availability of sources, however, it is first necessary to determine the order of magnitude. Therefore, an average for the end of the 14th century is simply calculated here: 190,000 TRB per year (Table 1)⁶³.

However, this does not include direct trade to the West (ummeland). In 1368/69, merchants from the Zuiderzee, England, Flanders, and Brabant had to pay roughly the same amount of customs duties in Scania as in Lübeck. However, their trading conditions were different. Less privileged in Scania, their main commercial interest likely lay in selling western products (e.g., textiles, wine) at the fairs. Since these were of higher quality than salted herring, the pound duty may have been levied primarily on exports. Thus, Weibull is cautious in his estimate of the volume of salted herring traded in ummeland: it may have amounted to 1.5% + x of Lübeck's trade volume.

Whether shipped via the ummeland or mediated by the Hanseatic trade, it is certain that the West imported considerable quantities of salted herring. In Sluis, in Flemish Holland, for example, an average of 20,280 TRB per year was recorded between 1374 and 1380. Even larger quantities may have been imported via Damme, the older port⁶⁴. Against this background, Holm estimates the volume of the ummeland trade in salted herring at least 50,000 TRB per year⁶⁵. This is followed here, especially since salted herring was inexpensive in the West compared to grain (Fig. 2). At the end of the 14th century, one kilogram of salted herring, for example, was the equivalent of 8 kg of wheat in England, whereas in Kraków it was 50 kg of rye (albeit about 10–15% cheaper)⁶⁶. Therefore, the demand for salted herring was likely significantly higher in the West than in the East. In 1368/69, 10,065 ½ TRB were imported by Mechelen merchants alone, presumably to supply the workers of the Flemish textile industry⁶⁷. According to this, the total trade volume of the Sound fishery at the end of the 14th century was approximately 240,000 TRB per year. In addition, there was the herring that was processed on behalf of the king, for example, to supply troops. The Crown could also assert a right of first refusal against the fishermen (kongekøb), in the amount of three whales each (80 herrings = 240 pieces = 0.2 TRB)⁶⁸. Presumably, the treasury acquired the fish at about half the market price⁶⁹. In 1524/25, according to Hermann Tellemann, Lübeck's bailiff in Falsterbo, the kongekøb amounted to 115,545 whales (7,703 TRB). The crews of 7,515 boats, each with approximately five fishermen, were assessed⁷⁰. Ideally, the kongekøb thus amounted to one TRB per boat (5 x 0.2 TRB).

⁶² Weibull 1967, pp. 66–67, also fn. 13; Lechner 1935, pp. 58–59.

⁶³ The Danzig pound customs book from 1409 and 1411 provides further data on import quantities. According to this book, Danzig's salted herring imports in 1409 amounted to 37,390 1/2 TRB. For 1411, only 2,820 TRB were recorded, the latter likely due to the war and a shortened fiscal year. Although the Danzig pound customs is well documented, the data cannot be used here. This was not a Hanseatic tax, but rather a sovereign tax that only the Prussian cities had to pay (Jenks 2012, pp. XVI ff., XLIV, XLVII). Thus, there is no standard for extrapolating Danzig's share of the salted herring trade.

⁶⁴ Degrijse 1957, p. 102 ff. From December 1382 to May 1383, Sluis imported 22,026.5 TRB. Of this, 3,356.5 TRB were accounted for by the osterlinge, i.e., by the Hanseatic merchants from the Baltic region. During the same period, the osterlinge taxed 7,344 TRB in Damme (HR I, 3, No. 447, § 5, p. 463). Assuming that the market share of the osterlinge was similar in both ports, a total of 70,000 TRB could have been imported.

⁶⁵ Holm 1996, p. 178 f.

⁶⁶ Abel 1978, p. 27.

⁶⁷ Jahnke 2000, p. 254, 422.

⁶⁸ Ebd., p. 181 f.

⁶⁹ Schäfer 1927, p. LVI, Fn. 4.

⁷⁰ Register paa the Slott, p. 313.

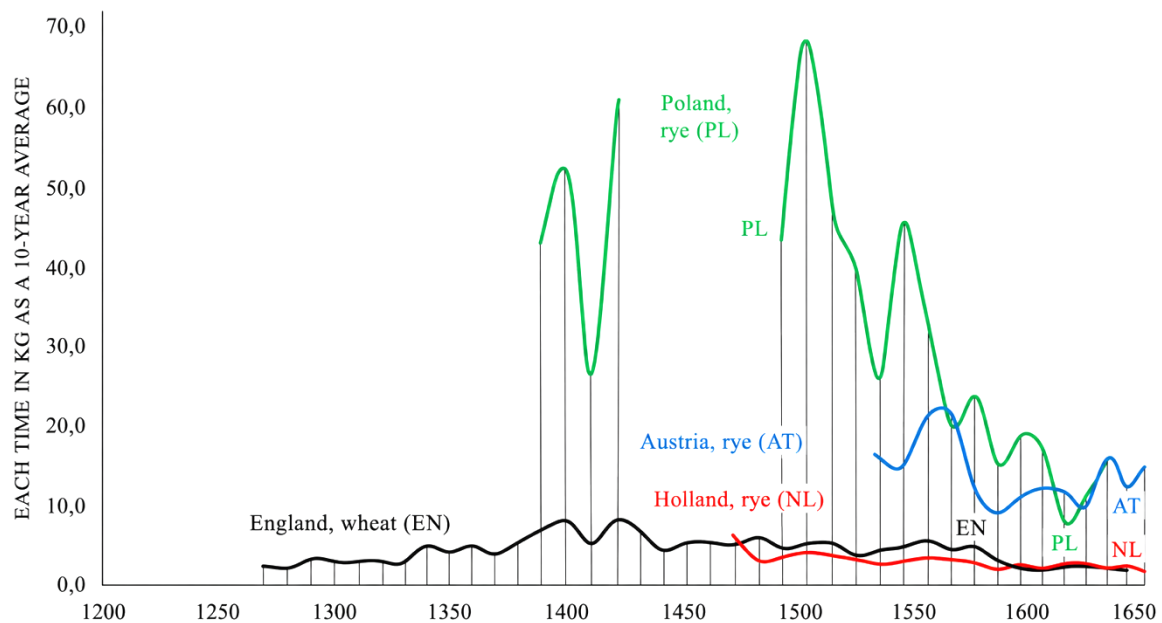


Fig. 2: Relationship between average salted herring prices in England, the Netherlands, Poland, and Austria and grain prices there (1200–1650). Sources: See footnotes 13 and 14.

What share of the kongekøb was in the total harvest? In 1537, Franz Trebau, Danish customs officer in Falsterbo, responded to a complaint from merchants who, among other things, complained about excessive levying of the kongekøb. Trebau explained that he only claimed the kongekøb on four mornings during the 60-day fishing season, but had recently had difficulty meeting the quota of 200 fuders each morning, so the collection period had been extended. In his justification, Trebau never tires of emphasizing that the amount of preemption was small compared to the daily catch, which amounted to at least 2,000 fuders. If we take the customs officer at his word, the catch for the entire fair should have amounted to 120,000 fuders, of which only 800 fuders would have been claimed as kongekøb (0.67%). However, Trebau's further information contradicts this. In Falsterbo, a customs duty of more than 8,000 fuders of herring (96,000 TRB) was registered, and a kongekøb of 300 fuders (3,600 TRB) was incurred for this⁷¹. This amounts to a duty rate of approximately 3.6% of the total yield (3,600/99,600 TRB). In his justification, Trebau apparently sought to exaggerate the catches landed in Falsterbo in order to make the kongekøb collected from the fishermen appear small in comparison⁷². Among other things, the customs officer presents it as if the daily catches had remained more or less unchanged throughout the entire fair period. Jahnke's analysis of the Malmö customs list of 1375 shows, however, that salted herring was by no means evenly taxed throughout the fair period, but rather that there were peak times⁷³. And the stated 2,000 fuders probably represented the average daily yield from such a peak period. Trebau's information, based on the customs register (see above), is likely more reliable, especially since a tax rate of 3.6% corresponds roughly to the ratio of the four half-days on which the royal right of preemption was usually exercised to the 60 days of the fair ($4 \times 1/2/60 = 3.33\%$)⁷⁴. Schäfer, on the other hand, assumes a royal right of preemption of 1/12–1/10 of the total proceeds (approx. 9%), but fails to provide any evidence for this⁷⁵. Suppose it had been 1/12–1/10. How could the Danish king then have accepted that Trebau only used the right of preemption to 40% (3.6%/9%)? Leniency in tax collection is not plausible. And so, Trebau's information is retained here with reference to the customs register. These also allow us to draw conclusions about the productivity of the fishing fleet: Based on Tellemann's figures for 1524/25, the kongekøb of 3,600 TRB stated for Falsterbo in Trebau's justification of 1537 ideally required 3,600 boats to be taxed. With a trade volume of 96,000 TRB (see above), this corresponds to

⁷¹ Schäfer 1927, p. 128 f., No. 4 ff.

⁷² Hitzbleck 1971, p. 182.

⁷³ Jahnke 1997b, p. 15 f.

⁷⁴ The situation is similar in the Limfjord (see below): 17% for a kongekøb collected on two days a week ($2 \times 1/2/7 = 14\%$; half days assumed).

⁷⁵ Schäfer 1927, p. LVI.

approximately 27 TRB (96,000/3,600 TRB) per boat. This would have resulted in a total trade volume of 240,000 TRB per year. By the end of the 14th century, about 9,000 boats with 45,000 fishermen were needed in the Sound. Philippe de Mézières contradicts this. In 1380, the French diplomat estimated the fishing fleet in the Sound at 40,000 boats. This would have meant 200,000 fishermen. However, de Mézières's figure is generally considered an exaggeration. Furthermore, the Frenchman describes how the fishermen's huts stretched for miles along the beach⁷⁶. In Falsterbo, they occupied a strip of approximately 3 km⁷⁷. According to archaeological finds, this area would have been sufficient to build dwellings for up to 40,000 fishermen⁷⁸, in Falsterbo alone. However, the Danish annual accounts for Skanör and Falsterbo from 1494 list only 433 huts for Falsterbo and 168 for Skanör⁷⁹. Based on the booth fees collected for these and the vrager-tegn⁸⁰, Ventegodt estimates the number of boats in Skanör and Falsterbo at 762 and their crew at 3,500. He also accounts for the merchants and support staff, such as the crews of the barges who landed the catch, and the carters, as well as the fishwives and the tapkeepers in the numerous taverns⁸¹. According to Ventegodt, all the Scanian fairs combined were attended by 20,000–25,000 people, of whom approximately 17,000 were fishermen⁸². But is the Danish annual account from 1494 complete with regard to the stall fee? Although Falsterbo was one of the most important fairs at the time⁸³, the fee amounted to only 244 marks⁸⁴. By comparison: in the less important Dragør, 656 marks of stall fee were collected in 1518⁸⁵. As will be shown, the income from the Sound fishery and thus also the number of fishermen increased significantly in the 16th century. However, due to the war, this could only have occurred from 1524 onwards (Chapter 6). A report by the Lübeck bailiff Henning Dethardes also raises eyebrows. According to this, a conflict between Danish and German fishermen in Dragør in August 1463 mobilized over 20,000 men⁸⁶. Did the bailiff exaggerate the number? At least, probably not grossly. Because Dethardes reported to the Lübeck Council. And there were long-distance traders who were very familiar with the conditions in the Sound fishery⁸⁷. Schäfer also assumes that the number of fishermen at the fairs must have been very high⁸⁸. Ventegodt's approach therefore falls short. The extrapolated total of 45,000 fishermen (end of the 14th century) remains.

Back to the estimate of yields: Holm/Bager want to add to the commonly assumed total trade volume of 200,000–300,000 TRB (see above) the (unregistered) personal consumption of the fishermen of 100,000 TRB. They base this on the market regulations of the fairs (modbøger). These allowed the fishermen to salt up to six TRB on their own. Based on Ventegodt's estimate of the total number of fishermen, Holm/Bager calculate as follows: 6 TRB x 17,000 = 102,000 TRB⁸⁹. This calculation cannot be followed. First of all, it should be noted that the allowance of up to six TRBs was not for personal use, which is traditionally exempt from customs duties (and thus not registered)⁹⁰. 480 kg of herring (6 x 80 kg) would far exceed a fisherman's personal consumption. This was not for personal use, but for personal trade. In this respect, it was not the individual fisherman who was entitled to the allowance, but rather the collective, i.e., the five-person crew of the boats (notlag)⁹¹. And such small quantities are indeed listed in the Danish annual accounts⁹², so that the tax suggested by Holm/Bager is not necessary. Moreover, given Denmark's aggressive fiscal policy (Chapter 5), it is unlikely that 40% of the total trade volume would have been allowed to pass through duty-free. Nevertheless, the fishermen at sea must have enjoyed themselves, as did the numerous staffs at the fairs (see above). On average, it would have been at least

⁷⁶ Jahnke 2000, p. 180.

⁷⁷ Hill 2006, p. 722.

⁷⁸ The fishermen's huts were embedded in sand pits measuring 2 x 3 m to 8 x 5 m and had an area of 1.5 x 1 m to 3.5 x 5 m. The distance between the pits was 6–8 m (Jahnke 2000, p. 180 ff.). Thus, up to 8,000 huts could have been built in a 3 km strip with a depth of 0.2 km, with each hut typically being occupied by one of the five-person crews (notlag).

⁷⁹ Schäfer 1927, p. LII, 105 f., No. 5, p. 119, No. 38 f.

⁸⁰ Ebd., LVII, footnote 3.

⁸¹ Ebd., p. LXIII f., LXXXI f., LXXXVIII, p. 100 ff.

⁸² Ventegodt 1990, p. 16 f.; Holm 1996, p. 179.

⁸³ Jahnke 2000, p. 129.

⁸⁴ Schäfer 1927, p. 105 f., no. 5.

⁸⁵ Jahnke 2000, p. 143.

⁸⁶ HR II, 5, no. 369, p. 257.

⁸⁷ For example, the Scania driver Johann Broling (Fehling 1925, No. 525, p. 74).

⁸⁸ Schäfer 1927, p. XLIII.

⁸⁹ Holm/Bager 2001, p. 108, footnote 9.

⁹⁰ Schäfer 1927, S. XCVI.

⁹¹ Ventegodt 1990, p. 9; also HR III, 1, no. 55, § 3, p. 37; Schäfer 1927, p. 85, no. 13 (*with syne geselschap*).

⁹² Schäfer 1927, p. 110 f.

four herrings per person per day, which would correspond to the volume of the kongekøb. By the end of the 14th century, this would have amounted to 9,000 TRB per year (9,000 boats). Since parts of the kongekøb were sold to merchants⁹³, there is a risk of double counting. Therefore, only two-thirds of the pre-purchase quantity (6,000 TRB per year) is used here. Together with the estimated total trade volume of 240,000 TRB per year. A total of approximately 246,000 TRB per year are likely to have been processed at the Sound. Added to this are the yields from smaller market fisheries: The Rügen fishery had already been marginalized by the Sound fishery in the 14th century. In 1368, Lübeck imported only 1,186 TRB from Stralsund⁹⁴. Following Weibull's approach (see above)⁹⁵, the total volume of the Baltic Sea trade in Rügen herring would have amounted to approximately 2,500 TRB. Given the dominance of Scanian herring, it seems unlikely that Rügen herring was shipped to any significant extent via ummeland, i.e., directly to the west. However, if necessary, production could be ramped up at short notice, as happened in 1393, when the Scanian trade was suspended due to the war. At that time, 3,152 ½ TRB were registered in Lübeck, although Wehrmann assumes a considerably higher import volume⁹⁶. Thus, an average yield of 5,000 TRB per year is assumed for the Rügen fishery.

		based on the Lübeck import quantity according to the Pfundzoll book						
Extrapolation of trade quantities	via the Scanian Pfundzoll for	Pfundzoll Schonen 1368/69 [Mark]	1368 (Weibull 1922) [TRB]	1368 (Weibull 1967) [TRB]	1398 (Weibull 1967) [TRB]	1399 (Weibull 1967) [TRB]	1400 (Weibull 1967) [TRB]	Average [TRB]
	Lübeck	530	36,400	76,000	66,558	71,043	66,877	70,120
	Wendish and Prussian towns	906	62,100	129,917	113,551	121,443	114,095	119,752
	Traded in the Baltic Sea	1,436	98,500	205,917	180,109	192,486	180,972	189,871
	Direct trade to the West	525	1,500+x	ca. 50,000	ca. 50,000	ca. 50,000	ca. 50,000	ca. 50,000
	Total trade quantity	1,961	100,000+x	255,917	230,109	242,486	230,972	239,871
	kongekøb			9,597	8,629	9,093	8,661	8,995
	of which estimated			6,334	5,695	6,002	5,717	5,937
	Total revenue			262,251	235,804	248,488	236,689	245,808

Tab. 1: Projection of the yields of the Sound fishery at the end of the 14th century.

Note on the pound toll in detail: Wendish and Prussian cities: Rostock 140, Wismar 160, Stralsund 314, Greifswald 94, Stettin 102, Kolberg 33, and Prussian cities 63 marks; merchants of the West: Kampen 240, Zierikzee 36, Harderwijk 30, Zutphen 24, Elburg 18, Amsterdam 19, Brielle 18, and England, Flanders, and Brabant 140 marks, cf. Weibull 1922, p. 19 f., where it is assumed for Greifswald that the 46 3/4 marks levied in 1368 were also paid in 1369; Weibull also assumed a much lower import volume from Lübeck: 36,400 TRB (cf. italics).

As for fishing in the Limfjord, figures on trade volumes are only available for 1518. At that time, 2,616 TRB were taxed in Aalborg⁹⁷. The herring sales amounted to 528 TRB⁹⁸. This is approximately 17% of the yield, significantly more than at the Scanian fairs (3.6%). However, the right of first refusal was exercised two days a week in the Limfjord, and not just four times during the entire season, as was the case in the Sound⁹⁹. Limfjord herring was traded not only in Aalborg, but also at other, smaller markets, e.g. B. in Nibe, Mou, and Hals¹⁰⁰. Therefore, it seems appropriate to round up Aalborg's total yield for 1518 (3,144 TRB) to 4,000 TRB. At the end of the 14th century, however, market fishing in the Limfjord was still in its infancy¹⁰¹, so an average yield of only 2,000 TRB per year is assumed.

⁹³ Jahnke 2000, p. 143, 241.

⁹⁴ Lechner 1935, p. 59.

⁹⁵ Minus the share for Stralsund (Table 1).

⁹⁶ Wehrmann 1867, p. 129 f.

⁹⁷ Jahnke 2000, p. 342.

⁹⁸ Holm/Bager 2001, p. 104.

⁹⁹ Jahnke 2000, p. 181, 339 f., see also footnote 73.

¹⁰⁰ Holm 1996, p. 194.

¹⁰¹ Jahnke 2000, p. 322 f.

Herring was also fished off Bornholm and in the Szczecin Lagoon. Figures that indicate trade volumes are only available for the turn of the 17th century: in 1607, a tax totalling seven TRB was levied on 105 fishermen on Bornholm. Calculating a ton of herring at 1,200, each fisherman would have had to pay 80, or exactly one whale¹⁰². In 1597, the number was 18 TRB¹⁰³, which suggests that 270 fishermen were taxed. Based on an average trade volume of 27 TRB per boat and a crew of five fishermen (see above), this results in a yield of 567 TRB for 1607 and 1,458 TRB for 1597. Therefore, an average of 1,000 TRB per year is assumed here. Although data are lacking for the fishery in the Szczecin Lagoon, this order of magnitude is also assumed for the yield there. The total yield of market fisheries in the western Baltic Sea could therefore have amounted to approximately 255,000 TRB per year at the end of the 14th century.

5. Stagnation (15th century)

The economic crisis persisted in the 15th century. Although the population slowly recovered, the shortage of precious metals worsened¹⁰⁴. The overall political situation for the Hanseatic League also began to deteriorate: Denmark sought to break the cities' dominance at the Scanian fairs, which intensified Dutch competition¹⁰⁵. Furthermore, the crown pursued an aggressive fiscal policy, which caused the Scanian fairs to lose their importance as "international" trading centres¹⁰⁶. The effects of the anti-Hanseatic policy are evident in the decline of Lübeck's salted herring trade. From 1492 to 1495, the city imported an average of 14,477 TRB per year from Scania (Lübeck pound customs records)¹⁰⁷, just one-fifth of the 70,000 TRB per year, which had been transhipped until the end of the 14th century (Table 1).

What was the state of the Sound fishery? According to the Danish annual accounts, 47,323 quarters of a ton of treacle were paid through customs in Falsterbo in 1494¹⁰⁸. And what share did Falsterbo account for in the total yield? In 1537, the customs officer Trebau reported that a total of more than 30,000 tonnes (360,000 TRB) had been processed at the Scanian fairs, on Bornholm, and on the Limfjord, of which 8,000 tonnes (96,000 TRB) had been processed in Falsterbo. At the time the report was written (August 30)¹⁰⁹, the yield for the season that had just begun (August 15 to October 9) was not yet foreseeable. Therefore, Trebau's estimates likely refer to the previous year (1536). To determine the share of the Sound fishery, 1,000 TRB for Bornholm and 2,000 TRB for the Limfjord are deducted from the 360,000 TRB. The fact that only half of the estimated yield for 1518 (Chapter 4) is assigned to the Limfjord fishery reflects the fact that Aalborg was destroyed by fire in 1530 and opened up to plunder during the Counts' Feud (1534–36)¹¹⁰.

According to this, Falsterbo's market share of the Sound fishery in 1536 was approximately 27% (96,000/357,000 TRB). This seems quite high, especially since numerous smaller fish warehouses operated alongside the (regular) fairs. Furthermore, Falsterbo was only nominally the main centre of the Scanian fairs at that time. Its trade volume had long been surpassed by Malmö¹¹¹. However, the figure for Falsterbo should remain at 27%, partly because this is a conservative approach with regard to the upcoming projections. A smaller share would make them higher. This circumstance also reduces concerns about applying the approach to the year 1494, although the uncertainties associated with the 42-year time jump cannot be ignored.

This results in a total trade volume of approximately 175,000 TRB (47,323 ¼ TRB/27%) for 1494. According to Caspar Weinreich, a citizen of Danzig, however, the yield in Scania was 1,000 Last lower in 1494¹¹². For a regular year, this would add another 12,000 TRB, making 187,000 TRB per year (end of the 15th century), plus a kongekøb of approximately 7,000 TRB per year, of which only two-thirds are considered (192,000 TRB per year), as well as the yields of smaller market fisheries (Chapter 4), so that a total yield of 203,000 TRB per year can be assumed for the western Baltic Sea. Compared to the projection for the end

¹⁰² Just as in Kronborg Len (Holm/Bager 2001, p. 110).

¹⁰³ Ebd., p. 112.

¹⁰⁴ North 2009, p. 40.

¹⁰⁵ Hoffmann 2006, p. 129 f.; Seifert 2006, p. 154 f.; Dollinger 1998, p. 382.

¹⁰⁶ Jahnke 2000, p. 56 ff.

¹⁰⁷ Bruns 1908, p. 382.

¹⁰⁸ Schäfer 1927, p. 111.

¹⁰⁹ Ebd., p. 128 f., no. 4 ff.

¹¹⁰ Jahnke 2000, p. 330.

¹¹¹ Ebd., p. 129 ff.

¹¹² Hirsch 1855, p. 85.

of the 14th century (255,000 TRB per year), production would have decreased by one-fifth. Let's look at the economic indicators (Fig. 3): As a result of the ongoing shortage of precious metals, coin depreciation is increasing. In Lübeck, the silver content of the pfennig falls by 27% between 1422 and 1433. The standard of the newly introduced shilling also soon declines. Between 1432 and 1468, the large coinage depreciates by 20%, but then remains stable¹¹³. The prices of salted herring and grain in silver largely follow the deflationary trend. The price of salt falls even more sharply. However, this does not necessarily indicate a decline in salt demand from the Sound fishery and thus lower yields (Chapter 6). Rather, the cheaper salt was probably primarily due to the fact that Baien salt (whose market share in Livonia was already 80%)¹¹⁴ was once again flowing unhindered into the Baltic Sea after the end of the Danish-Hanseatic War (1426–35) and the Hanseatic-Dutch War (1438–41)¹¹⁵.

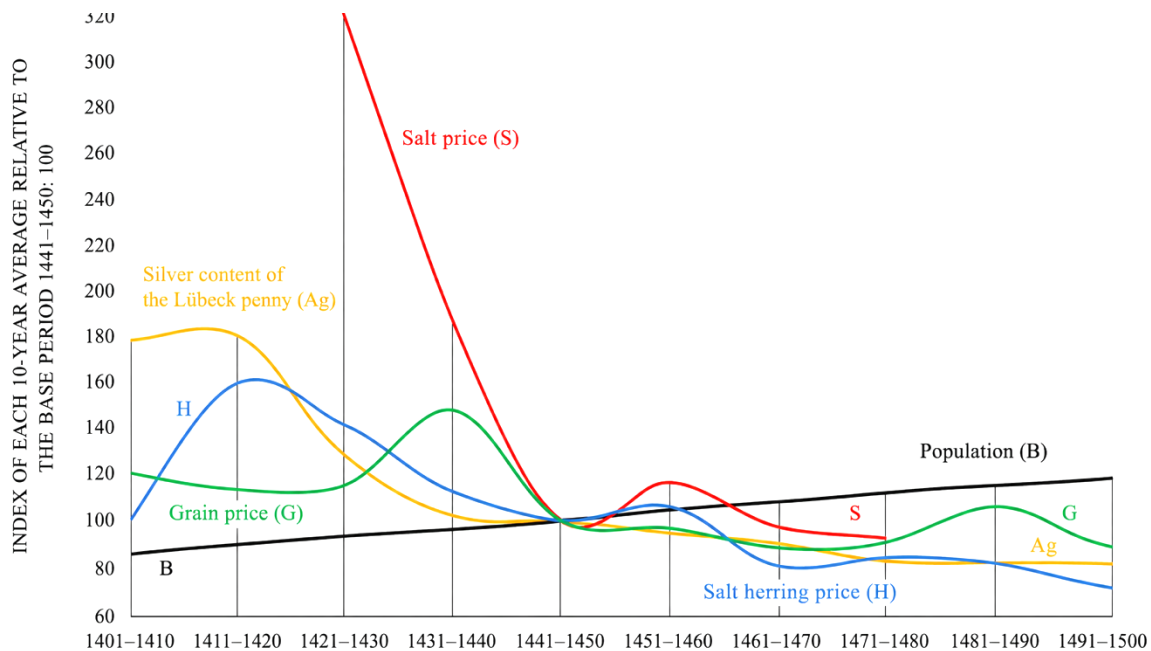


Fig. 3: Indices for the development of population figures, salted herring and grain prices, as well as the Danzig and (from 1450) Hamburg salt prices in silver, as well as the silver content of the Lübeck penny and (from 1432) of the twelfth part of the Lübeck shilling (1400–1500). Sources: See footnotes 12, 13, 14, and 15

The economy stagnated. And even the rising population was initially unable to change this. While demographics may have supported demand for salted herring, production will nevertheless have declined during the recession, but not as drastically as Lübeck's share of the salted herring trade: from 30% (70,000/240,000 TRB) at the end of the 14th century to 8% (14,477/187,000 TRB) at the end of the 15th century (-70%). This decline was primarily due to the fact that the city's trading conditions had deteriorated¹¹⁶. The decline in yields from the Sound fishery will have been less dramatic. This is supported not only by the above projections (-20%), but also by the evidence of sustained fishing pressure. The absence of shoals or a decline in production were repeatedly complained about, for example in 1402, 1411, 1416, 1425 ff., 1436, 1466, 1469, 1474/75, and 1494¹¹⁷. However, these reports should not be overestimated. The population was subject to natural fluctuations. And, as the example of 1494 shows, even minor declines in production (6.4%) were considered worthy of note. On the other hand, historical climate data indicate that ecological conditions for herring deteriorated. In the mid-15th century, temperatures in Europe plummeted by an average of 0.8°C (Fig. 8). Although the relationship between herring growth rate and temperature has not been conclusively clarified, such a sudden drop in

¹¹³ Jesse 1928, pp. 209, 211; North 2009, p. 40; *ibid.* 2006, pp. 754 f.

¹¹⁴ Henn 2006, p. 106; Irsigler 2006, p. 708.

¹¹⁵ Hoffmann 2006, p. 129 f.; Seifert 2006, p. 154 f.

¹¹⁶ Kuhn 2019, p. 111 f.

¹¹⁷ Jahnke 2008, p. 179; *ibid.* 2000, p. 103; Hirsch 1858, p. 146, Fn. 356.

temperature would have had a detrimental effect on the stock¹¹⁸, given that temperatures during the Little Ice Age were on average up to 2°C colder than today. If harvesting had continued unabated, the temperature anomaly could have increased fishing pressure.

It should be noted here that the protection of the herring stock was recognized as a problem early on. According to the *modbøger*, bottom trawls (*wantegarne*) were strictly prohibited in the Sound¹¹⁹. In Stralsund, herring fishing had already been prohibited in 1371¹²⁰. As can be seen from a complaint from 1386, the mesh size of the nets was also likely regulated¹²¹. And in Bohuslän, where the centre of herring fishing would shift in the 1580s (Chapter 6), the use of purse seines, which could catch entire shoals, was made a criminal offense in 1583¹²². Of course, the measures were probably based on economic rather than ecological reasons. Those involved in the fishing industry were supposed to have a "fair" income. This involved preventing the fish from being "caught" by overly efficient equipment and thus depriving other market participants of access. Furthermore, efforts were made to ensure quality assurance with regard to the marketing of the fish, including ensuring that no inferior bycatch was processed¹²³. The time limit on the fishing season (August 15 to October 9) also contributed to ensuring a minimum catch size¹²⁴. Nevertheless, the size of the herring caught has declined over the centuries. This is demonstrated by a comparison with the Viking Age: According to archaeological finds in Menzlin and Haithabu, the herring caught in the 9th and 10th centuries reached an average length of 26 cm¹²⁵, which suggests a weight of 154 g¹²⁶. Based on the (uncertain) tonnage (80 kg/1,200 pieces), the fish packaged during the Hanseatic period probably had an average weight of about 67 g. Considering processing losses (3/17), the weight of freshly caught fish would be 82 g (-47%). Based on the number of fishes mentioned by Weinreich for 1485 of 1,360–1,520, which is, however, an exception (Chapter 2), the weight of the processed fish sometimes fell to 53 g (67 g for freshly caught herring; -56%). The weight of the fish can be used to determine its age: while in the early Middle Ages they probably reached the age of six or seven before being caught in the net, the herring caught during the Hanseatic period was probably only two to three years old on average¹²⁷, although the comparison underlying this estimate with today's average age groups is subject to a possible acceleration of growth due to the eutrophication of the Baltic Sea (Chapter 8).

6. Late flowering (1524–71)

In the 16th century, the economy picked up speed again. The late medieval agrarian crisis had been overcome. The population grew. Furthermore, the supply of coin metal had improved. New deposits, including in Tyrol, had been discovered. Gold and silver from Africa and the New World were added. Furthermore, credit innovations increased the money supply¹²⁸. And although the political importance of the Hanseatic League declined, trade in the cities also flourished¹²⁹. The general upswing probably did not pass the Sound fishery by. In any case, the Lüneburg saltworks expanded its production capacity in 1497, initially by 15% (17,386 tons), and in 1569 by another third (23,181 tons). The fact that the expansion was not carried out more vigorously was simply because the brine was no longer sufficient¹³⁰. Figures that allow conclusions to be drawn about the yields of the Sound fishery in the first half of the 16th century are available – as already shown – for the years 1524/25 and 1536. 1536 can be considered a poor year due to the post-war period (Counts' Feud). Nevertheless, based on Trebau's figures, approximately 357,000 TRB were traded at that time. Let's consider the second, already known figure: According to Tellemann, in 1524/25 the kongekøb in Falsterbo amounted to 7,703 TRB. 7,515 boats were

¹¹⁸ Parmanne 1994, p. 52; MacKenzie 2002, p. 183.

¹¹⁹ Schäfer 1927, p. 84, no. 4.

¹²⁰ Jahnke 2000, p. 26.

¹²¹ HRI, 2, No. 320, § 7, p. 380.

¹²² Holm 2003, p. 287.

¹²³ Jahnke 2000, p. 302 f.

¹²⁴ Schäfer 1927, p. LIV f.

¹²⁵ Enghoff 1999, p. 74; Lepiksaar 1977, p. 34, although it is not known whether these were autumn or spring spawners (cf. Chapter 8).

¹²⁶ NOAA 2003, p. 2, 7, this for Atlantic herring in autumn.

¹²⁷ ICES 2020b, p. 345.

¹²⁸ North 2009, pp. 69 ff., 83 ff.; Abel 1978, p. 124.

¹²⁹ Dollinger 1998, p. 444.

¹³⁰ Witthöft 1976, pp. 50, 104.

assessed. With an average trade volume of 27 TRB per boat (Chapter 4), the yield could have amounted to approximately 203,000 TRB in Falsterbo alone. Assuming a market share of 27% (1536) for Falsterbo (Chapter 5), this would result in a total trade volume of just over 750,000 TRB. The fact that Scanian salted herring production is said to have quadrupled since the end of the 15th century (187,000 TRB per year) is puzzling. Holm assumes an average of 300,000 TRB per year for the 1520s¹³¹, but provides no evidence for this. Let's consider the European salted herring market: In response to the Hanseatic League's efforts to monopolize the herring trade at the Scanian fairs, herring fisheries developed in the North Sea in the 15th century, most notably the Dutch¹³². By the 1560s, this is said to have already reached a trade volume of up to 450,000 TRB per year. However, the Eighty Years' War (1568–1648), in which the Netherlands were to gain their independence from Spain, temporarily dampened growth¹³³. The gap was filled by the fishery off Bohuslän. Unlike in the Sound, the herring shoals did not visit the western Swedish coast regularly, but rather in batches for a few decades and then disappeared again¹³⁴. In 1556, the herring appeared again in the archipelago¹³⁵. For the peak in the 1580s, Holm estimates the yield of the Bohuslän fishery at up to 240,000 TRB per year. But the boom did not last long. Since 1590, the herring shoals off Marstrand once again disappeared¹³⁶. By 1600, Dutch salted herring finally dominated the European market. According to Poulsen, the catch amounted to approximately 55,000 tons. Added to this were the fisheries in the British Isles: 9,000 tons were landed in Scotland, and 5,000 tons in East Anglia. Emden (East Frisia) also had a herring fishery. In 1597, the yield was 1,322 tons¹³⁷. In total, the North Sea thus processed the equivalent of a good 700,000 TRB. At the end of the 14th century, the annual production was still around 250,000 tonnes. Sufficient to cover the majority of demand in Western, Northern, Central, and Eastern Europe, supply had almost tripled by the end of the 16th century (Fig. 7).

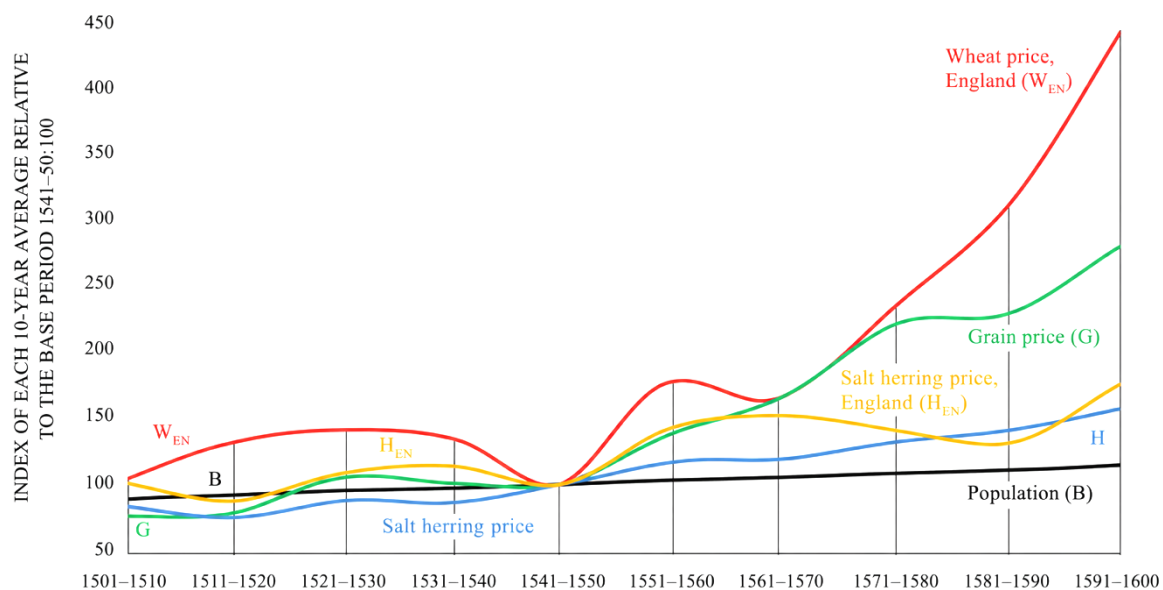


Fig. 4: Indices for population trends, salted herring and grain prices, and English salted herring and wheat prices in silver (1500–1600). Sources: See footnotes 12, 13, and 14.

How did demographics and prices develop? In the 16th century, the population in the main sales areas for Scanian herring continued to grow. By the middle of the century, the previous peak (around 1300) had already been exceeded. Until 1550, salted herring and grain prices largely followed this trend. Rising

¹³¹ Holm 2003, p. 282.

¹³² Jahnke 2000, p. 57.

¹³³ Holm 2003, pp. 282 f.

¹³⁴ Jahnke 2000, p. 282; Holm 2016, p. 17; MacKenzie 2002, p. 176.

¹³⁵ Jahnke 2000, p. 294.

¹³⁶ Holm 2003, pp. 287 f.

¹³⁷ Poulsen 2008, pp. 44, 55, 57 f., 61 f.

population numbers and food prices provided an incentive to expand production. Previously abandoned areas (Chapter 4) were ploughed again¹³⁸. The same can be assumed for the fisheries. In the second half of the 16th century, prices rose disproportionately (Fig. 4), especially for grain. The increase in prices can be attributed to the fact that land prices had risen as a result of the expansion of arable land. Fuelled by the influx of precious metals (see above), the so-called price revolution occurred. With rising prices, the proportion of the precariat increased. Low-income earners had to spend an increasingly large portion of their income on necessities, namely staple foodstuffs such as grain¹³⁹. Demand for salted herring is likely to have declined significantly as a result. The decline in demand could also have been a late consequence of the Reformation. The widespread use of salted herring in the Middle Ages was also due to its importance as a Lenten food¹⁴⁰. However, since dietary habits change only slowly, a connection is not sufficiently clear. In any case, it can be assumed that the herring market entered a sales crisis in the second half of the 16th century. This is also supported by the fact that yields from North Sea fisheries declined by about a third in the first three decades of the 17th century (Fig. 7). Therefore, the figures at the turn of the century (700,000 TRB per year) should not necessarily be understood as a peak. They could already have been a sign of the crisis. Thus, much higher total yields for herring fisheries in the North and Baltic Seas are conceivable even for the period shortly before the onset of inflation. Let's turn to the production factor of salt: From 1500 to 1571, ship salt deliveries (Chapter 3) averaged just under 10,000 t per year, compared to a total trade volume in Lüneburg of just over 20,000 t per year (1554 to 1614). However, in 1572/73, deliveries collapsed. And this was permanent. Until the outbreak of the Thirty Years' War, they averaged only 7,000 t per year (1573 to 1618). Lüneburg's total trade volume remained virtually unchanged. The decline in ship salt deliveries was therefore not due to capacity. Rather, we see this as a reaction to a decline in demand for brine salt in the Baltic region. In fact, around 1572/73, one of the main customers for Lüneburg salt began to decline, namely the Sound fishery (Chapter 7). The 3,000 t per year by which ship salt deliveries declined after the slump of 1572/73 was likely roughly the same amount used to salt Scanian herring until 1571 (Fig. 5). When herring was processed with Lüneburg salt, the preservative content was 23% (Chapter 2). The ship salt deliveries to the Sound fishery until 1571 were thus barely sufficient to salt 100,000 TRB. Was this the total yield of the Scanian fairs? Such a conclusion would be too simplistic. Baien salt had long dominated the market (Chapter 3). And as for the Lüneburg saltworks, the condition of the brine no longer allowed for further expansion (see above). Thus, they would have been unable to respond to significant increases in demand. Therefore, the fact that ship salt deliveries remained stable until 1571 does not imply that the yields of the Sound fishery had not changed in the period before its decline. Baien salt could have been used to increase production. Admittedly, this would have required large quantities: almost 10,000 tons for the trade volume of the Sound fishery in 1536 (357,000 TRB) assumed based on Trebau's report, and almost 25,000 tons for the total yield of 1524/25 (750,000 TRB) extrapolated from Tellemann's data on the kongekøb, each in addition to the usual Lüneburg ship salt quota of approximately 3,000 tons. These quantities were, however, available: between 1562 and 1657, an average of 45,000–50,000 tons of Baien salt passed through the Sound annually¹⁴¹.

¹³⁸ Abel 1978, pp. 107 ff.

¹³⁹ Ibid., pp. 122 f., 129 ff., 138 ff.

¹⁴⁰ Barrett 2008, p. 43.

¹⁴¹ Witthöft 1976, p. 110.

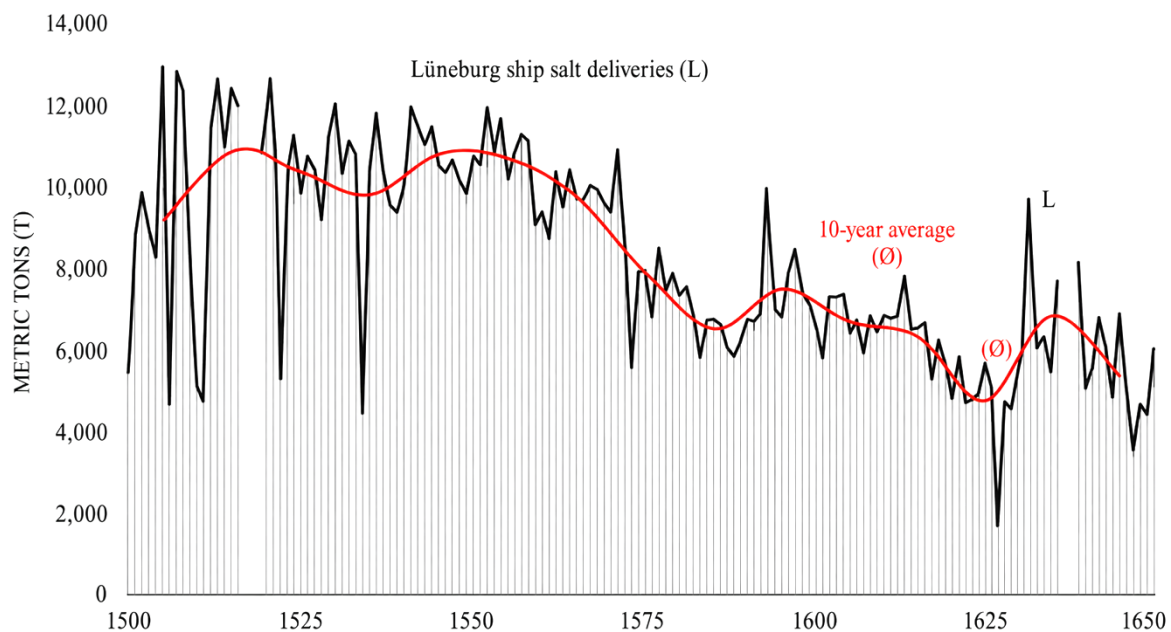


Fig. 5: Lüneburg ship salt deliveries (1500–1650). Source: Witthöft 1976, p. 83 ff.

Let's consider salt prices: From 1510 to 1523, Hamburg's prices fluctuated between 19 and 25 g of silver. In 1524, however, the price of salt exploded, rising to 53 g in 1525 (+140%). The value of salt had more than doubled within a very short period. Such jumps would not have been unusual in times of war (Chapters 3 and 5). However, the weapons were at rest, both in the North Sea, through which the Hamburg market was supplied with salt from the Bay of Hamburg, and in the Baltic Sea. A price revolution is also ruled out as an explanation for the sudden spike in the price of salt. As shown in Figure 4, inflation only gained momentum in the second half of the 16th century. Consequently, there must have been a sudden increase in demand around 1524/25.

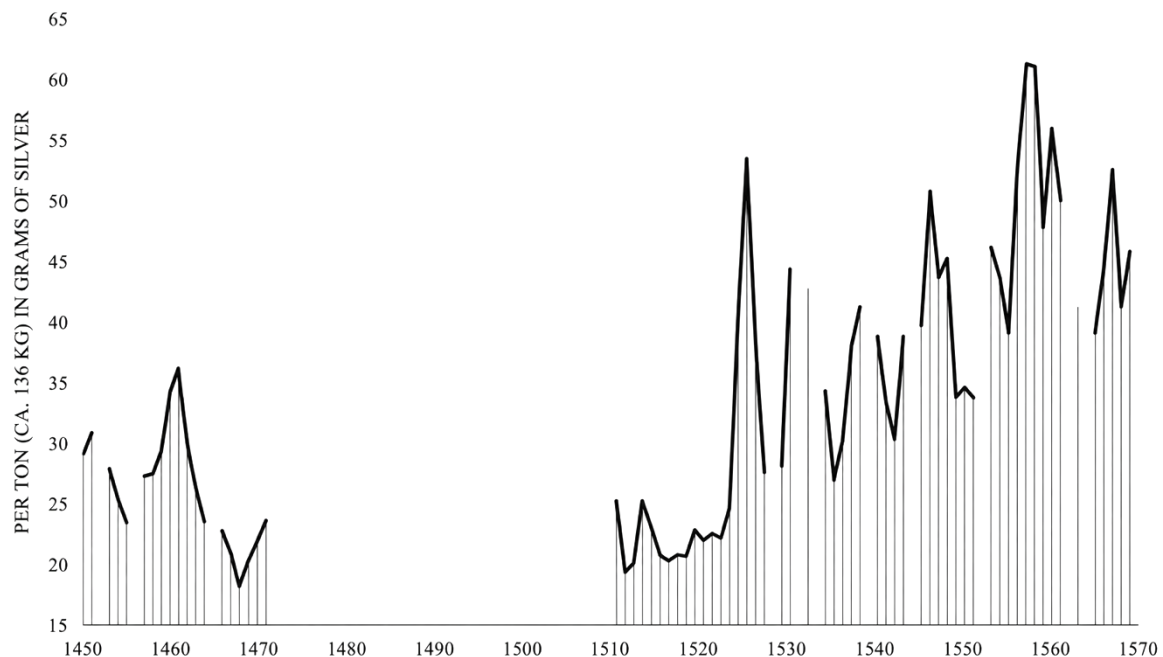


Fig. 6: Hamburg salt prices (1450–1569). Source: North 1990, p. 190; conversion to silver: Jesse 1928, p. 209 ff.

As already explained, the economy experienced an upswing at the beginning of the 16th century. However, the expansion of the Sound fishery was hampered by a succession of Danish-Swedish wars (1497–1500, 1501–12, 1512–20, 1521–23). These were turbulent times, as evidenced by the fluctuations

in ship salt deliveries during these years (Fig. 5). Only after the deposition of King Christian II (1523) did trading conditions improve¹⁴². Thus, the sudden increase in demand, which drove up the price of salt in Hamburg (see above), could, to some extent, be traced back to an investment backlog that emerged in 1524/25. And the general conditions for fishing were favourable: Herring was plentiful. At least, that's what was recorded for 1527¹⁴³. Indeed, the stock may have recovered. By the end of the 15th century, the average temperature had risen again by a good 0.6°C (Fig. 8), so the ecological conditions for herring must have improved significantly (Chapter 5). There was also no shortage of salt (see above) or labour. Danish farmers were still, in principle, available for an unlimited period during the herring season. And the prospect of lucrative additional income probably mobilized seasonal workers (Chapter 3) as quickly as salt could be ordered. At this point, we should recall the example of Rügen, where yields also increased significantly in the short term after the cessation of the Scanian trade in 1393 (Chapter 4).

In the following years, Hamburg salt prices were highly volatile. In 1527, prices plummeted to 28 g of silver. In 1530, they rose to 44 g (Fig. 6). Again, wars are ruled out as an explanation for the sharp fluctuations. The volatility was therefore likely demand driven. Unless the supply of salt changed significantly, the salt price remained proportional to demand, as was the case during the turbulent times of the Counts' Feud (1534–36). In 1535, the Hamburg salt price fell to 27 g. While in 1524/25 it was probably a sudden increase in demand from the Sound fishery that led to a price increase, the Hamburg salt market now apparently reacted to an excess supply caused by declining demand following a war-related collapse in salted herring production in the western Baltic Sea. And the fluctuations in production in the Sound fishery will have had a significant impact on the salt market. As shown above, as a result of an increase in yield since 1524/25, this probably accounted for more than half of the salt imported into the Baltic Sea (25,000 tons). Can Hamburg salt prices therefore be used as an indicator for the further development of yields in the Sound fishery in the 16th century? Let's put it to the test: Based on Trebau's data, the trade volume of the Sound fishery in 1536 was 357,000 TRB, at a Hamburg salt price of 30 g of silver per ton. In the second decade of the 16th century, the price of salt averaged 21–22 g, and in 1511, it was only 19 g. Assuming that the Sound fishery was only able to increase its yields slowly during this still turbulent period, reaching just 200,000 TRB per year, with a salt price of 20 g, a price increase of one gram of silver would have resulted in an increase in yield of approximately 15,700 TRB compared to the conditions in 1536. For the peak value of 1525 (53 g), the rule of three results in a trade volume of almost 720,000 TRB, which is quite close to the extrapolation based on Tellemann's figure for the kongekøb for 1524/25 (750,000 TRB). Between 1532 and 1576, the privileges for numerous fishing villages were confirmed. Jahnke concludes from this that fishing in the Sound had been reviving since 1553¹⁴⁴. This assessment is supported by the development of the price of salt in Hamburg. Since 1550, it rose again. In 1557/58, the 60 g limit was broken, thus exceeding the peak value of 1525. The price increases in the second half of the 16th century, however, must be seen against the backdrop of the price revolution. While this primarily affected grain prices (see above), it also had an impact (albeit to a much lesser extent) on wages and the prices of other goods, such as manufactured goods. However, according to the 25-year averages for silver compiled by Abel, the picture in the markets examined (England, Belgium, France, Germany, Austria, Poland) is highly inconsistent¹⁴⁵. Inflation rates that are solely attributable to the influx of coin metal, i.e., not distorted by the disproportionate rise in grain prices (and thus suitable as a corrective to salt price trends), cannot be easily determined using the 25-year averages. As a result, a price increase (in silver) of just over 100% in the 16th century is likely to point in the right direction. This roughly corresponds to the development of the salted herring price (Fig. 4), which was therefore used to adjust for inflation (base period 1531–40: 1). After that, the salt price factor determined above for the increase in trade volume per gram of silver (15,700 TRB) falls to 15,370 TRB. As a result of the correction, the projections are lower from the fifth decade onwards. However, they increase until the third decade. This results in a trade volume of 747,500 TRB for 1525, which corresponds almost exactly to the extrapolation based on Tellemann's report on the kongekøb (750,000 TRB).

¹⁴² Jahnke 2000, p. 58 ff.

¹⁴³ Schäfer 1927, p. XLII.

¹⁴⁴ Jahnke 2000, p. 115 f.

¹⁴⁵ Abel 1978, pp. 125 f.

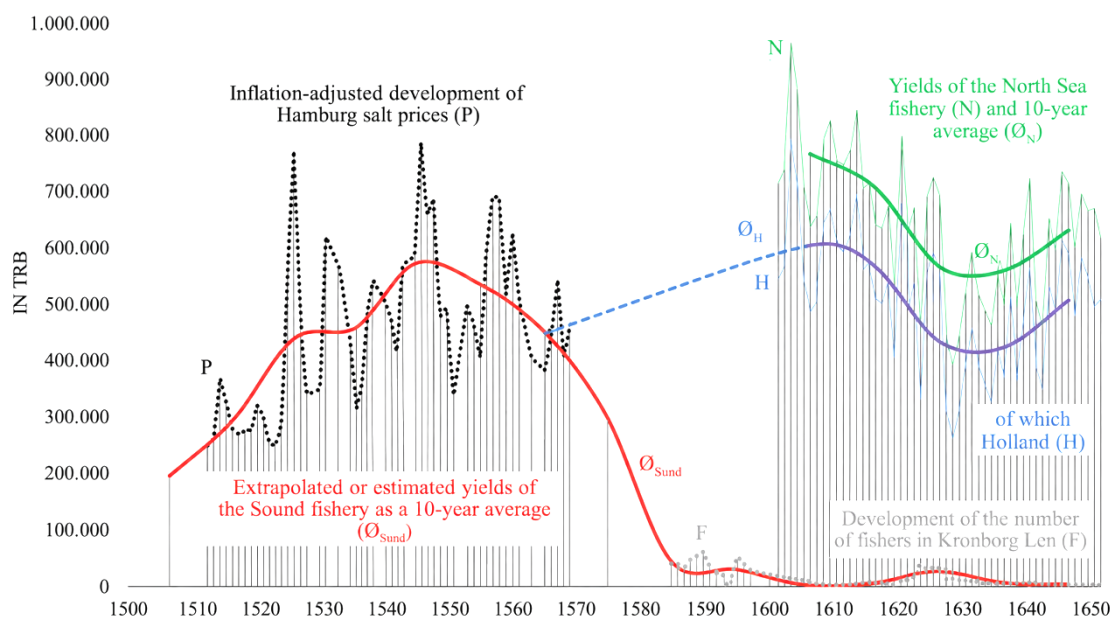


Fig. 7: North Sea fisheries yields (1600–1650) and projections of the Sound fisheries yields based on inflation-adjusted Hamburg salt prices in silver (1510–1669) and the number of fishermen in Kronborg Len (1585–1650), 1500–1650. Sources: See Fig. 6 and fn. 13 (for inflation adjustment); Holm 2001, p. 110 (number of fishermen in Kronborg Len); Poulsen 2008, p. 70, Fig. 4.12 (North Sea fisheries yields); Holm 2003, p. 282 (trade volume of the Dutch herring fishery in the 1560s).

Although accounting for inflation significantly reduces the results of the extrapolation for the second half of the 16th century, the estimates continue to rise. A peak of 780,000 TRB may have been reached in 1546 (Fig. 7). But is such a high yield still plausible? This would have resulted in catches that were not landed again by industrial herring fisheries in the western Baltic Sea until the end of the 1970s (Fig. 11). Assuming a trade volume of 27 TRB per boat, the fishing fleet in the Sound would have had to comprise up to 29,000 boats (145,000 fishermen) to achieve such a result. There would have been 39,000 fishermen in Falsterbo alone. Such military camps are not unthinkable. By comparison, the Roskilde Festival attracts up to 115,000 participants, while Wacken Open Air draws 85,000. At Woodstock (1969), the number is said to have been 400,000. And, as already shown, Falsterbo's Beach easily accommodated the homes of up to 40,000 fishermen (Chapter 4). But was there even a logistics system in place in the early modern period to supply such crowds with the essentials during the 60-day fishing season? First of all, food in the form of herring was plentiful. Furthermore, the Sound was a hub of East-West trade. And as Weibull shows for the end of the 14th century, shipping traffic intensified during the fair season¹⁴⁶. Unlike the early modern military supply system, which would have quickly reached its limits on such a scale due, among other things, to the poor road and path network, given the convenient location of the fairs, it seems quite possible that even the 145,000 fishermen estimated for the peak year of 1546, along with numerous support staff, could have been adequately supplied. Furthermore, it should not be forgotten that for the majority of the fishermen, this was a secondary occupation (and, given the vibrant market activity, probably also an 'event'). Throughout the year, for example, they had each earned his living as a farmer, farmhand, or craftsman. Against this background, it can be assumed that the labour factor is highly flexible (Chapter 3). To quantify the total yield of the Sound fishery, the extrapolation must be adjusted for the kongekøb, but only by two-thirds to avoid the aforementioned double counting. The yields of the smaller market fisheries must also be added (Chapter 4). According to this, an average of around 500,000 TRB per year were likely processed in the western Baltic Sea between 1524 and 1571. Compared to the end of the 14th century, the yield level would thus have doubled. However, in light of the production figures that the herring fisheries in the North Sea had meanwhile achieved (Fig. 7), the growth of the Sound fishery was not remarkable. It simply followed the general economic upswing that began at the turn of the 16th century.

¹⁴⁶ Weibull 1967, pp. 45 f.

7. Decline (End of 16th century)

The success did not last long. Shifting dunes plagued Skanör and Falsterbo. In 1573, disputes arose over the demarcation of the settlements (Vitten). The Hanseatic merchant was forbidden from re-erecting fallen Vitten crosses. The uncertainties surrounding the parcelling of land indicate that the dunes had already buried the neighbouring fishing villages in 1572/73, at the very same time that ship salt supplies collapsed (Chapter 6). Undeterred by the crisis, Denmark continued its aggressive fiscal policy. As late as 1573, taxes and customs duties were increased, including in Falsterbo, which suggests that the hopes for revenue were still hoped for. This hope was dashed. In 1577, Skanör and Falsterbo had to be granted tax exemptions. Apparently, the revenues from the buried fairs had not recovered¹⁴⁷. How high was the production loss? According to Trebau's figures for 1536, Falsterbo's market share was 27% (Chapter 5). Skanör's share of the Sound fishery in the 16th century is unknown. In 1494, 3,277 ½ TRB were paid through customs there¹⁴⁸, or about 2% of the total trade volume (175,000 TRB). Presumably, the problem of shifting dunes affected not only Skanör and Falsterbo, but (albeit less dramatically) other fairs as well. The total yield of the Sound fishery may have declined by about a third. Based on the extrapolated average for the previous decade, 1561–70 (450,000 TRB), the trade volume in the 1570s would have amounted to only 300,000 TRB per year (Fig. 7). And the crisis worsened. In the 1580s, the market in the herring town of Stege (Mön) began to falter¹⁴⁹. The herring shoals were increasingly absent. The commercial risk was becoming difficult to manage¹⁵⁰. The reason for the absence of the herring shoals may have been a cold snap. From 1560 to 1600, temperatures fell by an average of almost 0.85 °C (Fig. 8), even more than in the middle of the 15th century. The relatively warm period (1485–1560), which presumably laid the foundation for the previous recovery of the herring population and created the biological conditions for an increase in yields from the Sound fishery, ended abruptly. As early as the 15th century, the herring population had come under pressure due to such a drop in temperature (Chapter 5). At that time, the average catch was only 200,000 TRB per year. However, between 1524 and 1571, the average yield had risen to 500,000 TRB per year. In an attempt to maintain this yield level, the stock, which had been threatened by the cold snap, probably suffered lasting damage. The unfortunate fishermen fled to Bohuslän¹⁵¹, where herring fishing boomed in the 1580s (Chapter 6). This marked the end of the Sound fishery. In travel reports from 1592 and 1593, it is no longer mentioned at all, or is only thought of in the imperfect tense¹⁵². The extent of the decline of the Scanian fairs can also be seen in the quantities of salted herring shipped through the Sound: At the end of the 16th century, the trade flows began to reverse. Now the herring no longer flowed from east to west, but in the opposite direction. From 1601 to 1610, almost 110,000 tons per year passed through the Sound, mostly Dutch herring (Fig. 9).

¹⁴⁷ Jahnke 2000, pp. 116, 133.

¹⁴⁸ Schäfer 1927, pp. 117 f.

¹⁴⁹ Holm/Bager 2001, p. 107.

¹⁵⁰ Jahnke 2000, p. 118.

¹⁵¹ Holm/Bager 2001, p. 110.

¹⁵² Jahnke 2000, p. 118.

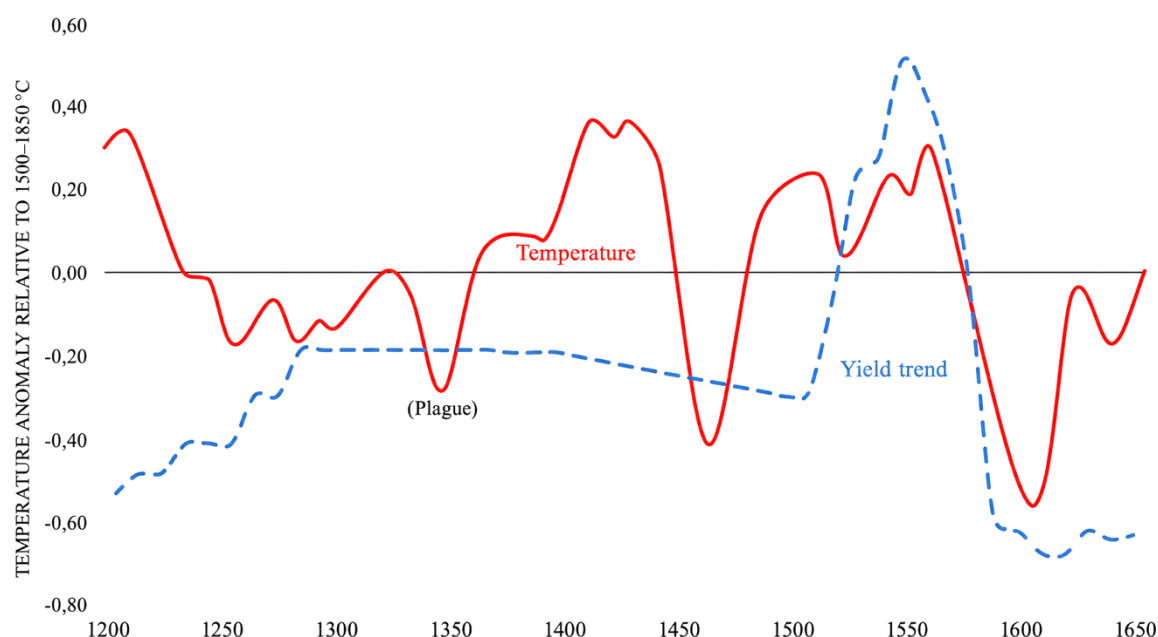


Fig. 8: Reconstruction of the historical temperature anomaly in Europe compared to the trend in herring fishery yields in the western Baltic Sea (1200–1650). Source: See fn. 11 and Fig. 10 (projection without unit).

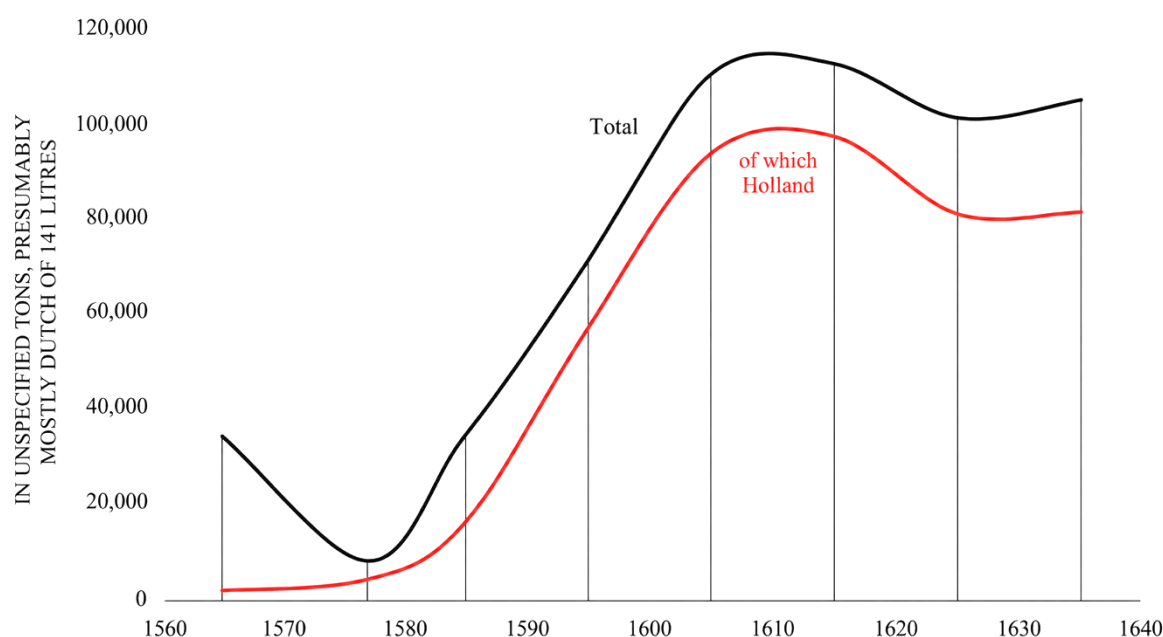


Fig. 9: Average quantities of salted herring shipped through the Sound (1560–1640). Source: Christensen 1941, p. 371 (ton measurement not specified).

Furthermore, Hamburg became an important port of entry. In the 1620s and 1630s, the city imported approximately 50,000 tons per year¹⁵³. Together with the volume from the Sound Passage, at the beginning of the 17th century, at least 150,000 tons per year were sent to the sales areas in the east; a quantity that likely largely covered demand there, especially since, given the price difference compared to grain (Fig. 2), it can be assumed that herring was consumed primarily in the west. It should also not be forgotten that the salted herring market was already experiencing a sales crisis at the end of the 16th century (Chapter 6), so the market volume must have declined in the east as well. The signs of decline

¹⁵³ Poulsen 2008, p. 91 (ton measurement not specified).

were unmistakable, for example, on Møn: According to tax lists, eight of the eleven fishing villages that the island still had in the 1540s were deserted in the 1620s¹⁵⁴. In 1658, Skanör and Falsterbo lost their town charter. While fishing in the Sound may not have ceased completely in the 17th century, some of the huts destroyed in the Torstensson War (1643–45) were at least rebuilt in Scania¹⁵⁵. However, the income was probably no longer worth mentioning.

Data on which extrapolations could be based are scarce for this period. Holm/Bager cite the number of fishermen determined from the tax revenue for Kronborg Len (North Zealand) as evidence of the decline. According to this, fishing there was practically abandoned around 1600. Although the number of fishermen briefly rose to around 300 in the 1620s, it soon plummeted again. On average, it was around 100¹⁵⁶, in the first half of the 17th century. Kronborg Len's market share of the remaining Sound fishery is unknown. Estimates based on this alone are therefore not possible. Therefore, it is necessary to broaden our perspective. According to a Danish census, there were still 784 fishermen working on Zealand in 1771¹⁵⁷. The same number could have been in Scania, which was then Swedish – let's say 1,800 in total. Between 1700 and 1760, an average of about 60 fishermen were subject to tax in Kronborg Len, even fewer than in the first half of the 17th century. Assuming that there had been the same number in 1771 (100 fishermen): Let us further speculate that Kronborg Len's market share would have remained essentially unchanged over two centuries. The average total yield of the Sound fishery in the first half of the 17th century would then have been only 10,000 TRB per year. (1,800 fishermen $\triangleq$ 360 boats $\triangleq$ 9,720 TRB; Fig. 7). In Scania, however, hopes of reviving the Sound fishery were still high. Until 1664, the Hanseatic League repeatedly renewed its privileges. Until 1674, bailiffs were appointed for the fairs. After Scania was annexed by Sweden, the establishment of a state fishery was considered in 1661. Stettin also attempted to bring back the "fishing industry" (1665/1764). The fact that all these plans failed¹⁵⁸ may also have been due to the fact that the peasants' labour had since been absorbed by Danish agriculture. At the beginning of the 17th century, the ox trade boomed¹⁵⁹. The territorial lords began to enforce the plaice levy, which led many farmers to abandon their boats¹⁶⁰. They would therefore no longer have been available for a revived Sound fishery. Furthermore, the centre of herring fishing had shifted to the North Sea. Capital was invested in the Dutch deep-sea fleet, which was far more efficient than the coastal fishing off Scania. Firstly, the Haringbuis (Büse) had more tonnage than the barge in the Sound, which allowed the Dutch fleet to stay at sea for months and follow the herring shoals. Secondly, the Dutch processed the fish on board. Specially provided boats (ventjagers) transported the herring barrels, so the fishing trip didn't even have to be interrupted to unload the cargo. According to Poulsen, the average yield of a Büse was 60 tons, more than twenty times that of the barge in the Sound (27 TRB $\triangleq$ 2.7 tons). However, the Dutch season was almost three times as long¹⁶¹. Thus, the North Sea fisheries were able to meet the declining demand for salted herring (Chapter 6) due to rising grain prices, even without the Sound fishery. The "fishing industry" therefore probably did not return to the Sound even when herring was presumably abundant again after several decades of recovery, thus providing the impetus for plans to revive the fishery. The market was saturated. A similar story is recorded for Bohuslän: When the herring shoals once again gathered off Marstrand in the mid-15th century, the abundance of fish went unnoticed. The demand for salted herring was already being met by the Sound fishery¹⁶², so there was no interest in establishing another fishing centre. Against this background, it cannot be assumed that the other market fisheries in the western Baltic Sea (e.g., Rügen) benefited from the loss of the Sound fishery and compensated for it to any significant extent. Rather, yields probably remained low. At most, the total was 25,000 TRB per year. Salt herring production in the western Baltic Sea remained at this level until the Limfjord fishery experienced its modest upswing in the mid-17th century, with an average trade volume of up to 30,000 TRB per year¹⁶³.

¹⁵⁴ Holm/Bager 2001, p. 111.

¹⁵⁵ Jahnke 2000, pp. 119, 133.

¹⁵⁶ Holm/Bager 2001, p. 110.

¹⁵⁷ Holm 1996, p. 198.

¹⁵⁸ Jahnke 2000, p. 119.

¹⁵⁹ Holm 2003, p. 288; Abel 1978, pp. 128–130.

¹⁶⁰ Holm/Bager 2001, p. 118.

¹⁶¹ Poulsen 2008, pp. 113, 135, 143, 147.

¹⁶² Jahnke 2000, pp. 293–130.

¹⁶³ Holm 1996, p. 194.

8. Conclusion: Trend and fisheries scientific classification

To reconstruct the development of the total yield of herring fisheries in the western Baltic Sea in the late Middle Ages and the early modern period, numerous bridges had to be built across the fragmented records. Sometimes (speculative) assumptions had to be made. However, these assumptions were always validated by considering the overall evidence. Furthermore, the extrapolated magnitudes were applied conservatively. In the following diagram, they are combined to form a trend (Fig. 10), converted into catch volumes (Chapter 2). The following section will therefore focus on answering the actual question, namely whether the decline of the Sound fishery can be attributed to overfishing or not.

The trend in catch quantities is based on the 10-year averages of the estimates of the quantities of processed herring, i.e., the commercial quantity plus two-thirds of the herring. The actual catch quantities will have been significantly higher. In order not to exceed the scope of this article, we have omitted the derivation of the yields from fisheries for the self-sufficiency of the cities¹⁶⁴ and the territorial lords, as well as from subsistence fishing¹⁶⁵. As a result, a base of up to an average of 3,000 t per year is likely to be added. Furthermore, it is to be assumed that considerable quantities of the catch were spoiled before processing. Given the lack of modern refrigeration technology and the fact that fishing in the Sound was primarily carried out by unskilled seasonal workers, meaning the catch had to be landed for salting, the percentage of spoilage is likely to have been at least 10%. The figures given in the diagram are therefore considered to be minimums. However, even this minimum would have been critical for the herring stock. For 2018, the International Council for the Exploration of the Sea (ICES) recommended limiting the catch for the Skagerrak (subdivision 20), the Kattegat (subdivision 21), and the western Baltic Sea (subdivisions 22–24) to 34,618 tonnes (maximum sustainable yield – MSY)¹⁶⁶. Due to the stock's poor regrowth production, which could be due, among other things, to climate change, ICES now recommends suspending herring fishing in the western Baltic Sea¹⁶⁷. Let's stick with the MSY for 2018: Since 2010, the actual catch in subdivisions 20–24 has averaged just over 50,000 tonnes. Of this, almost 22,000 t are attributable to the western Baltic Sea (43%)¹⁶⁸. Accordingly, an MSY of just under 15,000 t can be assumed for subdivisions 22–24. This mark was already reached in the 13th century and was significantly exceeded in the following period, especially in the mid-16th century (Fig. 10). However, the MSY refers to the spring spawning fishery and not to the autumn spawning fishery that was fished in the Sound during the Hanseatic League. These are separate stocks that do not mix¹⁶⁹ and are not easily comparable. Furthermore, today's ecological conditions cannot be easily transferred to the historical Sound fishery. Let us consider the factors on which the growth rate of herring can depend: food supply, population density, temperature, salinity, and genetic fixation¹⁷⁰. In the 20th century, the food supply improved significantly as a result of the increasing nutrient input from modern agriculture (eutrophication), which led to a strong increase in herring stocks¹⁷¹; an effect that Weber had already observed in the post-war period¹⁷². As for stock density, this is still under threat due to recent overfishing. However, there must have been considerable fishing pressure in the 15th and 16th centuries, as evidenced, among other things, by the small size of the processed fish. How the lower temperatures during the Little Ice Age affected herring growth is not fully understood. Parmanne et al. and MacKenzie et al. assume that temperature increases have a positive effect (Chapter 5). However, with the current warming of the western Baltic Sea, the level beneficial to herring has been exceeded (see above). There is no historical data available on salinity in the western Baltic Sea. Unlike cod, for example, herring is not dependent on a regular inflow of saltwater from the North Sea. Nor does it appear to be overly sensitive to changes in salinity¹⁷³, although the population in the Limfjord is said to have declined as a result of an inrush of North Sea water in 1825¹⁷⁴. Regarding genetic fixation, Weber concludes that, given the considerable

¹⁶⁴ Jahnke 1997a, p. 290 ff.

¹⁶⁵ Barrett 2008, pp. 36 ff.

¹⁶⁶ ICES 2017, p. 1.

¹⁶⁷ ICES 2018, p. 1, 2020a, p. 1.

¹⁶⁸ *Ibid.*, p. 10.

¹⁶⁹ Weber 1970, pp. 70 f.; Parmanne 1994, p. 30.

¹⁷⁰ Weber 1970, p. 54.

¹⁷¹ MacKenzie 2002, p. 175; Thurow 1997, pp. 459–460.

¹⁷² Weber 1970, p. 73.

¹⁷³ MacKenzie 2002, p. 187; Poulsen 2007, p. 191.

¹⁷⁴ Holm/Bager 2001, p. 103.

differences in length among the fish, this ranges over a wide range¹⁷⁵. It can therefore be neglected. As an interim conclusion, it can be stated that herring stocks were not necessarily more resistant to massive harvesting due to the ecological conditions in the late Middle Ages and the early modern period. Rather, current ecological conditions, particularly as a result of eutrophication, appear comparatively favourable for herring growth. Furthermore, the number of predators (porpoises, seals) has decreased considerably¹⁷⁶. Nevertheless, the MSY determined for the spring spawning season (15,000 t) cannot be simply transferred to the historical Sound fishery, especially since it is not a static, waterbody-specific limit. Nevertheless, the fact that catches after the increase in the 16th century averaged more than three times the MSY (50,000 t) can be seen as an indication that fishing was no longer sustainable. Remarkably, the stock may have been pushed to its limits as early as the 15th century. This is suggested by the numerous reports of a temporary absence of herring or a decline in production. However, the herring did not come under pressure because catches had suddenly increased. The economy stagnated. Rather, the cause was likely a cold snap. Between 1430 and 1460, average temperatures fell by 0.8°C. This likely increased the existing fishing pressure. This is also supported by evidence of a declining average catch weight: in the early Middle Ages, when no market fisheries had yet been established in the Baltic Sea, it was 154 g, although it is unclear whether this was due to autumn or spring spawning. Subject to the uncertainties in calculating the Hanseatic tonnage, it was only 82 g by the end of the 14th century. According to Weinreich's information, it may have temporarily fallen to 67 g in 1485 (just after the cold snap) (Chapter 5). For comparison: In 2019, the spring spawners in the western Baltic Sea reached an average catch weight of 107 g¹⁷⁷. Although the stock may have already been under threat in the 15th century, the average yields of the Sound fishery have more than doubled since 1524/25. This is at least what the figures provided by Trebau and Tellemann suggest, which could be verified based on economic indicators. If the stock had remained unchanged, this would have led to acute overfishing, the effects of which would have become noticeable within a few decades. However, the high catches were maintained at least until 1536 and (based on the subsequent development of the Hamburg salt price) probably until the early 1570s, which is also supported by the renewal of fishing privileges (1532–76). No reports of a lack of shoals have survived for this period. On the contrary: in 1527, the abundance of herring was praised. It can therefore be assumed that the population had recovered by the beginning of the 16th century due to rising temperatures at the end of the 15th century and initially stagnating catches (Fig. 8) (Chapter 6). Around 1580, however, the Sound fishery came to an end. Is this the result of overfishing? Let us first consider other causes: First, it is striking that the amount of salt shipped from Lüneburg to the Baltic Sea region had already declined permanently in 1572/73, i.e., at the very time when Skanör and Falsterbo were being hit by shifting dunes. This was also the period of the Bohuslän fishery's boom. However, the herring boom in the archipelago had already ended by 1590. If it had only been the shifting dunes and the competition in Marstrand that had affected business at the Scanian fairs, it could have resumed in full by the end of the 16th century. But that did not happen. Rather, the Sound fishery practically ceased. The reason for this may have been Dutch competition. The Dutch fishing fleet was far more productive (although still hampered by the Eighty Years' War) (Chapter 7). This advantage may have already existed in the 1580s, when herring fishing off Bohuslän was at its peak. However, simple coastal fishing was carried out in the archipelago with a productivity probably similar to that in the Sound¹⁷⁸. The fact that the Sound fishery did not recover after the decline of the Bohuslän fishery cannot therefore be attributed solely to the higher productivity of the Dutch deep-sea fleet. Overall, the evidence suggests that the decline of the Sound fishery was triggered by a persistent lack of herring shoals around 1580. The herring population had evidently suffered severe damage, but not because catches had increased sharply. The salted herring market had already entered a sales crisis. Again, it was a cold snap that likely took its toll on the herring. Between 1560 and 1600, temperatures fell by almost 0.85°C. With catches of up to 20,000 t per year, the stock could probably have coped reasonably well, as it did in the 15th century, but not with the already critical 50,000 t per year. And so, it was likely the combination of unsustainable fishing and a sudden deterioration in ecological conditions for herring that caused the stock to collapse (Chapter 7). The cold snap also affected herring fisheries in the North Sea. However, despite the increased

¹⁷⁵ Weber 1970, p. 54.

¹⁷⁶ MacKenzie 2002, pp. 177, 179 ff.

¹⁷⁷ ICES 2020b, p. 345.

¹⁷⁸ Jahnke 2000, p. 302.

catches (1600: 70,000 t), fishing pressure there was not yet critical. For the North Sea, the Skagerrak and Kattegat, and the Eastern English Channel, ICES set the MSY for 2020 at 431,062 t¹⁷⁹.

In the following centuries, herring fishing in the western Baltic Sea was virtually suspended. It was not until the 20th century that significant catches were landed again¹⁸⁰. Based on the catch quantities listed by Thurow for subdivision 22, Hanseatic trade volumes were again reached in the 1950s, and yields continued to increase in the following years (Fig. 11)¹⁸¹. Remarkably, the proportion of autumn-spawning herring was only 35%, according to Weber's study for the 1960s¹⁸². Unlike in the historical Sound fishery, spring-spawning herring are the primary target in modern Baltic Sea fishery. During Hanseatic times, spring-spawning herring were primarily the basis of the Limfjord fishery¹⁸³, which, however, long remained in the shadows. This only changed after the decline of the Sound fishery. The resurgence of the Limfjord fishery in the 17th and 18th centuries could therefore also be attributed to the fact that the spring spawning season increasingly replaced the autumn spawning season in the ecosystem, which had temporarily become virtually vacant due to overfishing around 1580.

In the 1980s, yields increased significantly again. As a result of overfishing, the autumn spawners have completely lost its economic importance for the fishery. In recent decades, only a few hundred metric tons have been landed. The current stock is classified as very low and is no longer considered by fisheries scientists. Parmanne et al. cite increased fishing pressure and a possible lack of oxygen as the reason for the virtual extinction of the autumn spawners¹⁸⁴. The fact that the autumn spawners has suffered disproportionate damage from recent overfishing could also be due to the lower stock strength compared to the spring spawners. And the evidence presented here suggests that this may have been due to the overexploitation of natural resources by the Sound fishery in the 16th century, after which the spring-spawning species permanently replaced the autumn-spawning species as the dominant population. The recent collapse of the autumn-spawning species population would therefore be a late legacy of the Hanseatic period. The fact that herring fishing in the western Baltic Sea only resumed on a significant scale in the 20th century is unlikely to have been due to a lack of fish. Rather, it was likely that the consolidated market power of deep-sea fisheries in the North Sea no longer allowed for additional production capacity, especially since a functioning fishing organization and distribution structure had developed there, tying up capital. Furthermore, there was a shortage of labour for the traditional Sound fishery. The previously employed seasonal workers were needed in the emerging Danish agricultural sector (Chapter 7). The overfishing of herring in the 16th century may therefore have merely provided the impetus for the structural change. However, it was probably not the compelling reason for the permanent relocation of the centre of herring fishing to the North Sea.

¹⁷⁹ ICES 2019, p. 1.

¹⁸⁰ Parmanne 1994, pp. 35 ff.; hardly any sources are available for the period before that (MacKenzie 2002, p. 173).

¹⁸¹ Thurow 1997, p. 451; also Weber 2000, pp. 42 ff.

¹⁸² Ibid., pp. 59 ff., 70; Parmanne 1994, pp. 30 f.

¹⁸³ Holm 1996, p. 194.

¹⁸⁴ MacKenzie 2002, p. 182; Parmanne 1994, p. 31.

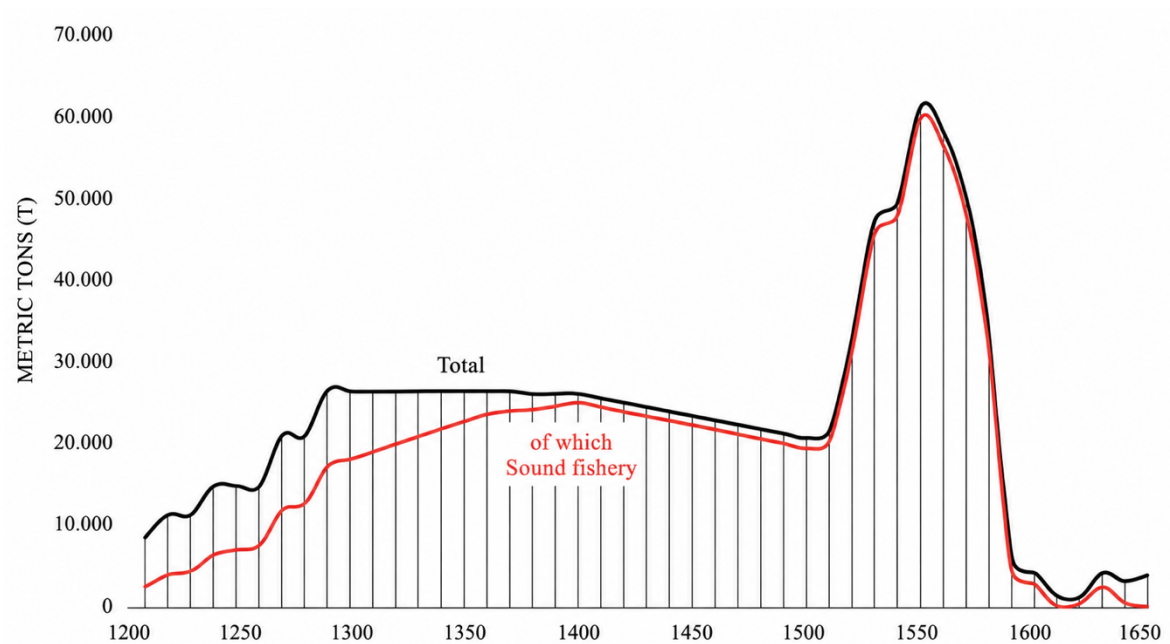


Fig. 10: Trend in catch volumes of herring fisheries in the western Baltic Sea (1200–1650).

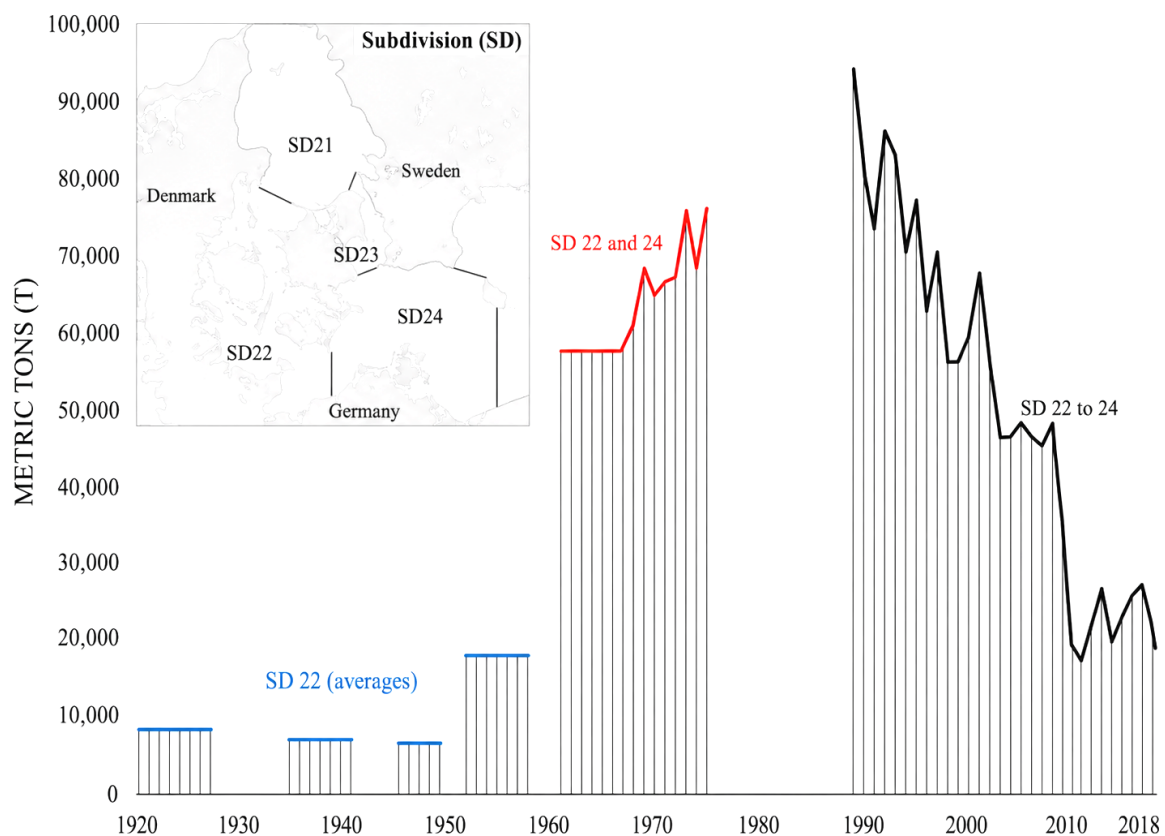


Fig. 11: Catch quantities in the ICES subdivisions. Source: Thurow 1997, p. 451; ICES 2020a, p. 10.

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